AN ABSTRACT OF THE THESIS OF

Larry W. Bass for the degree of Doctor of Philosophy

in Chemistry presented on July 11, 1979

Title: PART I. CYCLIZATION OF ORGANOLITHIUM AND -ZIRCONIUM COMPOUNDS. PART II. REARRANGEMENTS OF SELECTED ANIONIC COMPOUNDS IN HIGHLY DISASSOCIATIVE SOLVENTS

Abstract approved: Redacted for privacy

Gerald J. Gleicher

Intramolecular cyclization of organometallic compounds represents a promising tool for synthesis. The reaction involves exothermic consumption of intramolecular double bonds via insertion into a carbon metal sigma bond. This represents an intramolecular example of the reaction type responsible for metal catalyzed polymerization of olefins.

Organolithium reagents were found to cyclize forming mono- and bicyclic compounds stereospecifically in average yields. The organolithium reagents were prepared by the reaction of alkenyl halides with lithium metal or radical anions. Zirconocene was found to effect carbocyclization of simple dienes forming 5- and 6-membered carbocycles.

The stereochemistry of the elimination of hydrogen chloride from 2-benzylchlorocyclopropane when treated with a strong base

forming E-1-phenyl-1,3-butadiene was found to be stereochemically consistent with that of the thermally allowed opening of halocyclopropanes.

The potassium salt of 6,6-dimethyl-2,4-cyclohexdien-1-ol was found to undergo a [1,5] hydrogen shift at 65° when dissolved in hexamethylphosphoramide (HMPT) producing 6,6-dimethyl-3-cyclohexen-1-one when neutralized.

Part 1. Cyclization of Organolithium and -zirconium compounds

Part 2. Rearrangements of Selected Anionic Compounds in Highly Disassociative Solvents

by

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PART 1. CYCLIZATION OF ORGANOLITHIUM AND -ZIRCONIUM COMPOUNDS

I. INTRODUCTION

One obvious method of increasing efficiency in organic synthesis involves reducing the total number of steps by accomplishing as many bond making processes as possible in a single step. Many of the target molecules of organic synthesis are polycyclic structures. Any method of forming several rings stereoselectively at one time from a single linear precursor could be of considerable synthetic consequence. Intramolecular cyclization of organometallic compounds represents a promising tool for accomplishing this objective. The reaction involves exothermic consumption of intramolecular double bonds by means of insertion into carbon-metal sigma bonds. Such a transformation represents an intramolecular example of the reaction type responsible for metal catalyzed polymerization of olefins.

Intramolecular cyclizations have been observed or proposed for organometallic compounds containing lithium (1), magnesium (2), aluminum (3), zirconium (4), titanium (5), gallium (6), indium (6), rhodium (7), nickel (8), iron (9), palladium (10), copper (11), thorium (12), and cobalt (13). Organolithium compounds were found to undergo intramolecular cyclization efficiently and stereospecifically, resulting in the formation of cyclic and bicyclic compounds.

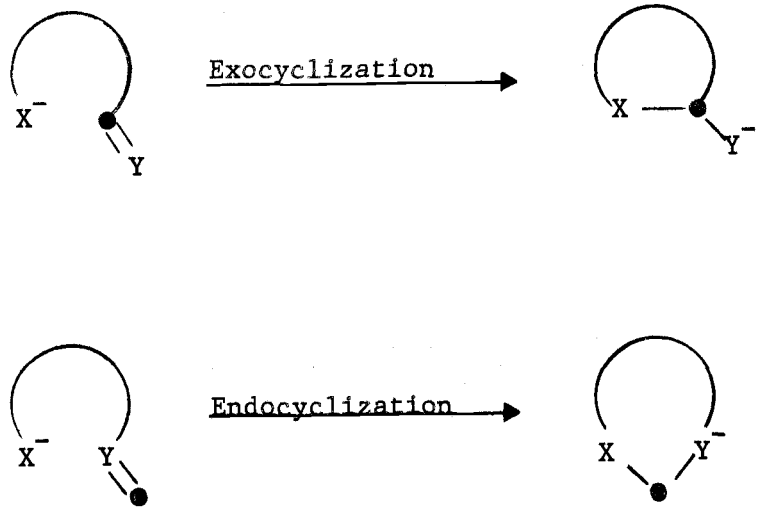
Zirconocene has been shown to effect carbocyclization of unstrained dienes by the process of oxidative coupling. The scope and possible synthetic applications of the cyclizations involving lithium and zirconium were explored.

II. HISTORICAL

It has been known for many years that intramolecular cyclization of polyenes can occur through common organic intermediates; free radicals, carbonium ions and carbanions. Some have been studied in greater detail than others, but all have the ability to form polycyclic compounds from linear precursers in a single step.

In principle, two modes of closure from the mentioned intermediates are commonly observed in ring forming reactions, i.e., the formation of exocyclic or endocyclic rings as illustrated in Scheme 1. These differ in the regiochemistry of addition to the unsaturated unit, and result in the construction of rings of differing size.

Scheme 1

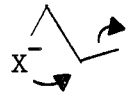


A set of rules useful in predicting the relative facility of the different modes of ring closure has been developed by Baldwin (14). These rules are based on the stereochemical preferences of the transition state for various modes of the ring closure process; each mode of ring closure is most facile in a specific transition state geometry. The rules are summarized below and generalized examples of each type are provided.

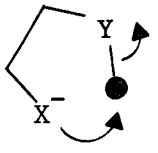
Baldwin's Rules for Ring Closures

Rule 1: Tetrahedral Systems

(a) 3- to 7-Exo-Tet are all favored
(b) 5- to 6-Endo-Tet are disfavored



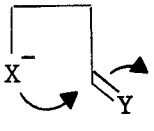
3-Exo-Tet
(favored)



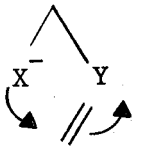
5-Endo-Tet
(disfavored)

Rule 2: Trigonal Systems

(a) 3- to 7-Exo-Trig are favored
(b) 3- to 5-Endo-Trig are disfavored;
6- to 7-Endo-Trig are favored



4-Exo-Trig
(favored)

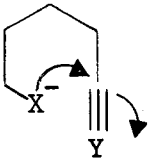


4-Endo-Trig
(disfavored)

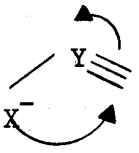
Rule 3: Digonal Systems

(a) 3- to 4-Exo-Dig are disfavored;
5- to 7-Exo-Dig are favored

(b) 3- to 7-Endo-Dig are favored



6-Exo-Dig
(favored)

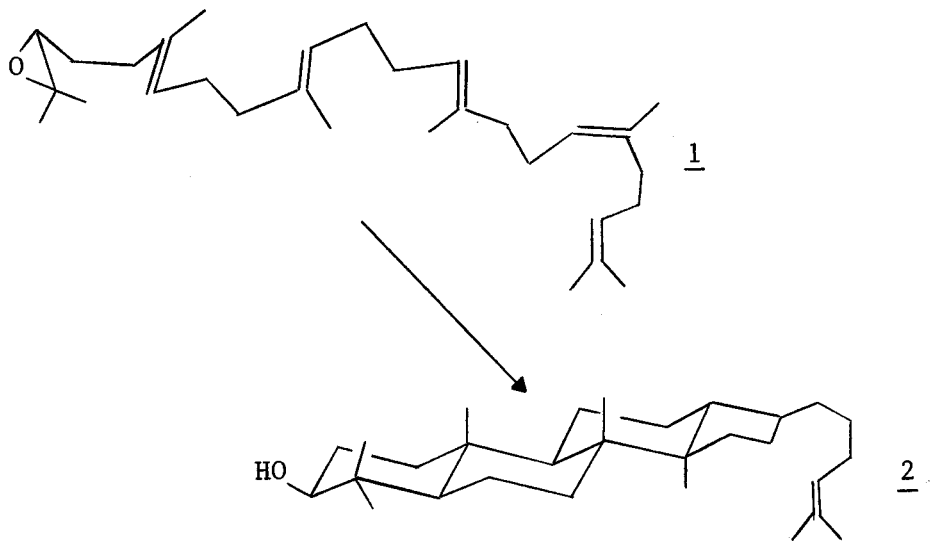


3-Endo-Dig
(favored)

The mode of ring closure is designated by the use of a number, indicating the number of atoms incorporated in the new ring; Exo or Endo, indicating exocyclization or endocyclization; and Tet, Trig or Dig which refer to the hybridization state of the carbon atom undergoing the ring closure reaction. Reasonable adherence to these rules is expected only when X is a first row element since these display small enough radii and bond lengths to be strongly influenced by the geometric restraints of the suggested transition states. Many known examples lend experimental support to these rules, but a few "exceptions" are recognized. One of the major drawbacks to these rules is the lack of stereospecificity predictions when more than one diastereomer may be formed.

Polycyclization of trigonal systems proceding through carbonium ion intermediates has proven to be one of the most elegant synthetic examples for trigonal systems. The conversion of squalene-2,3-oxide (1) into dammaradienol 2 is an example of a highly stereoselective efficient multiple bond forming carbocyclization which

results in the production of virtually one diastereomer (15a) (Scheme 2).



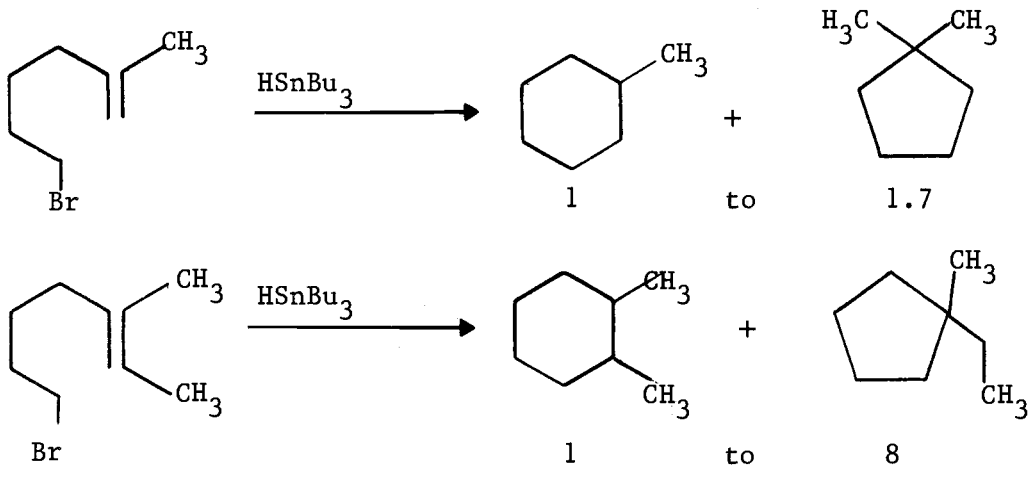
Using Baldwin's rules, the overall process is three 6-Endo-Trig cyclizations followed by one 5-Exo-Trig cyclization, all being favored cyclizations. The stereospecificity which is the most significant feature of this cyclization has been rationalized using the Stork-Eschenmoser hypothesis (16) which envisions simultaneous bond formation requiring trans addition across the olefinic units. This hypothesis predicts stereospecificity since the stereochemistry of the ring fusion is dependent upon the stereochemistry of the double bond undergoing cyclization.

There are many examples of carbonium cyclizations generated

from allyl alcohols, epoxides, sufonate esters, and acetals (15). Many have proven to be stereospecific and to proceed in good yields. Caution is dictated when using the Stork-Eschenmoser hypothesis though, since exceptions do exist.

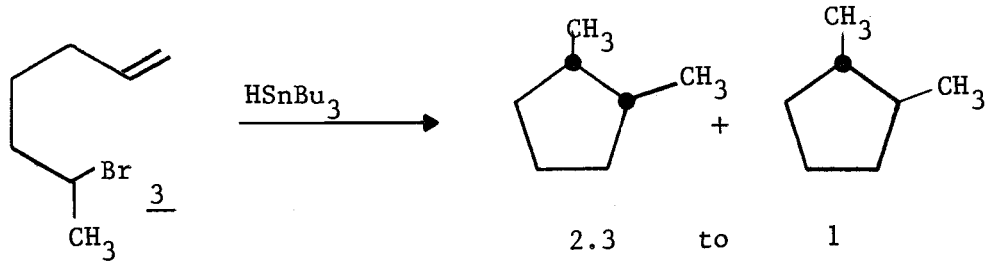
Free radical cyclizations are generally found not to be very regiospecific with the regiospecificity heavily dependent upon the substitution patterns about the double bond (17a) (Scheme 3).

Scheme 3



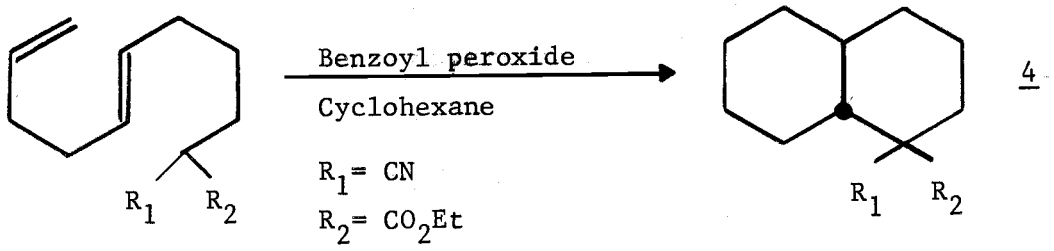
Free radical cyclizations are not very stereospecific. When 2-iodo-6-heptene (3) is treated with tri-n-butyl tin hydride, a mixture of cis- and trans-1,2-dimethylcyclopentane is produced in which the less thermodynamically stable cis isomer is found preferentially by a factor of 2.3 to 1 (18) (Scheme 4).

Scheme 4



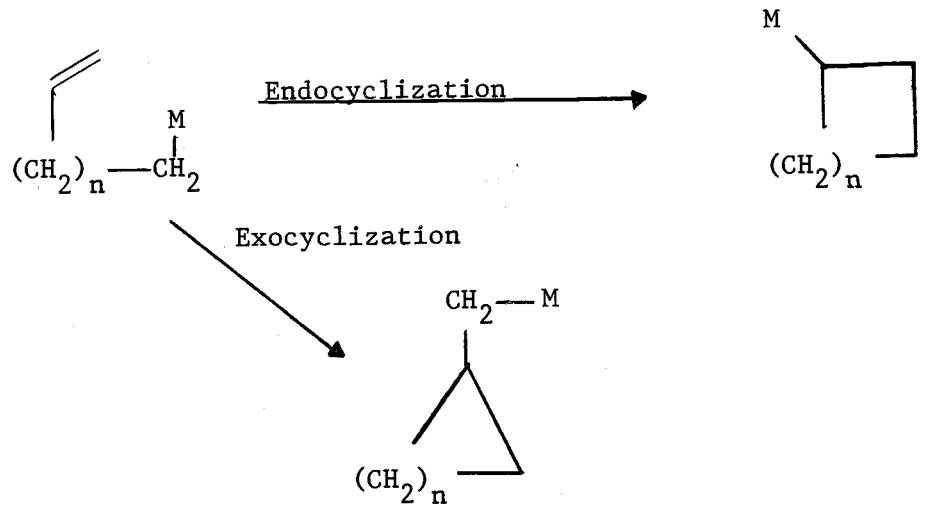
Multiple cyclizations have also been accomplished using free radical intermediates, although in most cases a mixture of isomers is produced. Occasionally, a single diastereomer 4 is formed preferentially (17b) (Scheme 5).

Scheme 5



Intramolecular additions of organometallic reagents across a carbon-carbon bond resulting in the formation of three to six membered rings have been observed or proposed for many organometallic compounds (1-13). A number of literature examples are available, mostly involving organolithium, -magnesium, and -aluminum reagents and indicate the exocyclic route is preferred for n=1, 2, and 3 (Scheme 6) (1, 2, 3).

Scheme 6

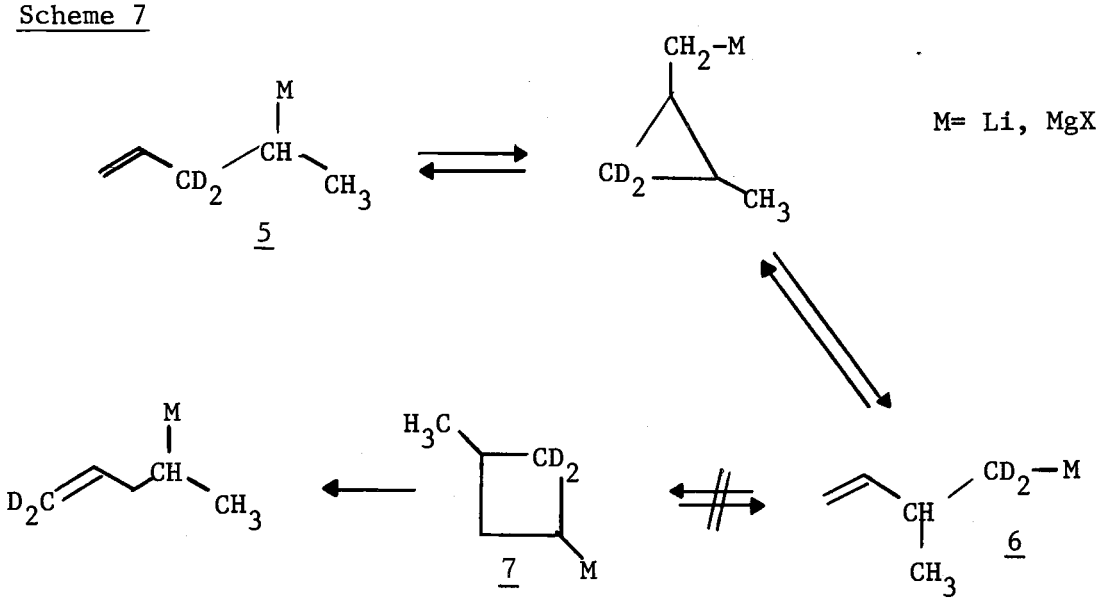


For the n=1 cyclization, it has been found that the cyclization is reversible with the exocyclization mode of addition being favored for the metals lithium and magnesium. Sufficient proof for the exocyclic mode has been provided by the deuterium labeled reagent 5 (19). The ready interconversion of 5 and 6 were observed but no deuterium appeared in the vinyl region. Clearly, this negates the creation of the 4-membered ring 7 which would be expected to undergo a retro-cyclization to give a product which has vinylogous deuterium atoms (Scheme 7).

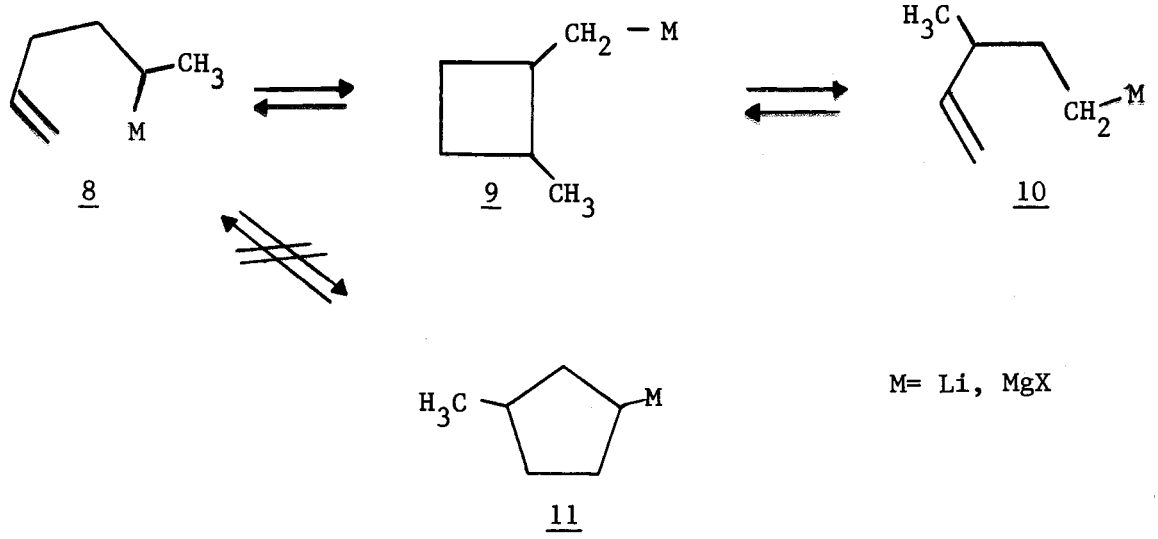
As with the n=1 process, the n=2 cyclization process for the metals lithium and magnesium favor the exocyclization mode of addition and also tends to be reversible. Reagent 8 which is a secondary organometallic rearranges to the primary organometallic 10.

This reorganization can be rationalized by the intermediacy of a cyclobutyl carbinyl metal 9, i.e., the product of an exocyclic process (Scheme 8) (20).

Scheme 7



Scheme 8

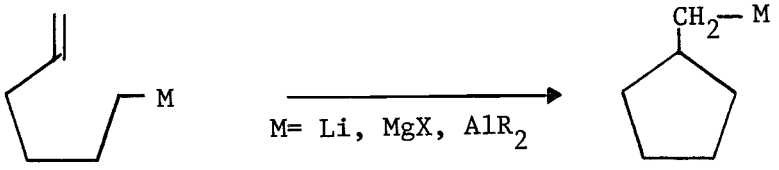


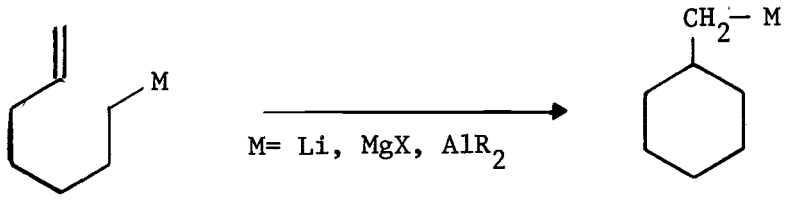
Substantial ring strain inherent in the cyclopropyl (28 kcal/mole) and the cyclobutyl (26 kcal/mole) rings (23) usually commands the equilibrium to be displaced toward the open chain structures (19, 20), but exceptions involving special polycyclic structures and highly stablized carbanions do exist (21).

For the n=2 process, one would assume 11 to be more stable than 9 even though 11 possesses a secondary carbanionic center. The Gibb's free energy difference calculated by the method of Benson (22) shows the 5-membered ring to be more stable than the 4-membered ring by 16.3 kcal/mole (24); whereas, the difference between primary and secondary carbanionic centers is approximately 3.7 kcal/mole in favor of the primary (39). Apparently, the cyclization preferred thermodynamically need not be kinetically accessible with the energy of activation required for forming the endocyclic organometallic being higher than that needed to form the exocyclic organometallic.

For the n=3 and n=4 cases, the exocyclic route for cyclizations is favored and supported by experimental evidence (Scheme 9) (1, 2, 3).

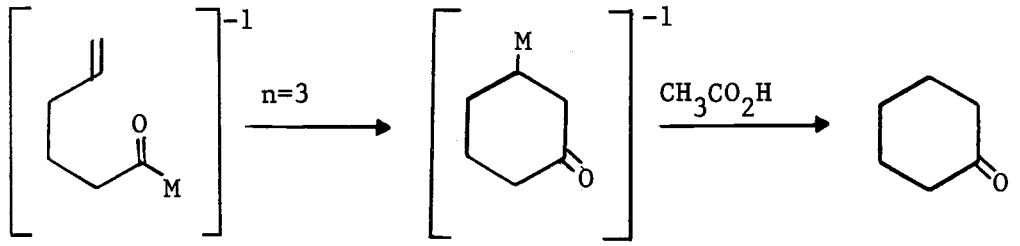
Scheme 9



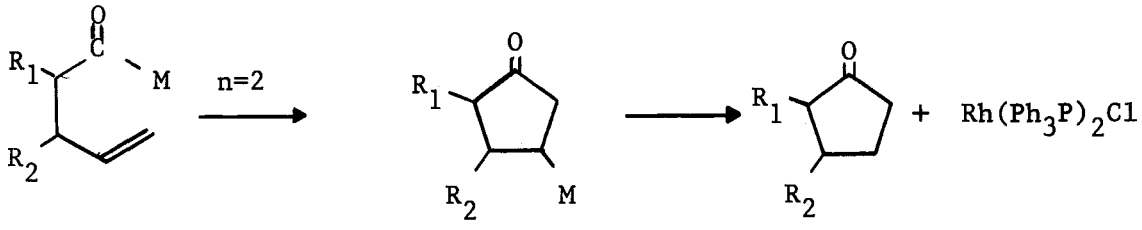


For the n=2 and n=3 cases, exceptions to the exocyclizations do exist. The insertion of an olefinic unit into an acyl-transition metal sigma bond often proceeds in an endocyclic fashion (Scheme 10) (9a, 7a).

Scheme 10



M= $Fe(CO)_3$

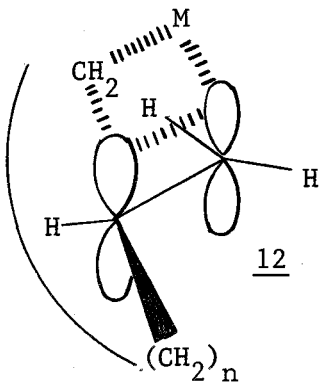


M= $RhHCl(Ph_3P)_2$

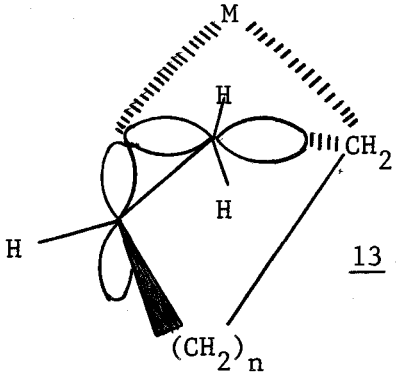
Some caution should be taken when an "apparent" endocyclization exists. The overall endocyclization may be achieved by a series of exocyclization routes (25).

A consistent rationale behind the kinetic bias toward cycloalkyl carbinyl metal formation suggests that the transition state for cyclization maintains partial double bond characteristics reminiscent of the open chain isomer (26). Formation of the exocyclic organometallic readily permits continuous overlap of the double bond p orbitals, whereas the endocyclic reaction requires the p orbitals of the double bonds to twist out of overlap in generating 4- through 6-membered rings as depicted in models 12 and 13 (Scheme 11).

Scheme 11



12

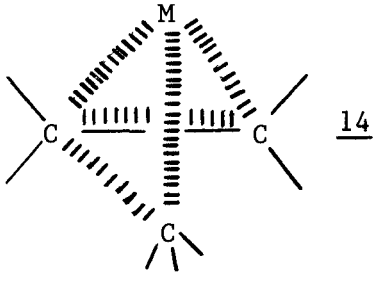


13

The veracity of the above discussion depends upon the stereochemical restrictions associated with the addition to an unsaturated bond. The stereochemical outcome of the intramolecular nonreversible addition to both double and triple bonds have been shown to favor mostly cis addition for the meager number of systems studied (27). This does not mean that trans addition is impossible. Certain endocyclizations apparently proceed in a trans fashion (28). Most

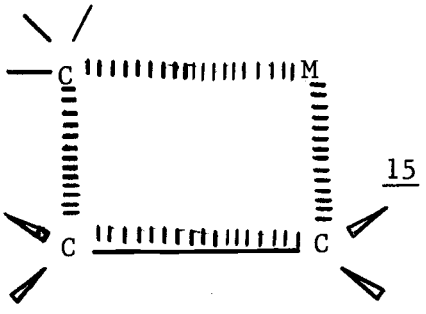
pictorial views of the transition states for the addition of an organometallic reagent to a double bond involve a 4-centered molecular array; "perpendicular" 14 or "coplanar rectangular" 15 leading to cis addition (Scheme 12). The 4-centered transition state depending on the orbitals and electrons involved need not impart any special stabilization.

Scheme 12



14

Perpendicular



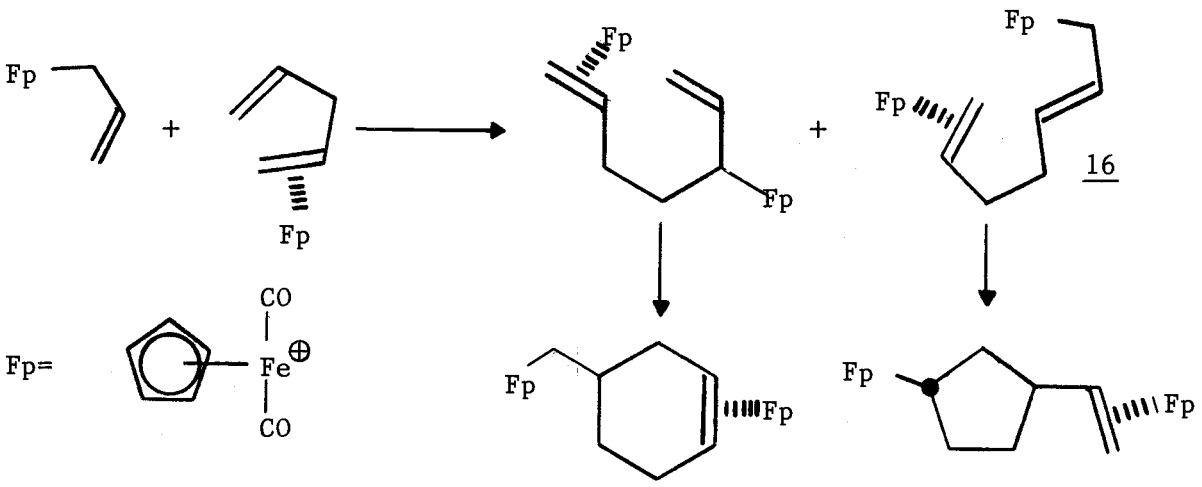
15

Rectangular Coplanar

The occurrence of trans addition would tend to negate the theoretical arguments rationalizing preferential exocyclization. A concerted trans addition would be difficult process to imagine. Either free radicals or the intervention of two metal atoms could be involved in plausible trans addition mechanisms (29a). Systems that do proceed through free radicals have rarely been investigated but a few have been reported in the literature (29b, c). Cyclizations requiring the presence of two metal atoms are likewise quite rare. The work of Rosenblum on olefinic iron complexes gives preliminary indications

that endocyclization of the iron complex 16 proceeds by a trans addition mechanism (Scheme 13) (30).

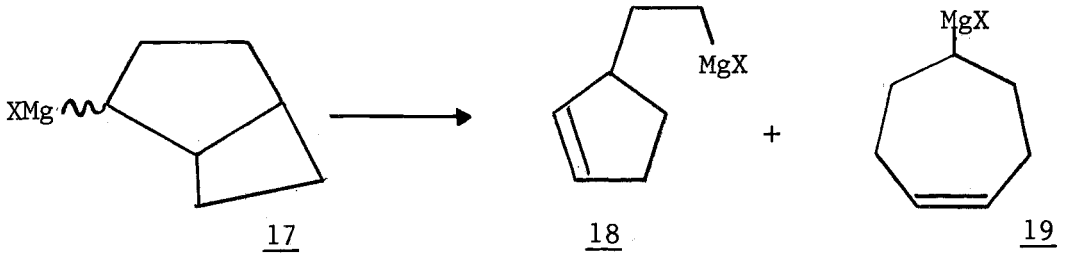
Scheme 13



E. Alexander Hill (31) has reported kinetics performed on the retrocyclization of certain Grignard reagents which provides useful information concerning the structure of the transition state leading to cyclization (or retrocyclization by the Principle of Microscopic Reversibility). These experiments lend credence to the preferential formation of the "perpendicular" rather than the "coplanar rectangular" transition state mentioned earlier.

Bicyclic Grignard reagent 17 experienced retrocyclization due to considerable loss of strain energy to relinquish a secondary Grignard 19 and a primary Grignard 18 (Scheme 14) (31a).

Scheme 14

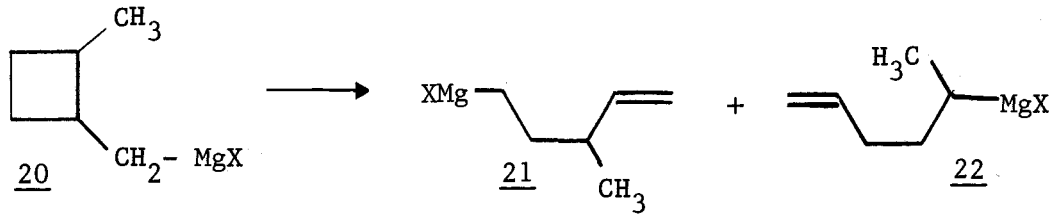


17 18 19

9 to 1

The ratio of primary 18 to secondary product 19 was shown to be 9 to 1. Surprisingly, a similar ring opening of the monocyclic Grignard 20 also provided two products but in a primary 21 to secondary 22 ratio of 100 to 1 (Scheme 15) (31b). Kinetic studies confirmed that the two secondary Grignard reagents 19 and 22 were generated with similar rate constants. The latter system possesses considerable conformational freedom and would presumably assume the optimum transition state geometry.

Scheme 15



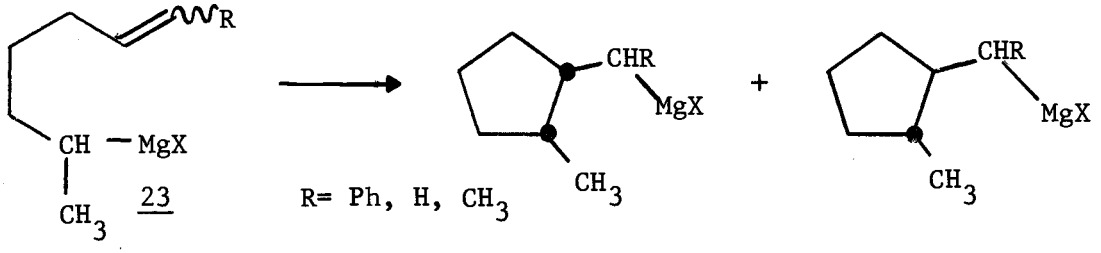
20 21 22

100 to 1

The former system is much more restricted and would require the transition state leading to the secondary Grignard 19 to approximate the "perpendicular" arrangement. Generation of 21 is much faster than that of 18, which leads to the conclusion that the rearrangement of bicyclic Grignard 17 to give 18 is slow because the system cannot attain the "perpendicular" transition state geometry.

Richey and Veale (32) have pointed out that the stereochemical results in the cyclization of the substituted hexenyl Grignards 23 are incompatible with the "coplanar rectangular" transition state (Scheme 16).

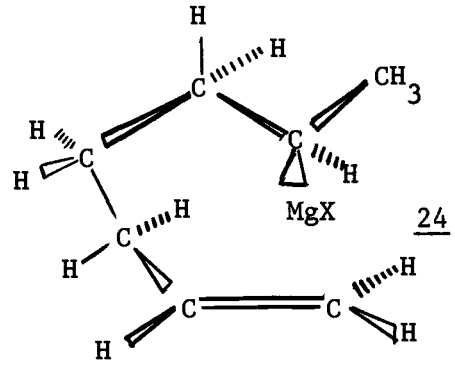
Scheme 16



During Grignard formation, some cyclized reagent was formed which was relatively rich in the cis isomer. This initial cyclization was attributed to the radical character of the Grignard formation process. However, rearrangement of the reagents after formation produced a predominance of trans isomers. In the case of R = phenyl, the preference was at least 25 to 1. Examination of the models for the 4-centered transition states indicate there exists two low energy

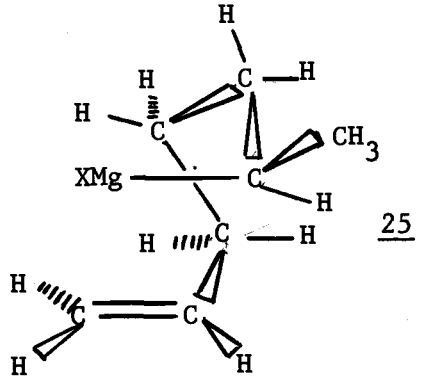
conformational coils which would lead to trans formation ("perpendicular" transition states) 24 and cis formation ("coplanar rectangular" transition state) 25. These coils are depicted in Scheme 17.

Scheme 17



24

Perpendicular

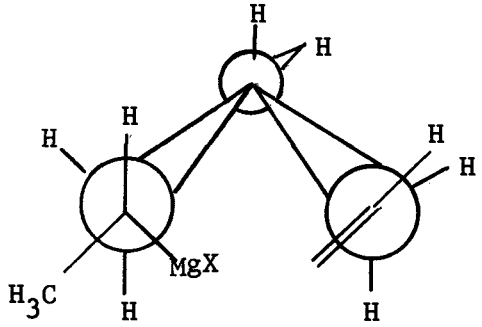


25

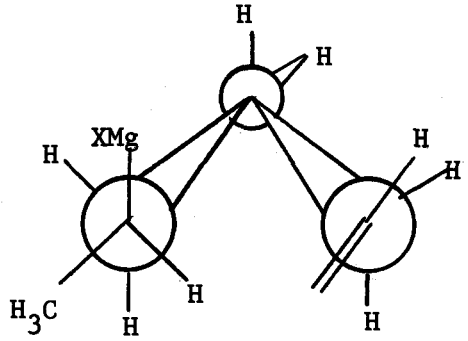
Rectangular Coplanar

The Newman projections for R = H clearly show the steric interactions are minimized by these coils (Scheme 18). In both cases, the methyl group is trans to the carbon 2 - carbon 3 bond. This is presumably energetically more favorable than the gauche conformation.

Scheme 18



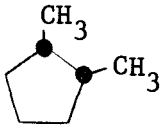
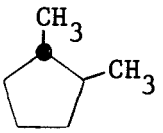
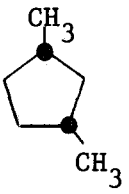
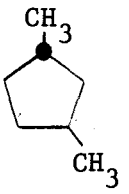
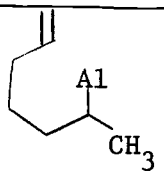
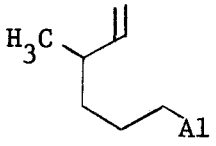
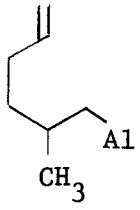
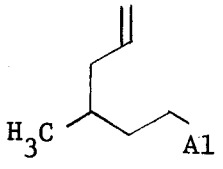
Rectangular Coplanar



Perpendicular

Stefani has also studied the stereochemistry of the ring closure of 1-methyl-5-hexenyl along with the 2-, 3-, and 4-methyl aluminum systems (33). The cyclizations were found to proceed stereospecifically and the results of the cyclizations are presented in Table 1.

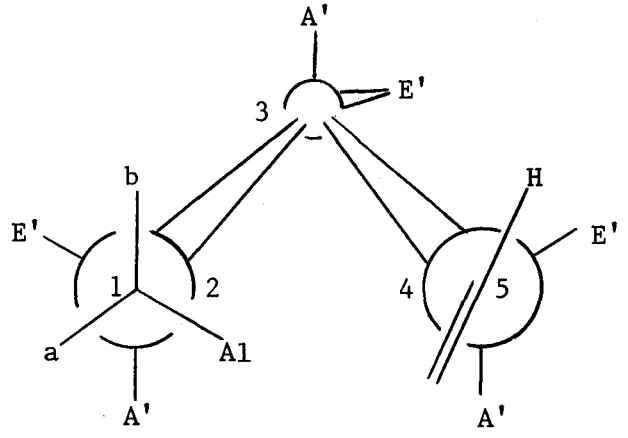
Table 1

Starting Organoaluminum	Product			
				
	72.3	27.7		
	2.3	97.7		
			4.1	95.7
			91.1	8.9

Inspection of the table reveals that the cyclization for the 1-methyl derivative proceeds with opposite stereospecificity as that of the Grignard suggesting that a "coplanar rectangular" transition state is preferentially operable. However, the ratio of the cis- to

trans-1,2-dimethylcyclopentane is 2.6 to 1. This is suspiciously close to the reported ratio of 2.3 to 1 for the radical cyclization of the same hexenyl system. On further examination of the stereochemical results of the hexenyl aluminum systems, it is found that the position of the methyl groups influences the preference of the major isomer produced, i.e., changing the methyl group from the 1-position to the 4-position or from the 2-position to the 3-position. Stefani rationalizes these results by implying that the stereochemical outcomes of the cyclizations are not due to direct interaction of the methyl substituent with the reaction center but are solely due to preferred conformational coils leading to cyclization. In Scheme 19, carbons 2, 3, and 4 have quasi equatorial positions available for substituents. The stereochemical outcomes were rationalized by permitting the methyl groups to occupy one of these quasi equatorial positions during ring formation.

Scheme 19



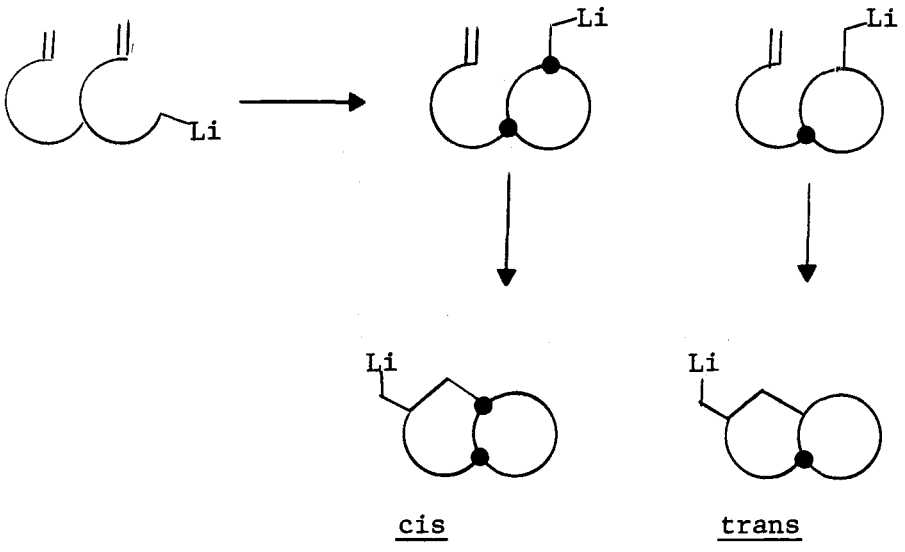
A'= Quasiaxial

E'= Quasiequatorial

III. RESULTS AND DISCUSSION

It has been recognized for several years that 5-hexenyl lithium will cyclize intramolecularly to produce cyclopentylmethyl lithium in high yield (1). Theoretically, this intramolecular insertion reaction could be extended to produce polycyclic structures from appropriate polyene presursors (Scheme 20).

Scheme 20

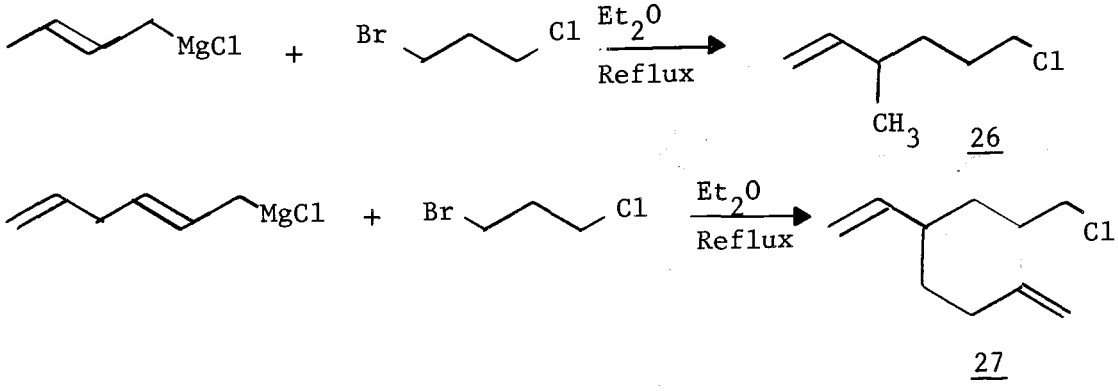


In order to predict the likelihood of such continued cyclizations as well as the eventual structures of the products, it is necessary to know the stereochemical outcome of the initial cyclization. A number of methylated hexenyllithium cyclizations have been studied in order to predict the stereochemistry of the ring junctures of possible multicyclic compounds produced by this cyclization process. The hexenyl

systems studied were the 1-, 2-, 3-, and 4-methyl-5-hexenyllithiums. Two extentions of the three systems found capable of generating bicyclic moieties were also investigated along with two trigonal cyclizations from alkenyl lithiums and two digonal cyclizations from primary lithium reagents.

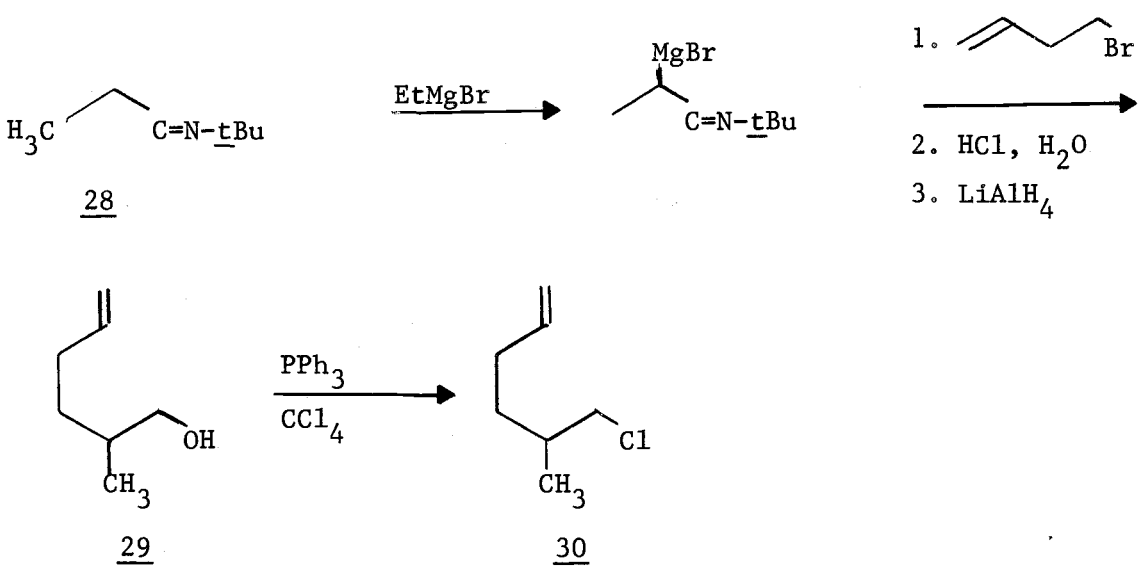
By taking advantage of the fact that unsymetrical allylic Grignard reagents tend to alkylate at the more highly substituted position (34), two of the ten systems studied were easily generated as shown in Scheme 21.

Scheme 21



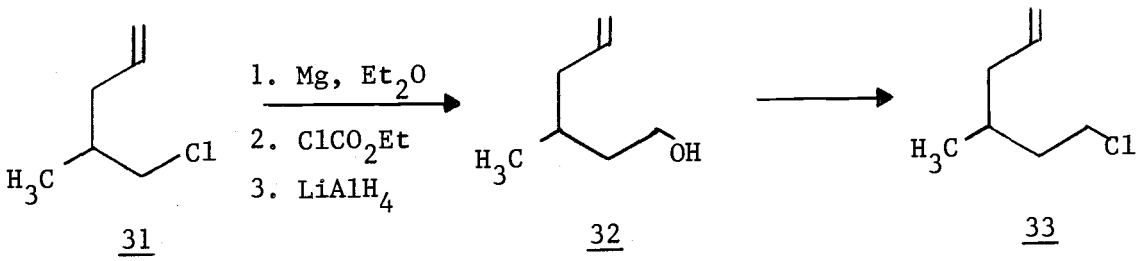
Alkylation of the metalloenamine 28, a procedure developed by Stork (35), was employed in the preparation of 6-chloro-5-methyl-1-hexene (30). Hydrolysis of the intermediate imine followed by reduction gave 2-methyl-5-hexen-1-ol (29). Subsequent treatment of the alcohol with triphenylphoshine - carbon tetrachloride provided the desired chloride 30 (Scheme 22).

Scheme 22



The preparation of 6-chloro-4-methyl-1-hexene (33) was accomplished using a one carbon chain extention of 5-chloro-4-methyl-1-pentene (31) (Scheme 23).

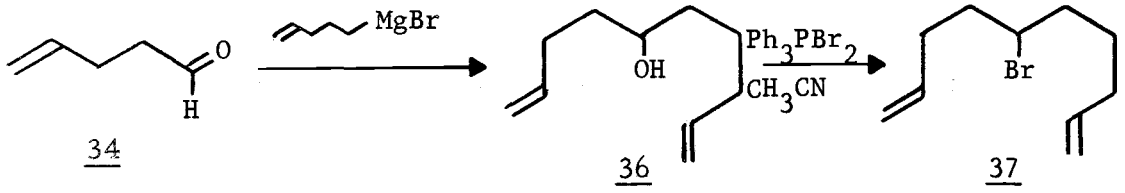
Scheme 23



A two step synthesis of 5-bromo-1,9-decadiene (37) was initiated by the reaction of 4-pentenal (34) with 4-pentenyl magnesium bromide (35). Conversion of the resultant dienol 36 into the desired bromide 37 was achieved by using equal molar amounts of both

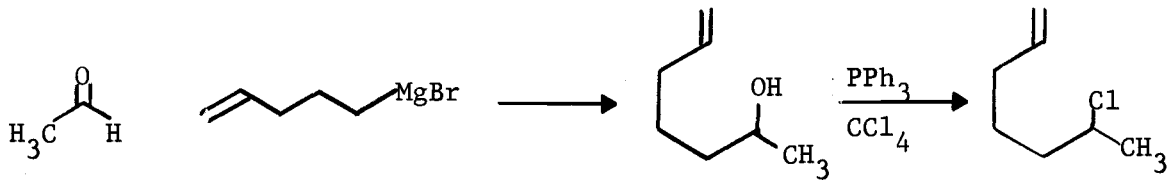
triphenylphosphine and bromine in acetonitrile (Scheme 24). A similar procedure was used to prepare 2-chloro-6-heptene (39) (Scheme 25).

Scheme 24



34 36 37

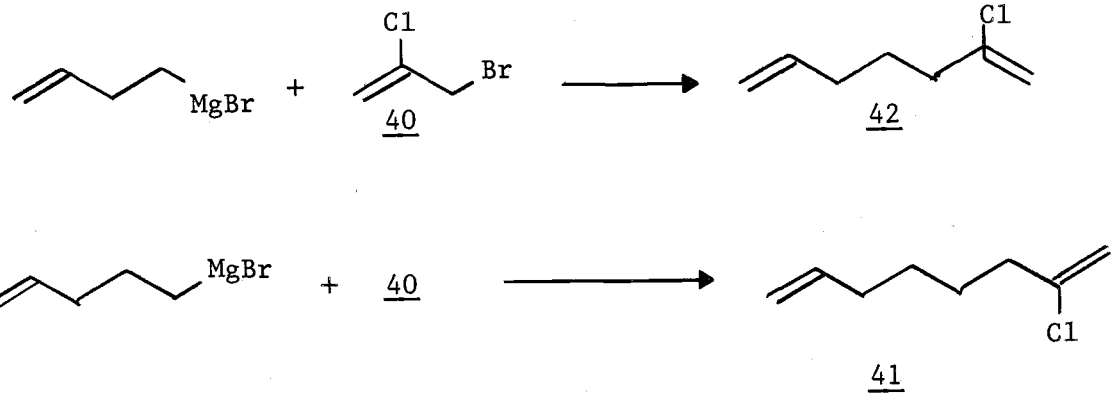
Scheme 25



35 38 39

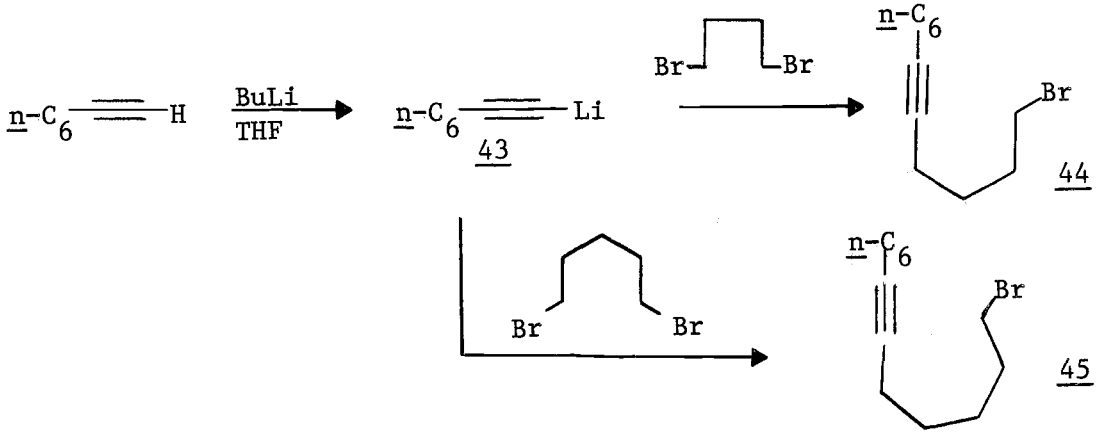
Advantage was taken of the fact that magnesium reagents couple with allyl halides to prepare 2-chloro-1,6-heptadiene (42) and 2-chloro-1,7-octadiene (41) from 2-chloro-3-bromo-propene (40) and appropriate Grignard reagents (36) (Scheme 26).

Scheme 26



The systems used in the study of the digonal cyclizations were prepared by alkylation of the lithium acetylide 43 which was prepared from the reaction of butyl lithium with 1-octyne (Scheme 27).

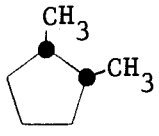
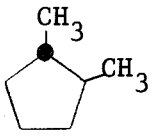
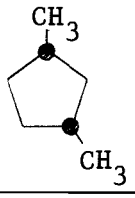
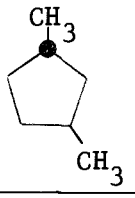
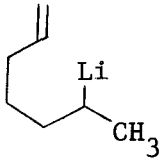
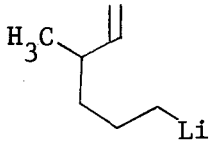
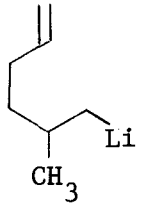
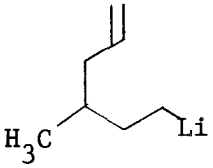
Scheme 27



Most of the halides which acted as immediate precursers to the lithium reagents were purified by preparative gas chromatography

before use. All but one of the lithium reagents were prepared by the reaction of the alkylhalides in diethyl ether with lithium metal (wire or dispersion; both containing 2% sodium). The lithium reagent from 37 was generated in higher yield by addition of 37 to an excess of lithium p,p'-di-tert-butylbiphenyl (LiDBB) in THF at -78°(37). The stereochemical outcomes of the cyclizations involving the four methylated 5-hexenyl lithium systems are presented in Table 2.

Table 2

Starting Organolithium		Product				Yield
						
	39a	3	97			43%
	26a	3	97			61%
	30a			10	90	47%
	33a			90	10	52%

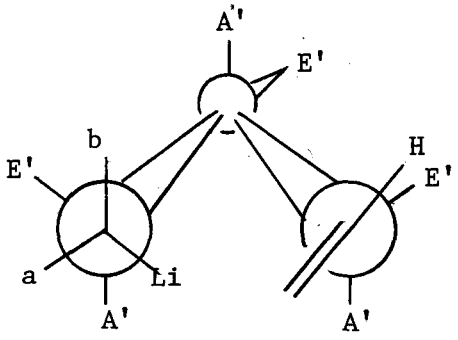
All the reactions are reasonably stereoselective with the first two entries showing exceptionally high diastereomeric discrimination. The cyclizations which produce the 1,2-dimethylcyclopentanes appear to be influenced by the greater thermodynamic stability of the trans over the cis isomer. The trans isomer has been shown to be 1.71 kcal/mole more stable than the cis isomer by the difference in heats of combustion (49).

In contrast, the cyclizations resulting in the generation of the 1,3-dimethylcyclopentanes depend dramatically on the location of the methyl substituent. When the substituent resides at the position immediately adjacent to the carbon bearing the lithium (30a), the less stable trans-1,3-dimethylcyclopentane is generated preferentially. However, in the case of the 3-methyl derivative 33a, cis-1,3-dimethylcyclopentane is formed as the major product. This behavior was also observed by Stefani in the study of the ring closures of methylated 5-hexenyl aluminum systems (33).

The arguments used by Stefani can equally be employed to rationalize the stereochemistries of the lithium cyclizations with one exception. In contrast to the cyclization of the 1-methyl derivative 39a, a predominance of the unexpected cis-1,2-dimethylcyclopentane occurs for the aluminum cyclization. Obviously, an adjustment needs to be made in Stefani's arguments in order to accommodate the lithium cyclization results. If the conformational coils for magnesium and

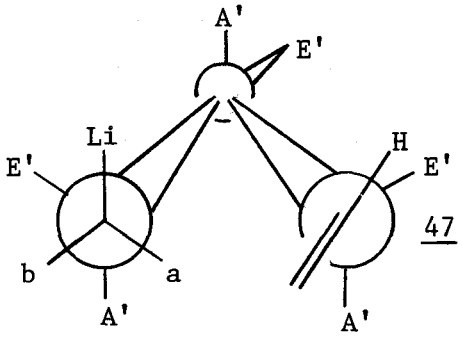
aluminum cyclizations are used for the lithium cyclizations, it is apparent that either coil would predict the stereochemical outcome of the cyclizations when the methyl group resides in the quasi equatorial position of either conformation for substituents in the 2-, 3-, and 4-positions (Scheme 28).

Scheme 28



46

Rectangular Coplanar



47

Perpendicular

However, the methyl substituent in the 1-position leads to a preferential production of trans-1,2-dimethylcyclopentane for the lithium cyclization as in the case of the magnesium cyclization. For the reaction coil 46 leading to the "rectangular coplanar" transition state, the methyl group would preferably be in the 'a' position over the 'b' position due to steric interactions between the 'b' position and the carbon 2 - carbon 3 bond. As the system approaches the transition state structure, the conformation will become distorted, but to an extent that the transition state still resembles 46. This would lead to a cis product.

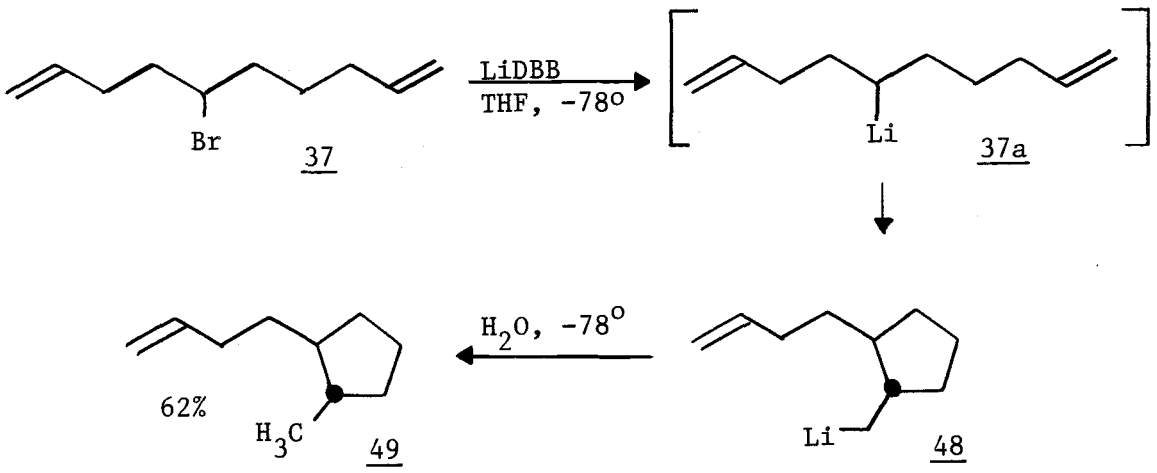
In contrast, the reactive coil 47 leading to a "perpendicular" transition state has a methyl group which would prefer to be in the 'b' over the 'a' position. If the transition state resembles this conformation, the trans isomer would be predicted as the major product just as in the case of the magnesium cyclizations. Since the trans-1,2-dimethylcyclopentane was produced as the major product, the cyclization lends support for the "perpendicular" transition state geometry for the lithium cyclizations.

Of the four cyclopentyl cyclizations, three appear to be capable of extended cyclization to produce bicyclic units. Stereospecificity is an important consideration in any initial ring closure. Either reaction used to generate 1,2-dimethylcyclopentane could be employed in a continuing cyclization process provided that a trans ring juncture was desired. However, only the cis-1,3-dimethylcyclopentane could be considered suitable for extended cyclization. Consequently, a substituent in the 3-position rather than the 4-position of the 5-hexenyllithium should be synthetically appropriate.

The two systems which produce 1,2-dimethylcyclopentane were extended and these extentions were found to produce one diastereomer of 5-methylhydrindane with high stereospecificity. Low temperature initial intramolecular cyclization of 5-lithio-1,9-decadiene (37a) was accomplished by the addition of 5-bromo-1,9-decadiene (37) to an excess of lithium p,p'-di-tertbutylbiphenyl (LiDBB) in THF under a

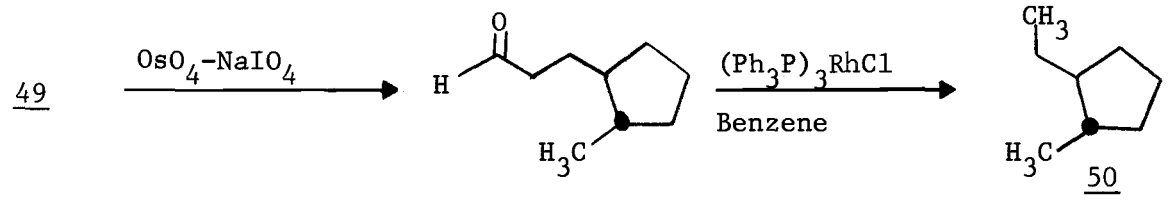
nitrogen atmosphere at -78° (37) (Scheme 29).

Scheme 29



Although treatment of an alkyl bromide with LiDBB is known to generate the corresponding organolithium compound, 1,9-decadiene was only a very minor product isolated by the addition of water to the low temperature solution. Intramolecular cyclization took place rapidly producing compound 48. After water quenching, 49 was isolated by preparative gas chromatography. The stereochemical outcome of the low temperature cyclization was expected to be a 5-membered ring with trans substituents. This was confirmed by degradation 49 into trans-2-ethylmethylcyclopentane (50) by oxidative cleavage of the double bond followed by decarbonylation (Scheme 30).

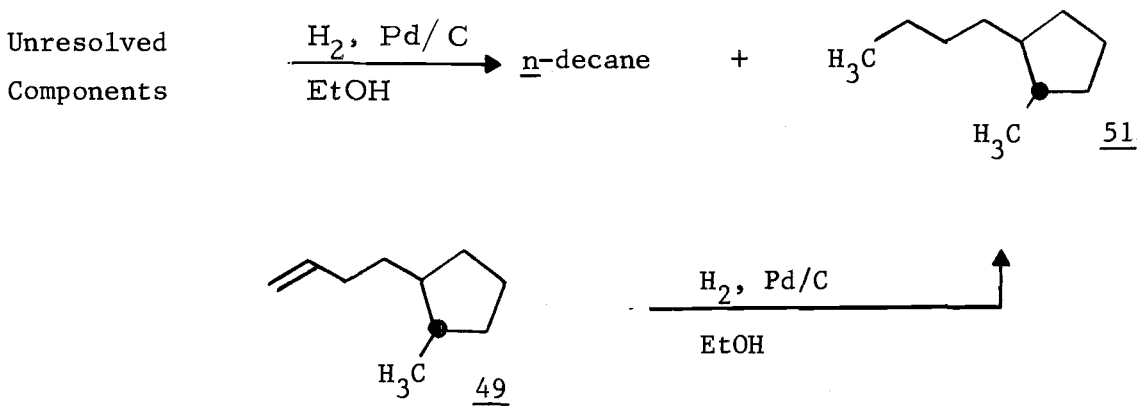
Scheme 30



The structure of the degradation product was confirmed by comparison of its NMR spectrum and gas chromatographic retention time to those of authentic samples of both cis- and trans-2-ethylmethylcyclopentane. The gas chromatogram of the low temperature quenched reaction displayed a very small peak at a somewhat longer retention time than that of 49. This material was isolated and assigned the structure cis-2-(3-butenyl)methylcyclopentane (49a) based on its NMR spectrum. Under the above conditions, it can be said that the cyclization proceeded with at least 95% stereospecificity to produce trans-2-(3-butenyl)methylcyclopentane (49). If the reaction is not quenched but allowed to sit undisturbed at room temperature for ten hours, additional products are formed. The gas chromatogram of the mixture of products displayed a partially resolved set of signals consisting of at least four components. An additional peak (29% of the product composition) appeared at a slightly longer retention time and was isolated from the other products by preparative gas chromatography. The NMR spectrum of this material showed no absorption in the

olefinic region. The other components were isolated as a group and the group's NMR spectrum displayed an olefinic proton region which indicated the presence of both terminal and internal double bonds. Catalytic reduction of the group using palladium resulted in the formation of only two compounds. The first compound to elute from the gas chromatograph (14% of the reduction mixture) was easily identified as n-decane. The other product gave an identical NMR spectrum to that of a substance isolated from the catalytic reduction of 49. This compound was assigned the structure trans-2-butylmethylcyclopentane (51) (Scheme 31).

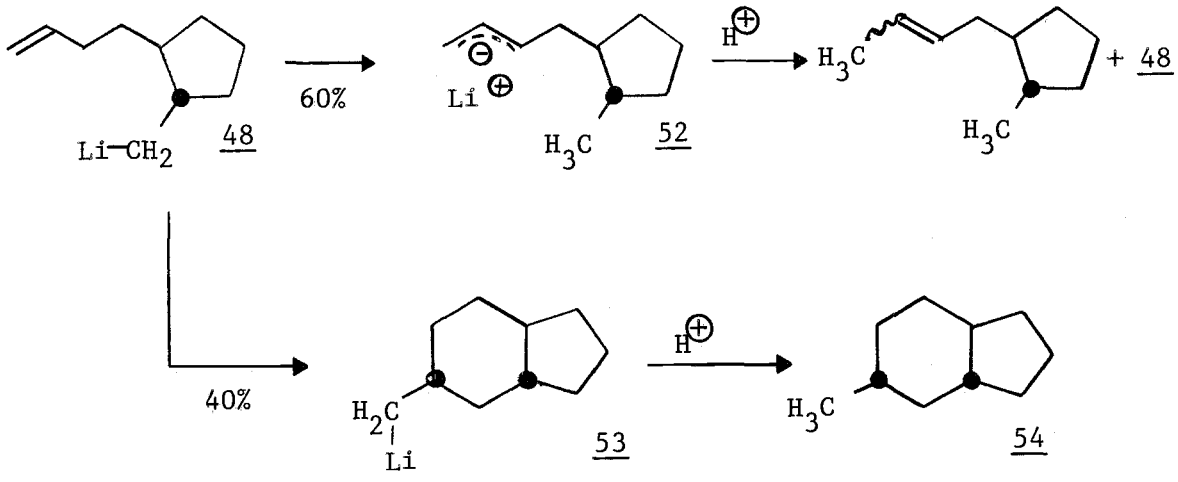
Scheme 31



These results have been interpreted in terms of a reaction pathway dichotomy available to lithium reagent 48. A major portion of the reaction involves allylic proton abstraction which generates a stable allylic anion 52 (Scheme 32). In spite of the proton abstraction, a sizable percentage of 48 experienced further cyclization to give 53.

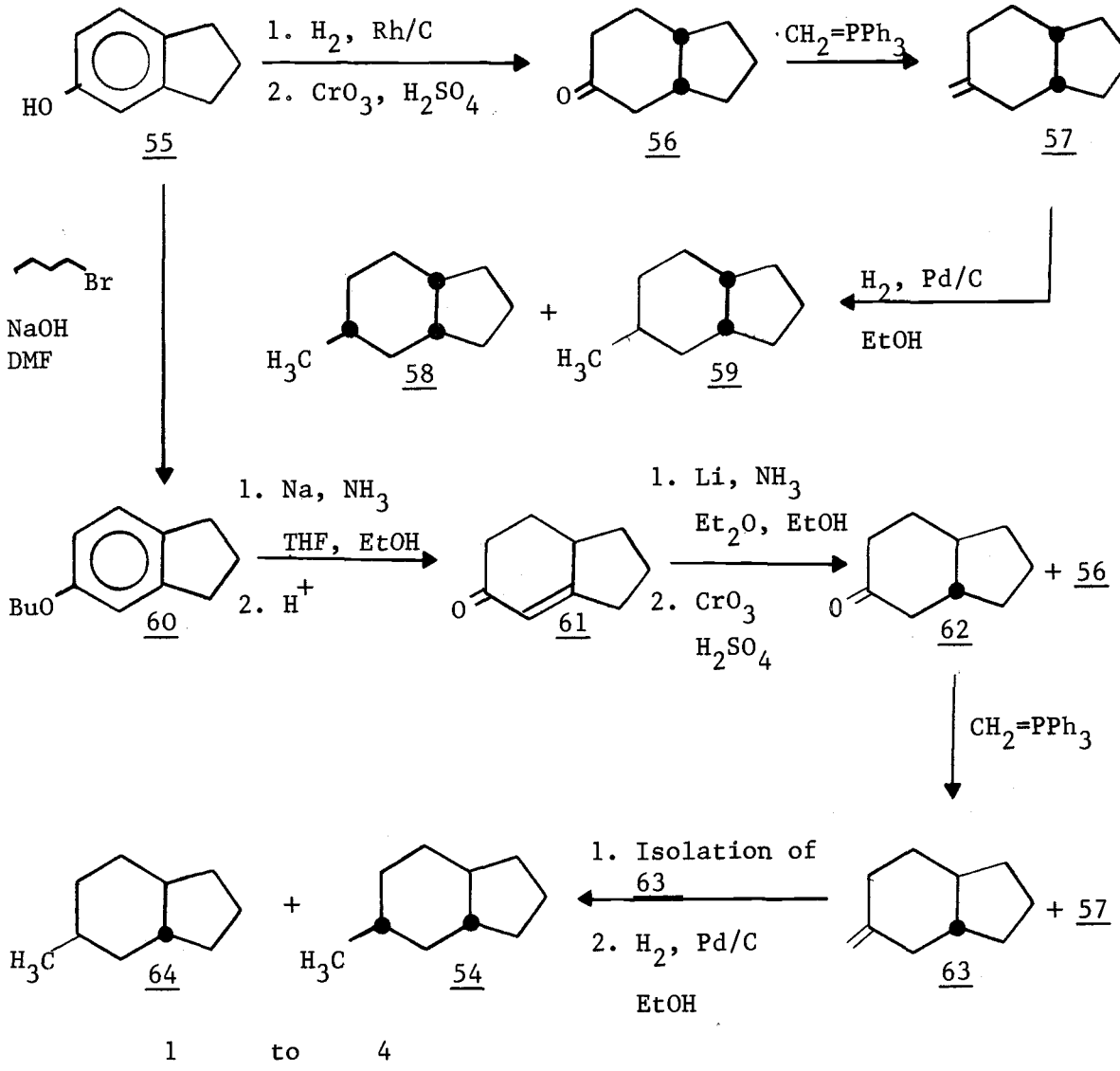
In order to be completely certain of the structure assigned to 54, the synthesis of all four possible distereomers of 5-methylhydrindane was undertaken.

Scheme 32



Two approaches beginning with a common starting material (5-indanol), 55, eventually led to the desired stereoisomers. In one procedure, the cis ring fusion was produced by catalytic reduction using rhodium on carbon. The two diastereomeric products ultimately resulting from this sequence, 58 and 59, showed gas chromatographic retention times far different from that of 54 (Scheme 33). The trans ring fusion was generated from the unsaturated ketone 61. One of the diastereomers resulting from this sequence displayed a NMR spectrum and gas chromatographic retention time identical to 54.

Scheme 33



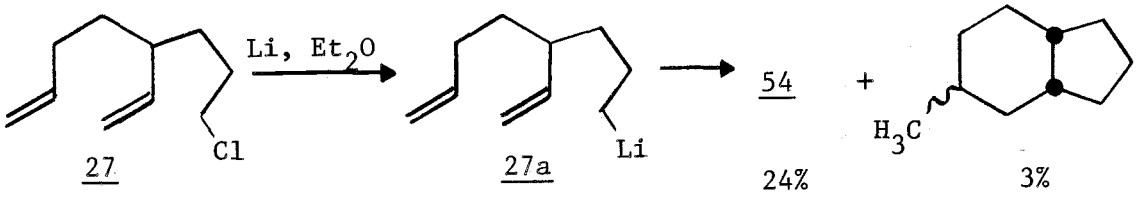
The structure of 54 was determined by the method of production of 54 and 64 and NMR information obtained from them. Reduction of exocyclic double bonds using palladium on carbon is known to produce an equitorial substituent preferentially (38a). The ratio of 54 to 64 was 4 to 1. Also, an equitorial methyl group generally shows a

higher field chemical shift than that of the corresponding axial methyl group (38b). The methyl doublet of 54 showed a chemical shift of d 0.90 while the methyl group of 64 displayed a doublet at d 0.95. Also, the coupling constant for the methyl group of 54 and the adjacent methine proton (J=6.0 Hz) was smaller than that observed for the methyl protons of 64 and the adjacent methine proton (J=7.2 Hz).

The cyclization of lithium reagent 27a also produced cis-5-methyl-trans-hydrindane (54) as the major bicyclic product (24%) along with a trace of unresolved 5-methyl-cis-hydrindane (3%) Scheme 34).

The gas chromatogram of the reaction products indicated that other products were present with shorter retention times than the four diastereomeric bicyclic compounds. They were assumed to be linear and monocyclic compounds and were not further investigated.

Scheme 34



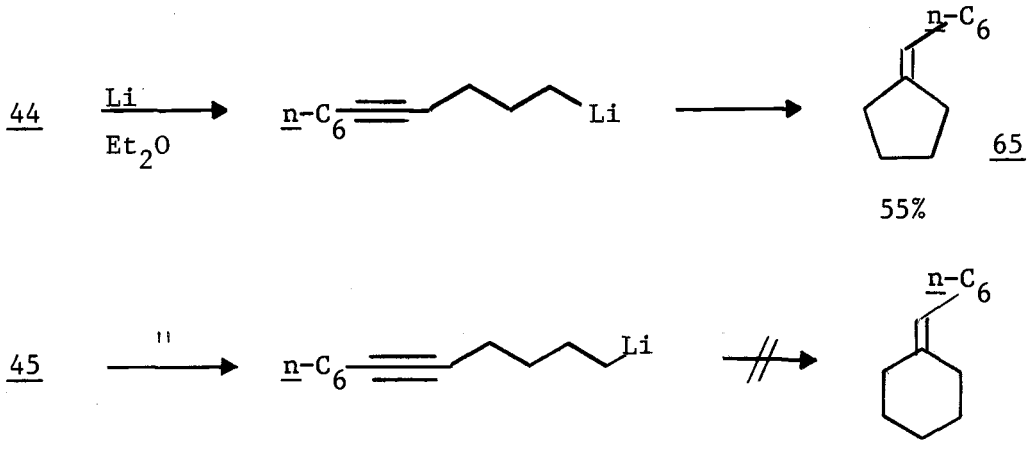
27 27a 54 24% 3%

Most functionalities are susceptable to reactions with lithium reagents. It was felt that incorporation of an alkenyl group into the system would generate functionality which could easily be transformed into other functional groups. In order to incorporate an alkenyl group

into the cyclic moiety, it has to be produced or be inert to the lithium cyclization process. Four systems were studied; two digonal cyclizations and two trigonal cyclizations from alkenyllithium reagents.

Only one of the two digonal systems, 44a, was found to cyclize producing an exocyclic alkenyl moiety in average yield (Scheme 35). The cyclization of 44a shows the feasibility of incorporating the functionality mentioned above. However, this cyclization only shows the possibility of the incorporation of an olefinic function in the terminal position of the cyclization process and only for the formation of 5-membered rings.

Scheme 35

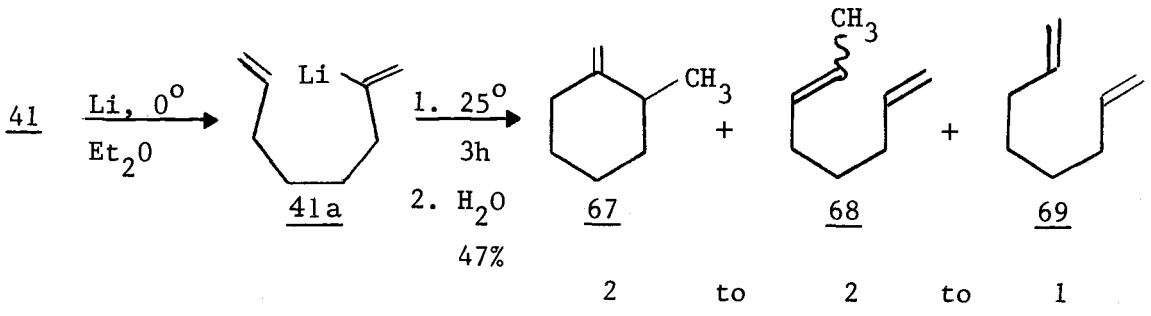


Cyclization of alkenyl lithium reagents had not been reported in the prior literature. In an attempt to evaluate such a reaction, two lithium reagents 41a and 42a were studied. From these investigations, two pieces of valuable information were obtained; the

possibility of continued cyclization from digonal systems and the ability of lithium cyclizations to incorporate functionality in positions other than those obtained from the digonal systems.

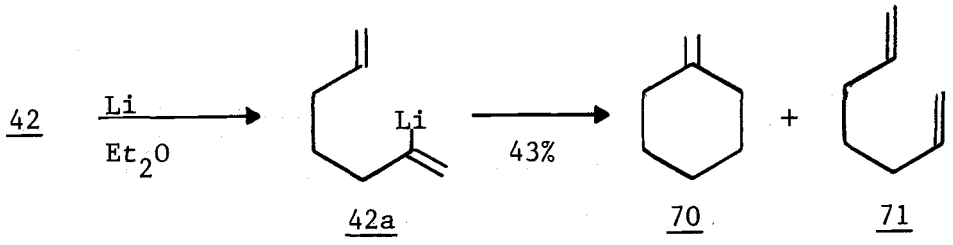
Lithium reagent 41a cyclized at room temperature to produce 67 after a reaction period of three hours and quenching. Unfortunately, other products were produced which indicates that the bothersome allylic hydrogen abstraction was effectively competing with the cyclization process (Scheme 36).

Scheme 36



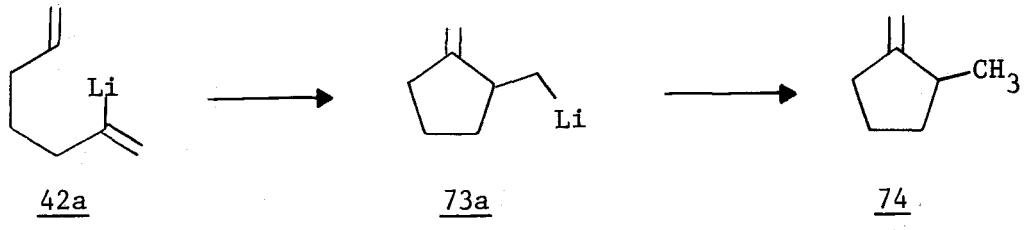
The products 67 and 69 were identified by comparison of their NMR spectra with those of authentic samples. Compound 68 was assigned its structure solely from its NMR spectrum. The analog of 41a, 2-lithio-1,6-heptadiene (42a) also underwent a cyclization process but the only isolatable cyclic product obtained from the reaction was methylenecyclohexane (70), a totally unexpected compound, after a reaction period of three hours (Scheme 37).

Scheme 37



The products 70 and 71 were identified by comparison of their NMR spectra with those of authentic samples. The expected course of this reaction was that of exocyclization to produce 2-methylene-methylcyclopentane (74) analogous to the cyclization of 41a (Scheme 38).

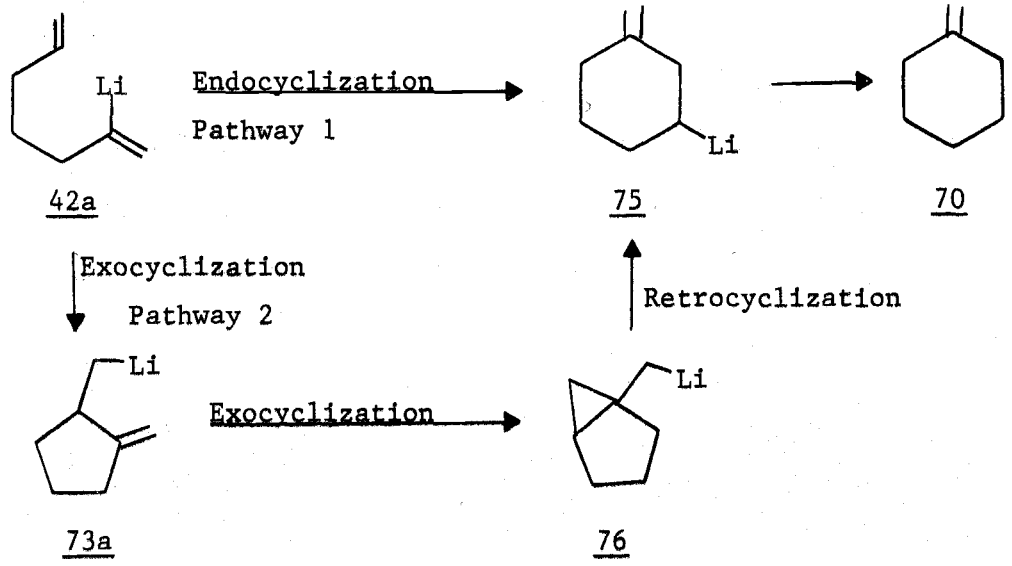
Scheme 38



There exists two plausible explanations for the production of 70 from 42a. The first explanation dictates an endocyclization pathway to produce 75 directly which is in accord with Baldwin's rules but does not comply with the normal exocyclization route which is the

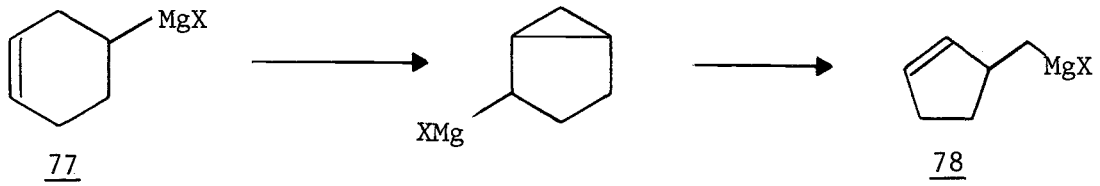
preferred route of most organolithium cyclizations. The second explanation deals with an indirect pathway which complies with the postulated transition states for cyclization, i.e., two exocyclizations followed by a retrocyclization to produce 75 (Scheme 39).

Scheme 39



The plausibility of the second pathway rests in the ability of 73a to isomerize to 75. There exists some evidence for this type of rearrangement. The organomagnesium reagent 77 was found to rearrange to 78 by a similar route as that proposed above (39) (Scheme 40). However, the Grignard reaction is in the "opposite" direction as that proposed; a primary magnesium reagent is obtained from a secondary magnesium reagent.

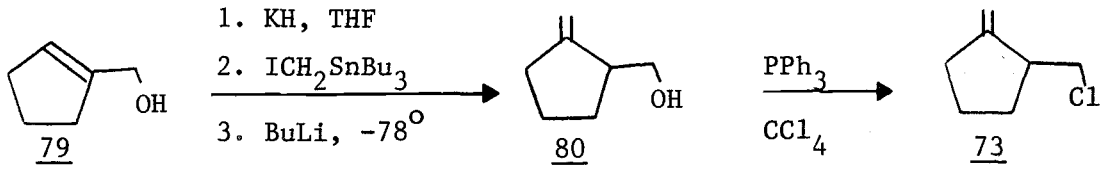
Scheme 40



77 78

Lithium reagent 73a was synthesized independently, trapped, and indeed was shown to isomerize to 75. The synthesis of 2-(chloromethyl)-methylenecyclopentane (73) was achieved by first preparing the homoallyl alcohol 80 from the allyl alcohol 79 using a method developed by Still (40) (Scheme 41). The homoallyl alcohol was transformed into the corresponding chloride 73 by treatment with triphenylphosphine - carbon tetrachloride.

Scheme 41

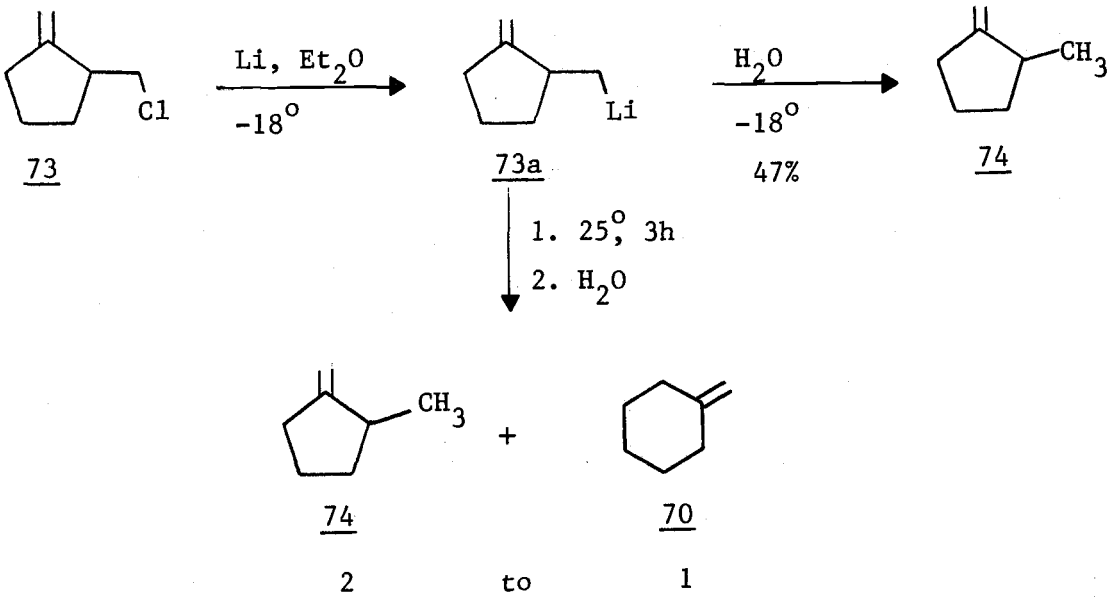


79 80 73

Lithium reagent 73a was prepared and trapped by the treatment of the halide 73 with lithium wire at -18° in diethyl ether as solvent. Upon quenching with water, 2-methylmethylenecyclopentane was produced

virtually as the only product along with a trace of material having the same gas chromatographic retention time as that of methylenecyclohexane (Scheme 42).

Scheme 42



73 73a 74

74 70

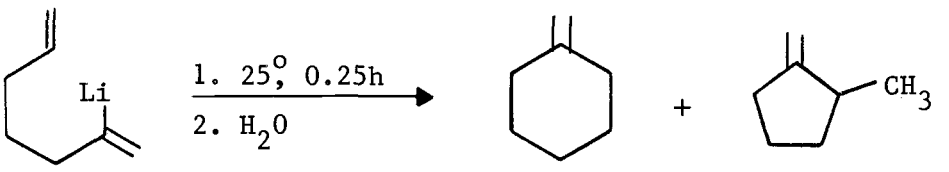
2 to 1

Upon warming to room temperature and quencing with water after three hours, 74 and 70 were produced in a ratio of 2 to 1.

In order to completely establish the correct pathway, it was necessary to trap 73a from the cyclization of 42a. This was accomplished by shortening the reaction time of the cyclization of 42a from three hours to fifteen minutes at room temperature. Using this reaction time period, 74 was found to be the major cyclic product and the ratio of 74 to 70 was 2.3 to 1 for this shortened reaction period (Scheme 43). It is felt that the difference in stability of the

secondary and primary lithium reagents is the reason that no 70 is found after a reaction period of three hours from the cyclization of 42a. A secondary lithium reagent can more easily abstract a proton from the solvent due to its increased basicity over that of a primary lithium reagent. If there exists an equilibrium between 73a and 75, an abundance of 70 should be produced over 74 due to this increased basicity.

Scheme 43



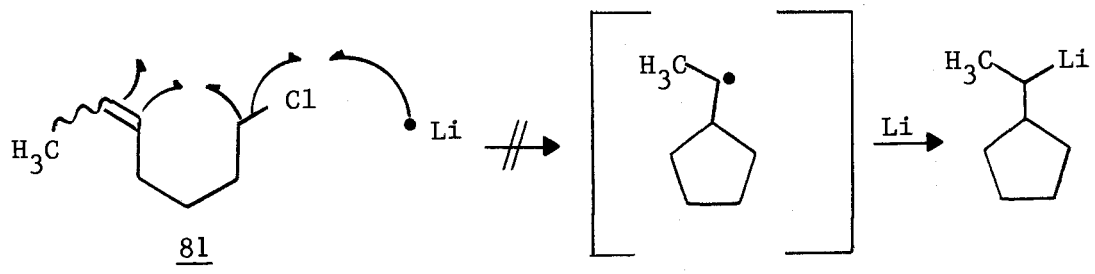
70 74

1 to 2.3

Evidence does not support the intervention of radicals in the cyclization process. The stereochemistry of free radical cyclizations differ from those observed in this text. When a 1,2-dialkylcyclopentane is produced from a radical cyclization, the major isomer produced is the cis isomer, whereas the major product from the cyclizations in this study was the trans isomer. Intramolecular assisted homolysis (41) was shown not to be responsible for the cyclizations by the attempted cyclization of the lithium reagent produced from 7-chloro-2-heptene (81). It is generally accepted that the first step in forming a lithium reagent is an electron transfer. The

possibility of intramolecular olefin assisted homolysis exists, but if it were in operation, the reaction of lithium with 81 would be expected to produce a cyclic lithium reagent faster and more efficiently than the reaction of lithium with 6-chloro-1-hexene. However, very little cyclic material is formed from the reaction of 81 with lithium after a reaction period of several hours. The reaction of lithium with 6-chloro-1-hexene produces mainly cyclic product even at very short reaction periods which indicates that intramolecular olefin assisted homolysis is not in operation (Scheme 44).

Scheme 44



81

The cyclization of the lithium reagent prepared from the radical anion can also be assumed to proceed in a radical fashion since studies have shown that electron transfer is diffusion controlled (42). The rate of cyclization of the 5-hexenyl radical was shown to be at least three orders of magnitude slower than that of electron transfer. This information coupled with the stereochemical results indicates there is little or no radical participation in the cyclizations of lithium reagents prepared in this fashion.

A great deal of information mechanistically is as yet unavailable for adequately interpreting lithium cyclizations. Kinetic information is needed to ascertain what degree of association of lithium - lithium bonding is responsible for cyclization. Lithium reagents exist as monomers to hexamers depending on the reagent and solvent used. The addition of a complexing agent such as TMEDA greatly accelerates the cyclization of 7-lithio-1-heptene to produce cyclohexylmethyllithium (48). Since complexing agents tend to disassociate lithium reagents into monomers, the monomeric lithium reagent seems to be the most reactive toward cyclization.

Very little is known about the stereochemical consequences at the four centers of reaction for the addition reaction. It is not yet known if the carbon - lithium bond adds with inversion or retention of configuration at the carbon center. It is also not known whether cis or trans addition is preferable although intermolecular examples indicate that the cis addition is preferable (27). The 4-centered transition states depicted in this text are consistent stereochemically with the results of the intermolecular examples.

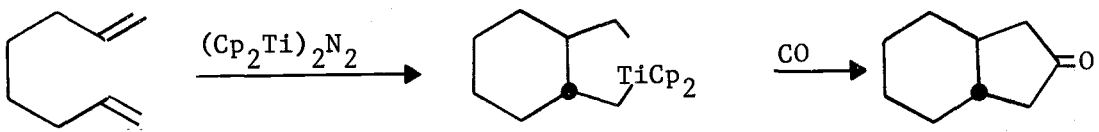
This study has shown that the cyclization of lithium reagents is stereospecific and a variety of lithium reagents undergo the cyclization process to form 5- and 6-membered rings, but organolithium reagents will not be useful synthetically for prepartive scale cyclizations until methods are found to increase the yields of formation

of lithium reagents and methods are found which minimize allylic hydrogen abstraction.

Organotitanium and -zirconium chemistry is rich in diversity and utility (43). Although several metals have been shown to promote the oxidative coupling of strained olefins (44), the more useful coupling of unstrained olefins to produce a metallocycle seems far more elusive. When both olefinic units are present in the same molecule, such a transformation offers a promising method of carbocyclization.

Recently, Whitesides reported the cyclization of 1, 7-octadiene (69) with titanocene (Cp_2Ti; Cp = cyclopentadienyl) in extremely low yield (45) (Scheme 45).

Scheme 45

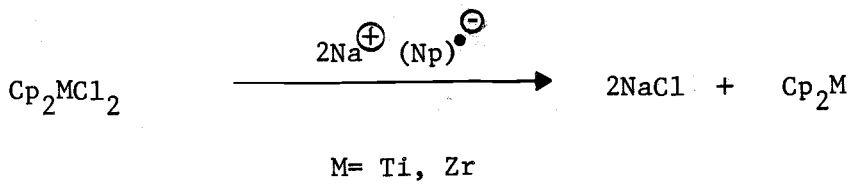


69 2%

With a desire to exploit the synthetic aspects of such a process, the reactions of a few unsaturated molecules with titanocene and zirconocene (Cp_2Zr) were investigated. The Cp_2M (M = Metal) species were generated in situ by the reaction of sodium napthalene with

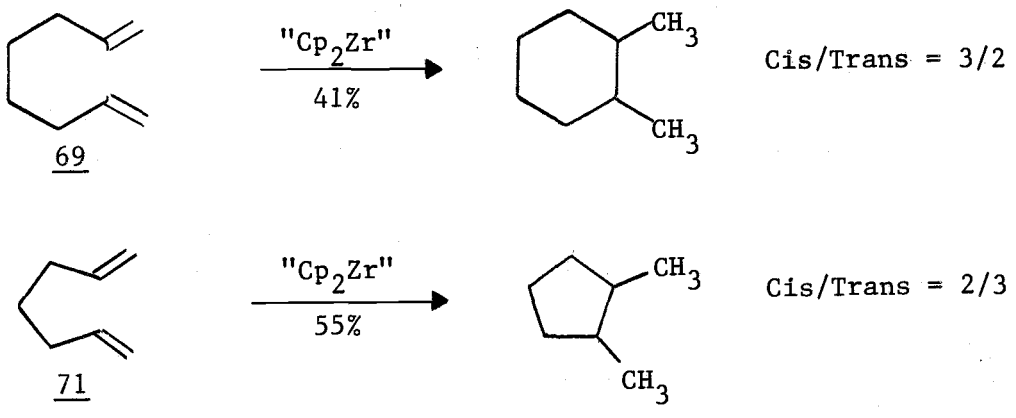
Cp_2MCl_2 in THF (46) (Scheme 46).

Scheme 46



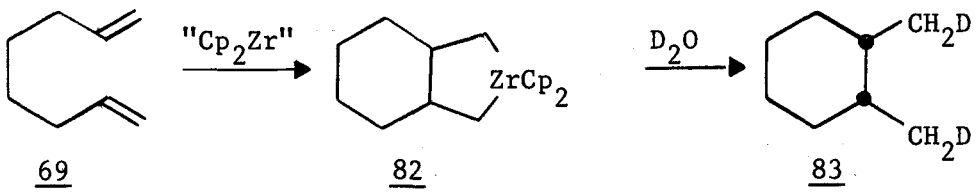
The desired oxidative coupling took place in fair yield only with zirconocene. The addition of solid Cp_2ZrCl_2 (4.0 mmoles) to a solution of THF containing 2.7 mmoles of 1,6-heptadiene (71) and excess sodium napthalene led to a mixture of products containing both cis- and trans-1,2-dimethylcyclopentane when quenched with a small amount of water. Similarly, cis- and trans-1,2-dimethylcyclohexane was produced from 1,8-octadiene (69) (Scheme 47).

Scheme 47



Evidence for the intermediacy of a metallocyclopentane 82 was found by using deuterium oxide as the proton source in the workup procedure for the cyclization of 1,2-octadiene (Scheme 48).

Scheme 48



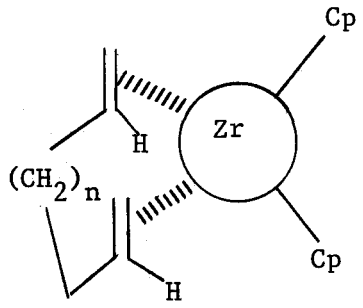
69 82 83

50% d_2, 30% d_1, 20% d_0

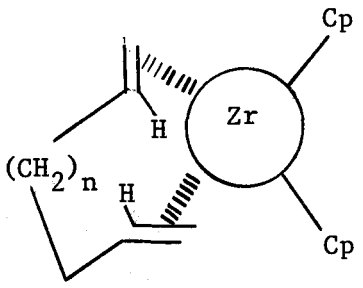
Mass spectral analysis of the resultant cis cyclic isomer 83 indicated the presence of 50% d_2 - 30% d_1-, and 20% d_o-cis-1,2-dimethylcyclohexane. The NMR spectrum pinpointed the location of the deuterium as being on the methyl groups.

The production of both cis and trans isomers is difficult to rationalize since very little information is known about the oxidative coupling process. One plausible explanation deals with the stereochemistry of the metal complexed olefins prior to oxidative coupling. If there exists two conformations for the metal complex; one with the olefinic units parallel 84 and the other with the olefinic units perpendicular 85, oxidative coupling would produce both cis and trans isomers (Scheme 49).

Scheme 49



Parallel



Perpendicular

Several experimental parameters were varied in order to determine their effect on the cyclization reaction. As expected, the identity of radical anion source had no effect on the reaction. Sodium biphenyl gave the same results (yield and isomer distribution) as that of sodium napthalene. Lower yields of cyclic products were obtained when either glyme or diglyme was employed as solvent. The presence of a ten fold excess of 1, 7-octadiene revealed that approximately 40% of the zirconocene participated in the carbocyclization to provide 1,2-dimethylcyclohexane. No noticeable difference in yield was observed when based on diene (Cp_2ZrCl_2 in excess) or on Cp_2ZrCl_2 (diene in excess).

Interestingly, little cyclization was observed when the Cp_2ZrCl_2 was prereduced at -40° followed by the addition of the diene and warming to room temperature. This suggests that the zirconium

complex responsible for carbocyclization must be trapped by diene prior to conversion into an inactive species toward cyclization. Substitution of Cp_2TiCl_2 for Cp_2ZrCl_2 resulted in the production of a complex mixture of reduced and isomerized compounds (also present in the zirconocene reactions) with only trace amounts of carbocyclization.

Simple reduction of terminal double bonds took place readily using either Cp_2ZrCl_2 or Cp_2TiCl_2 and sodium napthalene in THF. For example, 1-octene (86) was reduced to n-octane in 77% yield using either Cp_2TiCl_2 at -40° or Cp_2ZrCl_2 at room temperature. When deuterium oxide was employed in the workup of the reduction reactions, mass spectral analysis of the octane produced from 1-octene revealed approximately 5% monodeuteration from the titanium reaction and 34% monodeuteration from the zirconium reaction. Only a trace of dideuterated octane was formed from each reaction.

The mechanism generally postulated for the formation of metallocyclopentanes from olefins is a complexation process followed by oxidative coupling (44). This mechanism could very easily explain the cyclized products obtained from the zirconium reactions.

In order to better understand the mechanism for cyclizations and reductions by zirconocene and titanocene, much more mechanistic information is needed. It is not yet known the major source of hydrogen for the reduction of simple olefins by titanocene and

zirconocene. The hydrogen may be coming from the solvent or the cyclopentadienyl rings. More information may be found about the reactive intermediates in the reduction and cyclization reactions by using the electronically equivalent hafnium complex Cp_2HfCl_2. Organohafnium compounds are generally more stable the corresponding zirconium and titanium compounds. It is believed that the increased stability is due to greater polarity in the metal - carbon bonds for hafnium over that of titanium and zirconium (47). The utilization of the hafnium complex may lead to actual isolation of intermediates.

Zirconocene has been shown to promote oxidative coupling of simple dienes efficiently, but the most interesting result found in this study is production of both cis and trans isomers from the supposed oxidative coupling reaction. The production of both isomers indicates that either the oxidative coupling reaction is stepwise instead of being concerted or that the metal exists in at least two hybridization states for the olefin complexed intermediate. These different hybridizations would lead to both cis and trans isomer production.

IV. EXPERIMENTAL

General Laboratory Procedures and Conditions

All temperatures are uncorrected. Nuclear magnetic resonance (NMR) spectra were obtained on Varian Em-360 (60 MHz) and Varian HA-100 (100 MHz) spectrometers. Unless otherwise specified, tetramethylsilane was used as an internal reference, and the following abbreviations were used: s = singlet, d = doublet, t = triplet, q = quartet, J = coupling constant in Hertz. Infrared (IR) spectra were obtained on Perkin-Elmer 137 sodium chloride spectrophotometer. Low resolution mass spectra were obtained from an Atlas CH7 instrument using a 70 3V excitation potential. High resolution mass spectra were obtained from a CEC 110B instrument.

Gas-liquid chromatography (GLC) analyses were carried out on a Varian 920 (thermal conductivity detector, using 0.25 in. columns) and a Hewlett-Packard 5720A (thermal conductivity detector, using 0.125 in. columns). The chromatograms were recorded by either a Hewlett-Packard 7123A recorder, a Linear Instruments 445 recorder, or a Sargent-Welch XKR recorder.

In cases where the products were hydrocarbons, a hydrocarbon internal standard was added. Equal molar responses were assumed using the thermal conductivity detector. All peak areas needed to calculate yields were determined by use of a Hewlett-Packard

integator model 3373B, or by cutting out and weighing.

Analytical and preparative g.l.p.c. work was conducted using the following columns:

Column A SE-30 (25%) on Chromosorb P, 0.25 in. X 4 ft.

Column B TCEP (5%) on Chromosorb G, 0.25 in. X 6 ft.

Column C SE-30 (3%) on Chromosorb P, 0.25 in. X 6 ft.

Column D SE-30 (20%) on Chromosorb P, 0.25 in. X 6 ft.

Column E SE-30 (10%) on Chromosorb P, 0.25 in. X 6 ft.

Column F UCW-982 (10%) on WAW-DMCS, 0.125 in. X 1.7 ft.

Column G OV-101 (10%) on Chromosorb P, 0.25 in. X 5 ft.

Column H Carbowax (20%) on Chromosorb P, 0.25 in. X 20 ft.

Column I TCEP (5%) on Chromosorb P, 0.25 in. X 12 ft.

Column J OV-17 (5%) on Chromosorb G, 0.25 in. X 10 ft.

Column K OV-101 (3%) on Chromosorb P, 0.25 in. X 6 ft.

Column L SE-30 (20%) on Chromosorb P, 0.25 in. X 3 ft.

Column M SE-30 (20%) on Chromosorb P, 0.125 in. X 15 ft.

Column N OV-101 (10%) on Chromosorb P, 0.25 in. X 3 ft.

Column O Squalene (7%) on WAW-DMCS, 0.125 in. X 30 ft.

Column P OV-17 (5%) on Chromosorb P, 0.25 in X 18 ft.

Column Q Carbowax (20%) on Chromosorb P, 0.25 in. X 4 ft.

Column R OV-101 (10%) on Chromosorb G, 0.25 in. X 7 ft.

All elemental analysis of analytical samples were performed by Galbraith Laboratories, Inc. (Galbraith Laboratories, Inc.,

P. O. Box 4187, Knoxville, Tennessee).

6-Chloro-3-methyl-1-hexene (26)

To 300 mL of anhydrous ether was added 7.2 g (0.3 moles) of magnesium turnings under a positive argon atmosphere. About 10% of a solution consisting of 18.0 g (0.2 moles) of crotyl chloride dissolved in 50 mL of anhydrous ether was added rapidly. The mixture was stirred by the action of a magnetic stirring bar, and a cloudiness developed after several minutes. After discoloration, the reaction vessel was immersed in an ice bath and the remainder of the crotyl chloride solution was added dropwise over a 90 minute period. Following the addition, the ice bath was removed and the reaction mixture was stirred for an additional hour. Separation of the Grignard solution from excess metal was accomplished by transferring the solution under a positive argon atmosphere into another round bottomed flask by the use of a connecting glass tube. Exactly 7.2 g (0.3 moles) of 1-chloro-3-bromo-propane was added to the Grignard solution and the whole was refluxed for 120 hours. The flask was immersed in an ice bath and 100 mL of saturated aqueous ammonium chloride was added dropwise and cautiously. The ethereal layer was washed with saturated aqueous sodium chloride and dried using anhydrous magnesium sulfate. After a filtration process, most of the ether was removed using a rotorary evaporator. The remaining

clear solution was subjected to simple vacuum distillation. A clear liquid (4.6 g) was collected which distilled over a broad range, b.p. 37-50°/14 mm. This liquid was subjected to preparative scale g.l.p.c. using column I at 100° column temperature. The major component was isolated and provided a NMR spectrum consistent with that expected for 6-chloro-3-methyl-1-hexene (26); NMR(CCl_4) δ 5.45-5.84 (m, 1), 4.82-5.10 (m,2), 3.46 (t, J=6.2Hz, 2), 1.26-2.36 (m,5), 1.01 (d, J=6.3Hz, 3).

5-Chloro-4-methyl-1-pentene (31)

In 1000 mL of dry carbon tetrachloride was dissolved 50 g (0.5 moles) of 2-methyl-4-penten-1-ol and 136 g (0.52 moles) of triphenylphosphine. The mixture was stirred by the action of a magnetic stirring bar and heated to reflux for 5 hours. Approximately 400 mL of carbon tetrachloride was distilled at atmospheric pressure and an equal volume of pentane was added to the flask. The mixture was filtered and much of the solvent was removed using a rotorary evaporator. Simple distillation at atmospheric pressure eventually resulted in the collection of 21g (36%) of a clear liquid, b.p. 117-119°; NMR(CCl_4) δ 5.40-6.15 (m, 1H), 4.76-5.27 (m, 2H), 3.38 (d, J=8.5Hz, 2H), 1.3-2.3 (m, 3H), 0.98 (d, J=9.5Hz, 3H).

6-Hepten-2-ol (38)

To a Grignard solution prepared from 15.0 g (0.10 moles) of 5-bromo-1-pentene and 4.8 g (0.20 moles) of magnesium turnings in 300 mL of diethyl ether was added 4.4 g (0.10 moles) of acetaldehyde in 10 mL of ether slowly over a period of 30 minutes. The resulting solution was poured into 100 mL of ice containing 5 g of ammonium chloride slowly and cautiously. The organic layer was separated and washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration procedure, most of the ether was removed using a rotarory evaporator. The remaining clear liquid was distilled using vacuum. A clear liquid was collected during distillation (10.5 g, 86% yield, b.p. 72-76°/ 4 mm) which exhibited a NMR spectrum consistent with that expected for 38; NMR(CCl_4) δ 5.58-6.02 (m, 1H), 4.83-5.20 (m, 2H), 4.14 (broad s, 1H), 3.5-3.9 (m, 1H), 1.9-2.3 (m, 2H), 1.1-1.8 (m, 4H), 1.12 (d, J=6.0Hz, 3H).

6-Chloro-1-heptene (39)

The procedure for the preparation of 5-chloro-4-methyl-1-pentene (31) was employed using 5.2 g (0.042 moles) of 6-hepten-2-ol (38), 50 mL of carbon tetrachloride and 11.9 g (0.045 moles) of triphenylphosphine. Most of the carbon tetrachloride was removed

by simple distillation at atmospheric pressure. The products from the reaction were vacuum transferred from the precipitated triphenylphosphonium oxide (4.7 g) and analyzed by preparative g.l.p.c. using column L at 80°. The main product from the reaction was isolated and produced a NMR spectrum consistent with that expected for 39; NMR(CCl_4) δ 5.52-6.01 (m, 1H), 4.82-5.20 (m, 2H), 3.8-4.12 (m, 1H), 1.9-2.1 (m, 2H), 1.26-1.86 (m, 4H), 1.47 (d, J=6.0Hz, 3H).

3-Methyl-5-hexen-1-ol (32)

Following the method of Ricke (73), highly reactive magnesium metal was prepared from 17.0 g (0.18 moles) of anhydrous magnesium chloride and 10.5 g (0.25 moles) of potassium in 400 mL of dry THF. The flask containing the mixture was placed in an ice bath and 11.8 g (0.1 moles) of 5-chloro-4-methyl-1-pentene (31) was added rapidly. After a 15 minute period, the ice bath was removed and the mixture was stirred overnight under a positive argon atmosphere. The Grignard solution was transferred by syringe to an addition funnel which was attached to a flask containing 32.4 g (0.3 moles) of chloroethylformate in 100 mL of dry diethyl ether. The flask was immersed in an ice bath and the Grignard was added slowly over a 10 minute period while the contents of the flask was vigorously stirred by the action of a magnetic stirring bar. After the addition was complete, saturated aqueous ammonium chloride solution was dripped

into the flask slowly and cautiously resulting in the formation of a precipitate. The liquid was decanted into a separatory funnel, washed with dilute aqueous sodium hydroxide solution, saturated aqueous sodium chloride and dried using anhydrous magnesium sulfate. Most of the solvent was removed by means of a rotorary evaporator following a filtration procedure. About 14.0 g of a light yellow liquid remained which was dissolved in 25 mL of dry diethyl ether and added dropwise to 3.8 g (0.1 moles) of lithium aluminum hydride in 100 mL of dry diethyl ether maintained at 0° under a positive argon atmosphere. After the addition was complete, saturated aqueous ammonium chloride solution was added cautiously until a granular solid of the kind suitable for decantation had formed. The ethereal solution was decanted into another flask and the remaining solid was washed several times with small amounts of ether. The ethereal solutions were combined and dried using anhydrous magnesium sulfate. After filtration, most of the ether was removed by the use of a rotorary evaporator. The remaining liquid was distilled under vacuum. Two cuts were taken; 1.5 g (b.p. 72-77°/14 mm) and 2.5 g (b.p. 77-79°/14 mm). The lower boiling cut contained two major components, whereas, the higher boiling material was approximately 95% pure by g.l.p.c. analysis. This corresponds to an overall isolated yield of 22%. The higher boiling cut was further purified by preparative scale g.l.p.c. using column A at 130° column

temperature and provided a NMR spectrum expected for (32); NMR(CCl_4) δ 5.54-5.98 (m, 1H), 4.85-5.14 (m, 2H), 3.84 (s, 1H), 3.57 (t, J=6.2Hz, 2H), 1.15-2.26 (m, 5H), 0.90 (d, J=6.0Hz, 3H).

6-Chloro-4-methyl-1-hexene (33)

The procedure for the preparation of 5-chloro-4-methyl-1-pentene (31) was employed using 1.5 g (0.013 moles) of 3-methyl-5-hexen-1-ol and 4.0 g (0.015 moles) of triphenylphosphine in 25 mL of carbon tetrachloride. The product was vacuum transferred with occasional heating and purified by preparative scale g.l.p.c. using column M at 150° column temperature. The NMR spectrum of the major product was used to identify it as 6-chloro-4-methyl-1-hexene (33); NMR(CCl_4) δ 5.52-5.98 (m, 1H), 4.88-5.24 (m, 2H), 3.5 (t, J=6.0Hz, 2H), 1.40-2.28 (m, 5H), 0.91 (d, J=6.0Hz, 3H).

2-Methyl-5-hexen-1-ol (29)

A solution of ethyl magnesium bromide was prepared by the reaction of 16.4 g (0.15 moles) of ethyl bromide and excess magnesium turnings in 150 mL of dry THF. The Grignard solution was transferred from the excess magnesium under a positive argon atmosphere to a reaction flask maintained at 0° by the use of a glass connecting tube. To the Grignard was added 13.5 g (0.1 moles) of 4-bromo-1-butene followed by 13.6 g (0.12 moles) of the t-butyl imine of

propanal. The ice bath was removed and the solution was heated to reflux overnight. The solution was cooled by immersing the reaction vessel in an ice bath. After cooling, 3N HCl was added dropwise until acidic and the acidic material was heated to reflux for 3 hours. The reaction was allowed to cool to room temperature and the reaction mixture was extracted twice with 100 mL portions of diethyl ether. The ethereal extracts were combined and washed with water followed by dilute aqueous sodium bicarbonate and saturated aqueous sodium chloride. The ethereal extracts were combined and washed with water followed by dilute aqueous sodium bicarbonate and saturated aqueous sodium chloride. The ethereal solution was then dried using anhydrous magnesium sulfate. After a filtration procedure, most of the ether was removed using a rotorary evaporator. The remaining liquid was placed in an addition funnel attached to a flask containing 3.8 g (0.10 moles) of lithium aluminum hydride in 100 mL of diethyl ether maintained at 0° under a positive argon atmosphere. The addition funnel contents were added over a 45 minute period to the reaction flask. Saturated aqueous ammonium chloride was added cautiously and slowly until a grey granular precipitate had formed. The ethereal solution was decanted into another flask and the remaining solid was washed several times with small amounts of ether. The decanted ethereal solution and washings were combined and most of the ether was removed using a rotorary evaporator. The remaining liquid was

vacuum distilled. Material weighing 2.8 g (b.p. 74-90°) was collected. The major component was obtained in pure state by preparative scale g.l.p.c. using column M at 150° column temperature. The isolated material produced an NMR spectrum expected for 2-methyl-5-hexen-1-ol (29); NMR(CCl_4) δ 5.56-6.01 (m, 1H), 4.83-5.16 (m, 2H), 3.86 (s, 1H), 3.24-3.58 (m, 2H), 1.93-2.30 (m, 2H), .99-1.80 (m, 3H), 0.90 (d, J=6.0Hz, 3H).

6-Chloro-5-methyl-1-hexene (30)

The procedure was essentially the same as the one used to prepare 5-chloro-4-methyl-1-pentene (31). The reaction was conducted using 2.0 g (0.017 moles) of 2-methyl-5-hexen-1-ol and 6.6 g (0.025 moles) of triphenylphosphine in 50 mL of dry carbon tetrachloride. The product was vacuum transferred and purified by preparative scale g.l.p.c. using column P at 180° column temperature. The major product was identified as 6-chloro-5-methyl-1-hexene by its NMR spectrum; NMR(CCl_4)δ 5.54-6.00 (m, 1H), 4.84-5.18 (m, 2H), 3.41 (d, J=5.5Hz, 2H), 1.16-2.25 (m, 5), 1.02 (d, J=6.3Hz, 3H).

3-Chloro-1,6-heptadiene and 7-Chloro-1,5-heptadiene (87 and 88)

To a solution of 6.0 g (0.05 moles) of thionyl chloride in 50 mL of anhydrous diethyl ether maintained under a positive nitrogen

atmosphere was added dropwise a solution consisting of 5.0 g (0.045 moles) of 1,6-heptadien-3-ol in 100 mL of anhydrous ether. After the addition, the solution was stirred for 2 hours and most of the ether was removed by the use of a rotarory evaporator. The remaining light tan liquid was subjected to simple vacuum distillation which resulted in the isolation of 3.80 g (65% yield) of a clear liquid (b.p. 48-55°/10 mm). Analysis using g.l.p.c. indicated an isomeric ratio of 5 to 1. The major isomer was isolated in the pure state by preparative scale g.l.p.c. using column K at 120°. This isomer produced a NMR spectrum anticipated for 7-chloro-1,5-heptadiene (87); NMR(CCl_4) δ 5.42-6.07 (m, 3H), 4.88-5.20 (m, 2H), 3.96 (d, J= 6.0Hz, 2H), 2.08-2.43 (m, 4H).

3-(3-Chloroprophyl)-1,6-heptadiene (27)

The procedure used was essentially the same as that used in the preparation of 6-chloro-3-methyl-1-hexene (26). The reaction involved the use of 3.0 g (0.023 moles) of a mixture of 3-chloro-1,6-heptadiene and 7-chloro-1,5-heptadiene, 9.5 g (0.06 moles) of 1-chloro-3-bromopropane, 1.0 g (0.42 moles) of magnesium turnings, and two 50 mL portions of anhydrous diethyl ether. Most of the excess 1-chloro-3-bromopropane was removed by simple distillation at 10 mm pressure. The remaining liquid was distilled at a lower pressure producing a clear liquid (1.4 g) (b.p. 55-60°/1.2 mm).

This liquid was purified by preparative scale g.l.p.c. using column N at a column temperature of 120°. The major product was identified by its NMR spectrum as 3-(3-chloropropyl)-1,6-heptadiene (27); NMR(CCl_4) δ 5.32-5.99 (m, 2H), 4.82-5.14 (m, 4H), 3.47 (t, J= 6.1Hz, 2H), 1.19-2.28 (m, 9H).

1,9-Decadien-1-ol (36)

Into 200 mL of anhydrous diethyl ether under a positive nitrogen atmosphere was placed 4.7 g (0.19 moles) of magnesium turnings. About 10% of a solution containing 13.5 g (0.091 moles) of 5-bromo-1-pentene and 50 mL of anhydrous diethyl ether was added to the magnesium turnings rapidly at room temperature. After the solution turned grey, indicating Grignard formation, the flask was immersed in an ice bath and the remainder of the bromide was added dropwise over a period of 2 hours. After the addition was complete, the mixture was stirred for an additional 2 hours at room temperature. The Grignard was again immersed in an ice bath and a solution of 7.2 g (0.077 moles) of 4-pentenal in 40 mL of anhydrous diethyl ether was added to the solution dropwise over a period of 45 minutes. Approximately 100 mL of cold aqueous saturated ammonium chloride solution was added dropwise with caution. The organic layer was separated and washed once with 100 mL of saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After

filtration, most of the ether was removed using a rotarory evaporator. The remaining liquid was subjected to simple distillation and 10.2 g (86% yield) of a clear liquid was obtained (b.p. 43-44°/0.15 mm). It was identified as 1,9-decadien-5-ol (36) by its NMR spectrum; NMR(CCl_4) δ 5.56-6.01 (m, 2H), 4.81-5.12 (m, 4H), 3.36-3.70 (m, 1H), 3.40 (s, 1H), 1.86-2.40 (m, 4H), 1.21-1.72 (m, 6H). Anal. Calcd for $C_{10}H_{18}O$: C, 77.87; H, 11.6. Found: C, 77.66; H, 11.74.

5-Bromo-1,9-decadiene

To a solution of triphenylphosphine (16.8 g, 0.061 moles) in 80 mL of dry acetonitrile was added 9.75 g (0.061 moles) of bromine over a 10 minute period. The flask was immersed in an ice bath during the addition. A small amount of triphenylphosphine was required to discharge the bromine color after the addition was complete. The resulting suspension was allowed to warm to room temperature and a solution of 9.0 g (0.059 moles) of 1,9-decadien-5-ol (36) in 15 mL of dry acetonitrile was added over a 10 minute period. The reaction mixture was stirred at room temperature overnight. The liquid part of the reaction was decanted from the precipitated triphenylphosphine oxide and the precipitate was washed three times with small portions of acetonitrile. The washings were combined with the mother liquor and most of the acetonitrile was removed under 100 mm pressure. Simple vacuum distillation of the residual

material resulted in the isolation of 9.5 g (74% yield) of a clear liquid (b.p. 34-37°/0.01 mm). The NMR spectrum of the isolated material corresponded to that expected for 5-bromo-1,9-decadience (37); NMR(CCl_4) δ 5.54-6.02 (m, 2H), 4.7-5.3 (m, 4H), 3.97 (m, 1H), 1.3-2.6 (m, 10H). Anal. Calcd for $C_{10}H_{17}Br$: C, 55.31; H, 7.89. Found: C, 55.21; H, 7.80.

2-Chloro-1,6-heptadiene (42)

To 150 mL of dry deoxygenated THF maintained under a positive nitrogen atmosphere was placed 7.0 g (0.29 moles) of magnesium turnings. About 10% of a solution consisting of 15.0 g (0.111 moles) of 4-bromo-1-butene and 20 mL of dry THF was added quickly to the magnesium turnings. When a grey color appeared indicating the reaction had begun, the flask was immersed in a ice bath and the remainder of the bromobutene solution was added slowly over a period of two hours. The flask was removed from the ice bath and was allowed to stir at room temperature for one hour. The resultant Grignard was decated from the excess magnesium metal into a dropping funnel connected to a flask containing 50 mL of dry THF and 10 g (0.64 moles) of 1-bromo-2-chloro-2-propane. The flask containing the bromochloropropene was immersed in an ice bath and the Grignard was added slowly over a period of 15 minutes. After the addition was complete, the flask was removed from the ice bath and was refluxed

for two hours while stirring. The reaction was cooled to room temperature and the reaction mixture was poured into 100 mL of ice water containing 10 g of ammonium chloride. Diethyl ether (100 mL) was added to the mixture and the organic layer was separated. The aqueous layer was washed twice with two 50 mL portions of ether and the washings were combined with the mother liquer and washed with saturated aqueous sodium chloride and dried using anhydrous magnesium sulfate. After a filtration process, most of the ether was removed using a rotarory evaporator. The resulting light yellow liquid was subjected to simple distillation. A clear liquid, 7.2 g, was collected over a broad boiling range, b.p. 37-45°/10 mm. The liquid was analyzed by g.l.p.c. using column I at 80° column temperature. The major peak was isolated and provided an NMR spectrum consistent with that expected for 2-chloro-1,6-heptadiene (42); NMR(CCl_4) δ 5.56-5.98 (m, 1H), 4.90-5.24 (m, 4H), 2.34 (t, J= 7.0Hz, 2H), 1.96-2.26 (m, 2H), 1.5-1.9 (m, 2H).

2-Chloro-1,7-octadiene (41)

The procedure was essentially the same as that employed in the preparation of 2-chloro-1,6-heptadiene (42) using 20.0 g (0.134 moles) of 5-bromo-1-pentene and 12.0 g (0.077 moles) of 1-bromo-2-chloro-2-propane. A clear liquid, 4.5 g, was obtained (b.p. 40-55°/10 mm) which was analyzed by preparative scale g.l.p.c.

using column G at a column temperature of 120°. The major component exhibited a NMR spectrum consistent with that expected for 2-chloro-1,7-octadiene (41); NMR(CCl_4) δ 5.56-6.0 (m, 1H), 4.86-5.26 (m, 4H), 2.34 (t, J=6.0Hz, 2H), 1.9-2.24 (m, 2H), 1.22-1.80 (m, 4H).

1-Bromo-5-dodecyne (44)

To 100 mL of dry deoxygenated THF maintained under a positive nitrogen atmosphere was placed 6.2 g (0.56 moles) of 1-octyne and 10 mL of HMPT. The flask was immersed in a ice-acetone bath and 0.06 moles of butyllithium (26 mL, 2.3 M in hexane) was added slowly to the THF by the use of a syringe. After the addition, the reaction flask was stirred for 20 minutes. The contents of the flask were then decated into addition funnel connected to a flask containing 48.0 g (0.22 moles) of 1,4-dibromobutane, 50 mL of dry THF, and 10 mL of HMPT which was maintained under a positive nitrogen atmosphere. The flask containing the dibromobutane was immersed in an ice bath and the lithium acetylide was added slowly while the contents of the flask were vigorously stirred by a glass covered magnetic stirring bar over a period of 20 minutes. After the addition, the contents of the flask were poured into 100 mL of water and 100 mL of ether mixture. The organic layer was separated and was washed three times with water then with saturated aqueous sodium chloride

solution and dried using anhydrous magnesium sulfate. After a filtration process, most of the ether was removed using a rotarory evaporator. The resulting light yellow liquid was subjected to simple distillation. A clear liquid (11.0 g, 80% yield, b.p. 104-106°/ 1.5 mm) was collected which exhibited a NMR spectrum expected for 1-bromo-5-dodecyne (44); NMR(CCl_4) δ 3.39 (t, J=6.0Hz, 2H), 1.1-2.3 (m, 16H), 0.90 (t, J=6.0Hz, 3H). Anal. Calcd for $C_{12}H_{21}Br$: C, 58.78; H, 8.63. Found: C, 58.78, H, 8.45.

1-Bromo-6-tridecyne (45)

The procedure for the preparation of 1-bromo-5-dodecyne was employed using 0.06 moles of butyllithium, 6.2 g (0.058 moles) of 1-octyne, and 55.0 g (0.24 moles) of 1,5-dibromopentane. A clear liquid (8.8 g, 59% yield, b.p. 98-103°/0.2 mm) was collected which exhibited a NMR spectrum consistent with that expected for 1-bromo-6-tridecyne (45); NMR(CCl_4) δ 3.36 (t, J=6.0Hz, 2H), 1.1-2.3 (m, 18H), 0.89 (t, J=6.0Hz, 3H). Anal. Calcd for $C_{13}H_{23}Br$: C, 60.23; H, 8.93. Found: C, 60.50; H, 9.05.

5-Dodecyne (89)

The procedure for the preparation of 1-bromo-5-dodecyne was employed using 1.5 g (0.013 moles) of 1-octyne, 0.014 moles of butyllithium (6.2 mL, 2.3 M in hexane) and 1.87 g (0.013 moles) of

1-bromobutane. During vacuum distillation, a clear liquid was collected (1.0 g, 60% yield, b.p. 43-45°/0.3 mm) which exhibited a NMR spectrum consistent with that expected for 5-dodecyne (89); NMR(CCl_4) δ 1.9-2.4 (m, 4H), 0.80-1.80 (m, 22H).

6-Tridecyne (90)

The procedure for the preparation of 1-bromo-5-dodecyne was employed using 1.5 g (0.013 moles) of 1-octyne, 0.014 moles of butyllithium (6.2 mL, 2.3 M in hexane) and 2.00 g (0.013 moles) of 1-bromopentane. During distillation, a clear liquid was collected (1.70 g, 95% yield, b.p. 57-58°/0.3 mm) which exhibited a NMR spectrum consistent with that expected for 6-tridecane (90); NMR(CCl_4) δ 1.9-2.4 (m, 4H), 0.80-1.80 (m, 24H).

Heptylenecyclopentane (65)

The procedure for the preparation of 5-methylene-cis-hydrindane was employed using 11.0 g (0.015 moles) of heptyltriphenylphosphonium bromide, 3.0 g (0.035 moles) of cyclopentanone, and 0.4 g (0.017 moles) of sodium hydride. The resulting brownish liquid was subjected to vacuum distillation. A clear liquid (0.65 g, 22% yield, b.p. 90-95°/0.3 mm) was collected and further purified by preparative scale g.l.p.c. using column N at 140°. The NMR spectrum was consistent with that expected for heptylenecyclopentane

(65); NMR(CCl_4) δ 5.06-5.34 (m, 1H), 1.1-2.4 (m, 18H), 0.90 (t, J=6.0Hz, 3H). Anal. Calcd for $C_{12}H_{22}$: C, 86.67; H, 13.33. Found: C, 86.48; H, 13.46.

2-Hydroxymethylmethylenecyclopentane (80)

Into a round bottomed flask maintained under a positive argon atmosphere was placed 400 mL of dry deoxygenated THF and 6.0 g (0.15 moles) of potassium hydride. A solution consisting of 9.8 g (0.1 moles) of 1-hydroxymethylcyclopentene and 20 mL of THF was added slowly to the reaction flask. The temperature of the flask was kept below 25° by immersing the flask in an ice bath. After the addition was complete, the flask was removed from the ice bath and the contents were stirred for one hour. At the end of this time period, 35.5 g (0.11 moles) of iodomethyltributyltin was added to the reaction flask and the resulting mixture was stirred for 3 hours at room temperature. The flask was then cooled to -78° and 0.01 moles of butyllithium was added to the reaction flask by the use of a syringe. The addition of the butyllithium was regulated such that the temperature of the reaction did not rise above -70°. After the butyllithium addition, the reaction was stirred for thirty minutes at -78° and the excess potassium hydride was destroyed by the addition of 5 mL of water. The solution was warmed to room temperature and most of the THF was removed using a rotarory evaporator. The remaining

concentrated solution was added to 50 mL of pentane and the resulting solution was washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration procedure, the solution was again concentrated using a rotarory evaporator and the resulting liquid was subjected to simple vacuum distillation. A clear liquid was collected during distillation (6.2 g, b.p. 60-70°/7-10 mm). Analysis using g.l.p.c. (column D at 85°) indicated that two components were present in a ratio of 3 to 2. The larger component having a shorter retention time produced a NMR spectrum identical to the starting alcohol. The other component produced a NMR spectrum consistent with that expected for 80; NMR(CCl_4) δ 4.7-5.0 (m, 2H), 3.84 (s, 1H), 3.57 (d of d, J=6 and 11Hz, 1H), 3.38 (d of d, J=7 and 11Hz, 1H), 1.3-2.8 (m, 7H).

2-Chloromethylmethylenecyclopentane (73)

The procedure for the preparation of 5-chloro-4-methyl-1-pentene (31) was employed using 40 mL of carbon tetrachloride, 6.6 g of the mixture of 1-hydroxymethylcyclopentene and 2-hydroxymethylmethylenecyclopentane (80), and 15.0 g (0.058 moles) of triphenylphosphine. The products were vacuum transferred after most of the carbon tetrachloride was removed by simple distillation at atmospheric pressure. The resulting light yellow liquid (5.3 g) was analyzed by preparative scale g.l.p.c. using column D at 85°. The

chromatogram indicated two products were produced in a ratio of 3 to 2. The smaller component having a longer retention time was isolated and produced a NMR spectrum consistent with that expected for 2-chloromethylmethylenecyclopentane (73); NMR(CCl_4) δ 4.8-5.1 (m, 2H), 3.62 (d of d, J=4.5 and 9.5Hz, 1H), 3.33 (d of d, J=9.0 and 9.5Hz, 1H), 1.32-3.95 (m, 7H).

General Procedure for the Reaction of 1-Chloro-5-hexenes with Lithium Metal

All the reactions were conducted under an argon atmosphere in a flask possessing a sidearm stopcock for the purpose of easily washing the lithium metal. The lithium dispersion (containing 2% sodium) in mineral oil was added to the flask along with 30 mL of dry deoxygenated diethyl ether. The mixture was stirred for 15 minutes and the flask was tilted to permit the ether to drain away from the lithium through the sidearm. The flask was recharged with 20 mL of ether and the washing procedure was repeated. The flask was again recharged with 20 mL of ether and the washing procedure was repeated. The flask was again recharged with 20 mL of ether and was immersed in an ice bath. To this cooled mixture was added rapidly 500 mg of 1,3-dibromopropane which served to activate the metal surface. After being stirred for 10 minutes, the flask was removed from the ice bath and was allowed to stir for an additional 30 minutes at room

temperature. The flask was then immersed in an ice bath and after the contents of the flask were cooled to 0°, the chlorohexene was added quickly. The reaction was allowed to proceed for one hour at 0° and two hours at room temperature. Nonane was added as the internal standard and the etheral solution was quenched by ice water by adding the ethereal solution to the water through the sidearm. Most of the excess lithium remained in the flask. The organic layer was separated and washed with saturated aqueous sodium chloride solution and dried using anhydous magnesium sulfate. The percentage yield of the cyclized product was acertained by g.l.p.c. analysis. Most of the solvent was removed by distillation through a vigreux column at atmospheric pressure and the remaining material was vacuum transferred. The products were isolated by preparative scale g.l.p.c. and identified by comparison of chromatographic retention times and NMR spectra with those of authentic samples.

Reaction of 2-Chloromethylmethylenecyclopentane (73) with Lithium Metal

The general procedure for the reaction of chlorohexenes with lithium metal was employed using 0.3 g of lithium wire, 20 mL of diethyl ether, and 340 mg (0.0026 moles) of 73 at a temperature of -17°. The reaction was quenched by the addition of a small amount of water at -17° after a reaction time of one hour. Analysis of the

reaction mixture using column H at 80° indicated only one product was formed from the reaction. This product was isolated and produced a NMR spectrum identical to 2-methymethylenecyclopentane (74). The yield of this product was calculated to be 47%.

The reaction was repeated and allowed to warm to room temperature for 3 hours before quenching with water. Analysis using column H at 80° indicated that both 2-methylmethylenecyclopentane (73) and methylenecyclohexane (70) were produced in a corresponding ratio of 2 to 1.

Cyclization of 6-Lithio-3-methyl-1-hexene (26a)

The general procedure for the reaction of chlorohexenes with lithium metal was followed using 0.430 g (0.0033 moles) of 6-chloro-3-methyl-1-hexene (26), 0.75 g of lithium dispersion, and a final volume of 20 mL of diethyl ether. Nonane (380 mg, 0.0030 moles) was employed as an internal standard and the product composition was analyzed using column P at 160°. The ratio of trans to cis cyclic products was determined to be 25 to 1 in a total yield of 61%. The major product was identified as trans-1,2-dimethylcyclopentane and the minor product as cis-1,2-dimethylcyclopentane by comparison of their NMR spectra with those of authentic samples.

Cyclization of 6-Lithio-1-heptene (39a)

The general procedure for the reaction of chlorohexenes with lithium metal was followed using 0.530 g (0.004 moles) of 6-chloro-1-heptene (39), 0.75 g of lithium dispersion and a final volume of 20 mL of diethyl ether. Nonane (510 mg, 0.004 moles) was employed as the internal standard and the product composition was analyzed using column P at 160°. The ratio of trans to cis cyclic products was determined to be 25 to 1 in a total yield of 43%. The major product was identified as trans-1,2-dimethylcyclopentane and the minor product as cis-1,2-dimethylcyclopentane by comparison of their NMR spectra with those of authentic samples.

Cyclization of 6-Lithio-4-methyl-1-hexene (31a)

The general procedure for the reaction of chlorohexenes with lithium metal was followed using 340 mg (0.0026 moles) of 6-chloro-4-methyl-1-hexene (31), 0.75 g of lithium dispersion, and a final volume of 20 mL of diethyl ether. Nonane (330 mg, 0.0026 moles) was employed as the internal standard and the total cyclic yield was determined using column P at 160° to be 52%. Another column was required to separate the isomers for analysis. The use of column O at 70° indicated a trans to cis ratio to be 1 to 9. The major product was identified as cis-1,3-dimethylcyclopentane and the minor product

as trans-1,3-dimethylcyclopentane by comparison of their NMR spectra with those of authentic samples.

Cyclization of 6-Lithio-5-methyl-1-hexene (30a)

The general procedure for the reaction of chlorohexenes with lithium metal was followed using 150 mg (0.00114 moles) of 6-chloro-5-methyl-1-hexene (30), 0.50 g of lithium dispersion, and a final volume of 20 mL of diethyl ether. Nonane (145 mg, 0.00114 moles) was employed as the internal standard and the total cyclic yield was determined using column P at 160° to be 47%. Another column was required to separate the isomers for analysis. The use of column O at 70° indicated a trans to cis ratio to be 9 to 1. The major product was identified as trans-1,3-dimethylcyclopentane and the minor product as cis-1,3-dimethylcyclopentane by comparison of their NMR spectra with those of authentic samples.

Reaction of 5-Bromo-1,9-decadiene (37) with Lithium p,p'-Di-tertbutylbiphenyl

The reaction was performed in a three necked flask under a positive argon atmosphere using a glass covered magnetic stirring bar. To 125 mL of dry deoxygenated THF was added 14 g (0.06 moles) of p,p'-di-tertbutylbiphenyl. Lithium metal (0.25 g, 0.036 moles) was cut in a stream of argon and the resulting pieces were

allowed to fall into the THF solution. The reaction required about 5 minutes before the blue-green color of the radical anion persisted. Dried and deoxygenated ether (125 mL) was added to the flask which was lowered into an ice bath. The mixture was allowed to stir for 5 hours at 0° before all the lithium was consumed. The flask was then cooled in a dry ice - acetone bath. After sufficient time for temperature equilibration had elapsed, 1.0 g (0.0046 moles) of 5-bromo-1, 9-decadience (37) was added to 10 mL of ether and the resulting solution was added to the radical anion dropwise over a 2 minute period. No color change was observed. The resulting solution was stirred at -78° for an additional 10 minutes then 10 mL of methanol was added rapidly. With the addition of the methanol, the solution turned colorless. The flask contents were allowed to warm to room temperature and nonane (0.59 g, 4.6 mmoles) was added to the reaction as an internal standard. Approximately 200 mL of pentane was added and the resulting organic solution was washed seven times with 90 mL portions of 50% aqueous sulfuric acid, once with 100 mL of water, once with 100 mL of saturated aqueous sodium chloride solution and then dried using anhydrous magnesium sulfate and analyzed by g.l.p.c. using column J at a column temperature of 140° after a filtration process. The chromatogram indicated that one product was formed predominantly. The yield of this product and a small peak with a slightly longer retention time was calculated to be 65% and the ratio of the two

peaks was calculated to be 20 to 1. The solution was immersed into a dry ice - acetone bath which resulted in the precipitation of p,p'-di-tertbutylbiphenyl crystals. The crystals were separated by suction filtration and most of the solvent was removed by simple distillation at atmospheric pressure. More pentane was added and the crystallization procedure was repeated. The bulk of the solvent was again removed by simple distillation. The remaining small volume was vacuum transferred. Two products were isolated by preparative scale g.l.p.c. using column B at 95°. The major component was identified as trans-2-(3-butenyl)methylcyclopentane (49) by its NMR spectrum; NMR(CCl_4) δ 5.50-5.90 (m, 1H), 4.72-5.13 (m, 2H), 1.0-2.34 (m, 12H), 0.94 (d, J=5.0Hz, 3H). The minor component was assigned the structure of cis-2-(3-butenyl)methylcyclopentane (49a); NMR(CCl_4) δ 5.56-6.0 (m, 1H), 4.8-5.1 (m, 2H), 1.0-2.2 (m, 12H), 0.79 (d, J=7.0Hz, 3H).

The reaction was repeated using 1.0 g (0.0046 moles) of 5-bromo-1,9-decadiene and 0.59 g of nonane. However, the reaction was allowed to warm to room temperature and remained there for 12 hours before quenching with methanol. After the workup, the products were vacuum transferred and analyzed by g.l.p.c. using column P at 150°. The chromatogram revealed the presence of at least four unresolved products and a single compound of slightly longer retention time. The overall yield of the reaction was calculated to be 65%. The

yield of the resolved component was 19%. Preparative scale g.l.p.c. using column P at 150° resulted in the isolation of the unresolved components as a group which indicated the presence of both terminal and internal double bonds. The resolved component exhibited a NMR spectrum void of vinyl protons; NMR(CCl_4) δ 0.8-2.1 (m, 15H), 0.9 (d, J=6.0Hz, 3H).

Reduction of the Unresolved Components from the Reaction of 5-Bromo-1,9-decadienc (37) with p,p'-di-tertbutylbiphenyl

The unresolved components (0.280 g) were reduced with a palladium on activated carbon catalyst (5% Pd) in 25 mL of ethanol using a Paar Hydrogenation apparatus and 30-40 pounds of hydrogen pressure over a period of 4 hours. The catalyst was removed by filtration and most of the ethanol was removed by distillation at atmospheric pressure. About 20 mL of pentane was added to the remaining solution and the resulting solution was washed twice with 10 mL portions of water and most of the pentane was removed by simple distillation at atmospheric pressure. The remaining material was vacuum transferred and analyzed by g.l.p.c. using column P at a column temperature of 140°. The chromatogram indicated the pressence of two components in a calculated ratio of 6.4 to 1. The components were isolated by preparative scale g.l.p.c. using the same column and conditions. The smaller component having a shorter

retention time displayed a retention time and NMR spectrum identical to those of n-decane. The second material displayed the same NMR spectrum and retention time as that of the reduction product from trans-2-(3-butenyl)methylcyclopentane (49).

Reduction of trans-2-(3-Butenyl)methylcyclopentane (49)

Hydrogenation of 0.5 g (0.0036 moles) of trans-2-(3-butenyl)-methylcyclopentane and the isolation of the products were accomplished in the same manner as described for the reduction of the unresolved components from the reaction of bromodecadiene with the radical anion. One product was produced from the reaction by g.l.p.c. analysis; NMR(CCl_4) δ 0.96 (d, J=5.0Hz, 3H), 0.79-2.0 (m, 17H). The product was assigned the structure trans-2-butylmethylcyclopentane (51).

Conversion of trans-2-(3-Butenyl)methylcyclopentane (49) into trans-2-Ethylmethylcyclopentane (50)

To a solution consisting of a catalytic amount of osmium tetroxide in 50 mL of water - dioxane (50:50) was added 0.124 g (0.0009 moles) of trans-2-(3-butenyl)methylcyclopentane (49) and the whole was stirred for 15 minutes. Sodium periodate (0.260 g, 0.0012 moles) dissolved in 3 mL of water was added rapidly. The solution was light yellow after being stirred for 24 hours at room temperature.

The flask contents were poured into a separatory funnel containing 100 mL of pentane. The pentane solution was washed three times with 50 mL portions of water and three times with 50 mL portions of aqueous saturated potassium iodide solution. The organic phase was dried using anhydrous magnesium sulfate and after filtration, most of the pentane was removed by the use of a rotarory evaporator leaving a small amount of dark oil. This material was added to 1.0 g (0.0012 moles) of tris-(triphenylphosphine)rhodium (I) chloride in 3.0 mL of benzene and refuxed for three hours under a positive nitrogen atmosphere. The flask contents were vacuum transferred under a pressure of 0.2 mm. The flask was heated periodically with a heat gun during the transfer. Analysis of the products by g.l.p.c. using column I at 90° revealed the presence of a compound having the same retention time as that of an authentic sample of trans-2-ethyl-methylcyclopentane along with a trace of material having the same retention time as the cis isomer. The major component was isolated by preparative scale g.l.p.c. using the same column, it produced an NMR spectrum identical to that of trans-2-ethylmethylcyclopentane (50).

Cyclization of 8-Lithio-5-vinyl-1-octene (27a)

The general procedure for the reaction of chlorohexenes with lithium metal was employed using 0.75 g of lithium dispersion, 25 ml

of diethyl ether, 0.290 g (0.0017 moles) of 3-(3-chloropropyl)-1,6-heptadiene (27) and 0.220 g (0.0017 moles) of nonane as an internal standard. The product composition was determined by g.l.p.c. analysis using column P at 160°. The chromatogram indicated that two bicyclic components were present. The major bicyclic component produced an NMR spectrum and retention time identical to that of cis-5-methyl-cis-hydrindane (54). The other component (3% yield) was not isolatable but produced the same retention time as that of the mixture of cis- and trans-5-methyl-cis-hydrindane (58 and 59).

Butyl 5-Indanyl Ether (60)

To 50 mL of dimethyl formamide was placed 10 mL of water, 5 g of sodium hydroxide, 10.0 g (0.074 moles) of 5-indanol (55) and 11.0 g (0.08 moles) of 1-bromobutane. The mixture was stirred under reflux conditions for 5 hours. The reaction flask was immersed in an ice bath and after temperature equilibration, 50 mL of diethyl ether was added to the reaction flask along with 50 mL of water. The organic layer was separated and the aqueous layer was washed with two 50 mL portions of ether. The mother organic layer was combined with the organic washings and washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, most of the solvent was removed using a rotarory evaporator. The residual liquid was distilled using vacuum. A clear

liquid, 12.1 g 85.5% yield, was collected (b.p. 154-158°/14 mm) which exhibited a NMR spectrum expected for butyl 5-indanyl ether (60); NMR(CCl_4) δ 6.40-7.06 (m, 3H), 3.84 (t, J=6.0Hz, 2H), 2.63-3.0 (m, 4H), 1.16-2.24 (m, 6H), 0.94 (t, J=7.5Hz, 3H). Anal. Calcd. for $C_{13}H_{18}O$: C, 82.05; H, 9.53. Found: C, 82.18; H, 9.50.

4-Hydrinden-5-one (61)

To 250 mL of dry THF was placed 20.0 g (0.105 moles) of butyl 5-indanyl ether (60) and 125 mL of anhydrous ethanol. The flask was placed into a dry ice bath and approximately 200 mL of ammonia was condensed into the flask from an ammonia tank using a dry ice - acetone condensing column and a connecting tube. To this was added 7.0 g (1.0 moles) of lithium over a period of three hours piecewise as the solution was stirred by a mechanical stirrer. The solution never turned a deep blue color indicative of solvated electrons. The flask was removed from the dry ice - acetone bath and was allowed to warm to room temperature and to sit undisturbed overnight. The contents of the flask were poured into 1.0 L of ice and 100 mL of ether was added to the resulting solution. The organic layer was separated and the aqueous layer was washed twice with 100 mL of ether. The washings were combined with the mother organic liquor and the resulting solution was washed with aqueous saturated sodium

chloride solution and concentrated using a rotarory evaporator. Concentrated sulfuric acid (10 mL) was added to the resulting solution and heated to reflux for three hours. The solution was cooled to 0° and the organic components were extracted with 50 mL of ether. The ether extract was washed with 50 mL of water, saturated aqueous sodium bicarbonate solution, and saturated aqueous sodium chloride solution. The ethereal solution was then dried using anhydrous magnesium sulfate and most of the ether was removed using a rotarory evaporator. The resulting light brown liquid was subjected to simple vacuum distillation. A clear liquid, 12.0 g (84% yield), was collected (b.p. 72-78°/0.1 mm) which slightly discolored upon standing. The liquid was subjected to g.l.p.c. analysis using column N at 120° column temperature. Two components were present whose ratio was calculated to be 6 to 1. The major component was isolated by preparative scale g.l.p.c. and the NMR spectrum of the isolated material corresponded to that expected for 4-hydrinden-5-one (61); NMR(CCl_4) δ 5.74-5.9 (m, 1H), 0.70-2.95 (m, 11H).

trans-5-Hydrindanone (62)

Into 300 mL of dry diethyl ether was placed 10.0 g (0.075 moles) of 4-hydrinden-5-one (61) and 10 mL of dry ethanol. The ethereal solution was placed under a positive nitrogen atmosphere and the flask was immersed in a dry ice acetone bath and approximately

200 mL of ammonia was condensed into the solution using a dry ice acetone condenser, a connecting tube and an ammonia cylinder. The flask was equipped with a mechanical stirrer and 3.0 g of lithium (0.43 moles) was added to the reaction flask slowly over a period of two hours. When the lithium was completely consumed, the reaction color was blue-green. The reaction was quenched by the addition of 40 mL of dry ethanol. After the blue-green color dissipated, the flask was removed from the dry ice acetone bath and was allowed to sit undisturbed overnight. The contents of the flask were poured into 1.0 L of ice and 100 mL of diethyl ether was added to the resulting solution. The organic layer was separated and the aqueous layer was washed twice with 100 mL portions of ether. The washings were combined with the mother liquor and the resulting solution was washed with saturated aqueous sodium chloride solution and concentrated using a rotarory evaporator. The concentrate was subjected to the same oxidizing conditions used for the production of cis-5-hydrindanone (56). The resulting organic solution was subjected to vacuum distillation. A clear liquid (7.5 g, 75% yield, b.p. 56-67°/0.1-1.0 mm) was collected and was subjected to analysis using g.l.p.c. The use of column N at a column temperature of 120° indicated that two products were formed in a calculated ratio of 3.2 to 1. The components were isolated by preparative g.l.p.c. using column P at 140°. The smaller component which had a longer

retention time gave the same NMR spectrum and retention time as those of cis-5-hydrindanone (56). The larger component was assigned the structure of trans-5-hydrindanone (62); NMR(CCl_4) δ 0.82-2.68 (m, with max at 1.81). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.03; H, 10.05.

cis-5-Hydrindanone (56)

A chromic acid oxidizing reagent was prepared by dissolving 17.2 g (0.172 moles) of chromium trioxide in 35 mL of water. To the solution was added 16.4 mL of concentrated sulfuric acid. The oxidizing reagent was placed into a dropping funnel attached to a flask containing 350 mL of acetone and 17.5 g (0.125 moles) of cis-5-hydrindanol which was prepared by the hydrogenation of 5-indanol using a rhodium on activated carbon catalyst (74). The flask was immersed in an ice bath and the oxidizing reagent was added slowly to the stirred solution at such a rate that the temperature of the solution did not exceed 30°. The chromic acid solution was added until the reaction solution sustained the orange color of the oxidizing agent for 30 minutes. Isopropanol was added to the reaction mixture to discharge the excess chromic acid. The acetone solution was decanted from the green chromium salts and the salts were washed with three 25 mL portions of acetone. The mother liquor and the washings were combined and neutralized by the slow addition of

saturated aqueous sodium bicarbonate. After a filtration process, most of the acetone was removed using a rotarory evaporator. To the resulting light green solution was added 50 mL of diethyl ether. This solution was then washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, most of the ether was removed using a rotarory evaporator. The resulting clear liquid was subjected to simple distillation using vacuum. A clear liquid was collected (13.5 g; 78% yield; b.p. 94-100°/5-7 mm) which exhibited an NMR spectrum which was consistent with that expected for cis-5-hydrindanone (56); NMR(CCl_4) δ 1.00-2.57 (m with max. at 2.25). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.41; H, 10.30.

5-Methylene-cis-hydrindane (57)

Into a flask equipped with a stirring bar and maintained under a positive nitrogen atmosphere was placed 1.3 g (0.030 moles) of 57% sodium hydride in an oil dispersion. The oil dispersion was washed three times with 20 mL portions of dry diethyl ether. To the remaining sodium hydride was added 50 mL of freshly distilled dimethy-l sulfoxide. The flask was heated to 75° for 20 minutes. At the end of this time period, all evolution of hydrogen had ceased. The flask was allowed to cool to room temperature and 9.0 g (0.025 moles) of methyltriphenylphosphonium bromide dissolved in 50 mL of dry

dimethylsulfoxide was added quickly to the contents of the flask. A deep red solution resulted from the addition. After stirring for 20 minutes, 3.0 g (0.021 moles) of cis-5-hydrindanone (56) was added to the flask. After stirring for 20 minutes, the reaction was quenched by the addition of 10 mL of water. The contents of the flask were poured into a mixture of 100 mL of water and 50 mL of pentane. The organic layer was separated and the aqueous layer was washed twice with 50 mL portions of pentane. The pentane washings were combined with the mother liquor and the whole was washed twice with water, saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, most of the pentane was removed using a rotarory evaporator. The remaining liquid which contained some precipitated triphenylphosphonium oxide was subjected to a vacuum transferring procedure which resulted in the isolation of a clear liquid. Most of the low weight organic material was removed by using a rotarory evaporator. The resulting clear solution was shown to be 95% pure by g.l.p.c. analysis using column N at a column temperature of 150°. The weight of the sample, 2.51 g, corresponded to a yield of 87%. The liquid was further purified by preparative g.l.p.c. using the same column and conditions and the NMR spectrum of the isolated material was consistent with that expected for 5-methylene-cis-hydrindane (57); NMR(CCl_4) δ 4.46-4.78 (m, 2H), 1.1-2.5 (m, 14H). Anal. Calcd

for $C_{10}H_{16}$: C, 88.16; H, 11.83. Found: C, 88.29; H, 11.69.

5-Methylene-trans-hydrindane (63)

The procedure was essentially the same as that used in the preparation of 5-methylene-cis-hydrindane using 3.00 g (0.021 moles) of a mixture of cis- and trans-5-hydrindanone (56 and 62) and the same molar equivalents of sodium hydride and methyltriphenylphosphonium bromide. The resulting clear liquid was subjected to vacuum distillation after the vacuum transferring procedure. A clear liquid (2.4 g, 83% yield, b.p. 32-34°/0.1 mm) was collected. The liquid was subjected to g.l.p.c. analysis using column P at a column temperature of 140°. The chromatogram showed the presence of two components which were calculated to have a ratio of 3.2 to 1. The components were isolated by preparative scale g.l.p.c. using the same column and conditions. The smaller component having a longer retention time gave the same retention time and NMR spectrum as those of 5-methylene-trans-hydrindane. The other component was assigned the structure 5-methylene-trans-hydrindane (63) by its NMR spectrum; NMR(CCl_4) δ 4.48-4.80 (m, 2H), 0.80-2.64 (m, 14H), Anal. Calcd for $C_{10}H_{16}$: C, 88.16; H, 11.83. Found: C, 88.31; H, 11.81.

cis- and trans-5-Methyl-trans-hydrindane (64 and 54)

Hydrogenation of 0.308 g (0.0023 moles) of 5-methylene-trans-hydrindane (62) was accomplished using approximately 0.25 g of palladium on activated carbon as the catalyst and 25 mL of ethanol as the solvent. The hydrogenation was performed using a Paar hydrogenation apparatus with a hydrogen pressure of 40 pounds over a period of 14 hours. Nonane, 0.295 g, (0.0023 moles) was added to the reaction mixture as an internal standard. The catalyst was removed from the reaction mixture by filtration and resulting ethanolic solution was poured into a mixture of 50 mL of diethyl ether and 50 mL of water. The ethereal layer was separated and the aqueous layer was washed twice with 50 mL portions of ether. The ethereal washings were combined with the mother liquor and washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. Most of the ether was removed by simple distillation at atmospheric pressure. The concentrated solution was analyzed by g.l.p.c. using column P at 130°. The chromatogram indicated the presence of two components which were calculated to be in a ratio of 4 to 1 with a total overall yield of 52%. The major component which produced a shorter retention time gave an identical NMR spectrum and retention time as the compound isolated from the high temperature quench of 5-lithio-1,9-decadiene (37a). The minor

component was isolated by preparative scale g.l.p.c. as was the major component using the same column and conditions; NMR(CCl_4) δ 0.70-2.50 (m, 15H), 0.96 (d, J=7.2Hz, 3H). Anal. Calcd for $C_{10}H_{18}$: C, 86.87; H, 13.20. Found: C, 87.60; H, 13.03. The minor component was assigned the structure trans-5-methyl-trans-hydrindane (64) and the major component was assigned the structure cis-5-methyl-trans-hydrindane (54).

cis- and trans-5-Methyl-cis-hydrindane (58 and 59)

The procedure was essentially the same as that used for the hydrogenation of 5-methylene-trans-hydrindane (62) using 0.310 g (0.0023 moles) of 5-methylene-cis-hydrindane (56). Analysis of the product mixture revealed that two components were present but they were not resolvable. The yield of the reaction was calculated to be 67%. The unresolved product mixture was purified and isolated using preparative scale g.l.p.c. using column P at a column temperature of 140°. The NMR spectrum of the product mixture was far different from the isolated product from the high temperature quench of 5-lithio-1,9-decadiene (37a); NMR(CCl_4) δ 0.70-2.44 (m, 15H), 0.84 (d, J=6.0Hz, 3H). Anal. Calcd for $C_{10}H_{18}$: C, 86.87; H, 13.20. Found: C, 86.69; H, 13.07.

Cyclization of 2-Lithio-1,6-heptadiene (42a)

The general procedure for the reaction of chlorohexenes with lithium metal was employed using 0.75 g of lithium dispersion, 0.40 g (3.08 mmoles) of 2-chloro-1,6-heptadiene (42), 0.28 g (2.19 mmoles) of nonane as an internal standard, and 25 mL of ether. The reaction was quenched after reacting at room temperature for three hours. The product composition was analyzed using g.l.p.c., column P at 175°. Two components were present in the ratio of 3 to 1 in a total calculated yield of 43%. There also existed a peak on the chromatogram which had a retention time between the two major components but was not isolatable. It was less than 4% of the product mixture. The two main products were isolated by preparative scale g.l.p.c. using the same column and conditions. The smaller of the two major components having a shorter retention time was identified as 1,6-heptadiene (71) by comparison of its retention time and NMR spectrum to that of an authentic sample. The larger major component produced the same NMR spectrum and retention time as an authentic sample of methylenecyclohexane (70).

The reaction was repeated but quenched at 0° before it was allowed to warm to room temperature. 1,6-heptadiene was essentially the only product produced with only a trace of the other two products.

The reaction was again repeated but was only allowed to react

at room temperature for 15 minutes before quenching. The products were analyzed by g.l.p.c. using column H at 80° column temperature. The chromatogram indicated that three products were formed in a ratio 2 to 2.3 to 1 by the order of retention times. The products were isolated by g.l.p.c. using the same column and conditions. The product with the shortest retention time was identified as 1,6-heptadiene. The product with the longest retention time was identified as methylenecyclohexane and the product with the intermediate retention time was identified as 2-methylmethylenecyclopentane (74) by its NMR spectrum; NMR(CCl_4) δ 4.92-4.66 (m, 2H), 1.0-2.4 (m, 7H), 1.08 (d, J=7.0Hz, 3H).

Cyclization of 2-Lithio-1,7-octadiene (41a)

The general procedure for the reaction of chlorohexenes with lithium metal was employed using 0.75 g of lithium dispersion, 0.35 g (0.0026 moles) of 2-chloro-1,7-octadiene (42) and 0.385 g (0.0030 moles) of nonane as an internal standard. The product mixture was analyzed by g.l.p.c. using column D at 90°. The chromatogram indicated the presence of three major components in a yield of 47% with the ratio of components by retention times of 1 to 2 to 2. The smallest component which had the shortest retention time produced a NMR spectrum and retention time identical to those of 1,7-octadiene (69). The component with the intermediate retention time was

identified as octadiene isomers by its NMR spectrum. The component with the longest retention time was identified as 2-methylmethylenecyclohexane by its NMR spectrum; NMR(CCl_4) δ 4.5-5.4 (m, 2H), 0.90-2.44 (m, 9H), 1.04 (d, J=7.0Hz, 3H).

Cyclization of 1-Lithio-5-dodecyne (44a)

The general procedure for the reaction of chlorohexenes with lithium metal was employed using 0.45 g of lithium metal, 0.735 g (0.003 moles) of 1-bromo-5-dodecyne (44) and 25 mL of diethyl ether. After reaction at room temperature for 10 hours, the reaction was quenched. The product mixture was analyzed by g.l.p.c. using column N at 160° column temperature. The chromatogram indicated two components were present in a ratio of 15 to 1 (62% yield). The smaller component having a shorter retention time was identified as 5-undecyne by comparing its NMR spectrum and retention time to those of 5-undecyne (89) which was prepared by a different procedure. The larger component was identified as heptylenecyclopentane (65) also by comparing its NMR spectrum and retention time to those of heptylenecyclopentane which was prepared by an alternate procedure.

The reaction was repeated but quenched after one hour at 0°. The ratio of linear to cyclic product was calculated to be 1.7 to 1.

Attempted Cyclization of 1-Lithio-6-tridecyne (45a)

The general procedure for the reaction of chlorohexenes with lithium metal was employed using 0.50 g (0.0019 moles) of 1-bromo-6-tridecyne (45), 0.5 g of lithium metal slices, and 0.25 g (0.0019 moles) of nonane as an internal standard. The resulting light yellow liquid was subjected to analysis by g.l.p.c. using column N at 180°. The chromatogram indicated that two components were present in a ratio of 11 to 1 and in a total yield of 28%. The first component produced a NMR spectrum and retention time as that of tridecyne. The larger component produced a NMR spectrum inconsistent with expected cyclic products; NMR(CCl_4) δ 4.86-5.14 (m, 2H), 1.8-2.2 (m, 4H), 1.1-1.6 (m, 12H), 0.80-1.1 (m, 6H). The structure of the compound was assigned the structure 5,6-dodecadiene (66).

Reaction of 1,6-Heptadiene (71) with Zirconocene

To 15 mL of dry deoxygenated THF was placed 2.5 g (0.019 moles) of napthalene and 0.30 g (0.013 moles) of sodium. The reaction was placed under a positive argon atmosphere and stirred by a glass covered magnetic stirring bar for two hours at 0°. At the end of this period, the solution was a deep blue-green color indicative of radical anion production. To the solution was added 0.26 g (0.0027 moles) of 1,6-heptadiene (71) and 0.35 g (0.0027 moles) of nonane as

an internal standard. To the resulting solution was added 1.1 g (0.004 moles) of bis(cyclopentadienyl)zirconium dichloride. The solution was stirred for one hour at 0° and then three hours at room temperature. The solution turned blackish in color after the addition of the zirconium dichloride. The solution was cooled to 0° and 3 mL of water was added slowly. The contents of the reaction vessel were allowed to stir for one hour at 0° open to the atmosphere and at the end of this time period, the reaction mixture was brownish in color. The contents of the flask was carefully vacuum transferred with occasional heating until napthalene started to sublime. The resulting liquid was analyzed by g.l.p.c. using column J at 110° and column H at 80°. The overall yield of the reaction was calculated to be 74% which consisted of reduced, cyclized, and isomerized octadienes. The liquid was added to 20 mL of pentane and washed with three 5 mL portions of concentrated sulfuric acid maintained at 0°. The pentane solution was then washed twice with fuming sulfuric acid maintained at 0°, washed with 10 mL of water and dried using anhydrous magnesium sulfate after neutralizing with dilute aqueous sodium bicarbonate. After a filtration process, the pentane solution was analyzed by g.l.p.c. using column H at 80°. The chromatogram showed the presence of three products. The product with the shortest retention time was identified as n-heptane by comparison of its NMR spectrum and retention time to that of an authentic sample. The

component with the longest retention time was identified as cis-1,2-dimethylcyclopentane by its NMR spectrum and comparison of its retention time to that of an authentic sample. Likewise, the other component was identified as trans-1,2-dimethylcyclopentane. The ratio of cis- to trans-dimethylcyclopentane was calculated to be 2 to 3. The yield of the cyclopentanes was 55% and heptane was 6%.

The reaction was repeated using biphenyl instead of napthalene (2.94 g, 0.019 moles). No noticeable difference in yield or isomer production was observed.

Reaction of 1,7-Octadiene (69) with Zirconocene

The procedure for the reaction of 1,7-heptadiene was employed using 0.30 g (0.0027 moles) of 1,7-octadiene (69) as the only deviation. Analysis using column J at 110° indicated a total yield of 76% of cyclized, reduced and isomerized octadienes. After the sulfuric acid wash, g.l.p.c. analysis indicated three components were present using column H at 80°. These components were isolated and identified as n-octane, cis-1,2-dimethylcyclohexane and trans-1,2-dimethylcyclohexane by comparison of their NMR spectra and retention times to those of authentic samples. The yield of octane was 14% and cis- and trans-1,2-dimethylcyclohexane was 41% in a ratio of cis to trans of 3 to 2.

The reaction was repeated using a tenfold excess of diene over

the zirconium dichloride. The yield of the cyclic products was calculated to be 40%.

The reaction was again repeated but quenched with deuterium oxide. The NMR spectrum of the isolated cis-1,2-dimethylcyclohexane showed complex splitting patterns in the methyl proton region. Low voltage mass spectral analysis indicated 50% d_2, 30% d_1, and 20% d_0 incorporation.

Reduction of 1-Octene (86) with Titanocene

The procedure for the reaction of 1,6-heptadiene (71) with zirconocene was employed for production of the radical anion formed from sodium and napthalene. The same molar quantities were also used. After the radical anion had formed, the solution was cooled to -40° and 0.34 g (0.0027 moles) of 1-octene (86) was added to the reaction flask followed by the addition of 1.1 g (0.004 moles) of bis(cyclopentadienyl)titanium dichloride. The temperature of the reaction flask was maintained at -40° for 6 hours and quenched at that temperature by the slow addition of 2 mL of water. After the sulfuric acid wash, g.l.p.c. analysis using column H at 80° indicated that n-octane was produced in a 77% yield.

The reaction was repeated but quenched with deuterium oxide. Low voltage mass spectral analysis indicated that only 5% of the octane produced was monodeuterated with only a trace of

dideuterated material.

Reduction of 1-Octene (86) with Zirconocene

The procedure for the reaction of 1,6-heptadiene (71) with zirconocene was employed for the preparation of the radical anion formed from sodium and napthalene. The same molar quantities were also used. The radical anion solution was cooled to 0° and 0.34 g (0.0027 moles) of 1-octene (86) was added to the reaction flask followed by the addition of 1.0 g (0.004 moles) of bis(cyclopentadienyl)zirconium dichloride. The reaction was stirred at 0° for one hour then the flask was allowed to warm to room temperature and sit undisturbed at that temperature for 24 hours. The reaction was immersed in an ice bath and after temperature equilibration was achieved, the reaction was quenched by the slow addition of 2 mL of water. After the sulfuric acid wash, g.l.p.c. analysis using column H at 80° indicated that n-octane was produced in a yield of 77%.

The reaction was repeated but quenched with deuterium oxide. Low voltage mass spectral analysis indicated that only 34% of the octane produced was monodeuterated. Only a trace of dideuterated material was observed.

PART 2. REARRANGEMENTS OF SELECTED ANIONIC COMPOUNDS IN HIGHLY DISASSOCIATIVE SOLVENTS

I. INTRODUCTION

Recently, much interest has developed in the area of the rearrangements of alkoxy-1,5-hexadienes. Most of the rearrangements studied thus far have been [1,3] and [3,3] sigmatropic shifts. In an attempt to investigate the scope of these apparent accelerated thermal rearrangements by a proximal negative charge, two types of model systems were studied. The thermally allowed concerted ring opening of halocyclopropanes and the suprafacial [1,5] hydrogen shift in a cyclohexadienol were shown to belong to this class of rearragements.

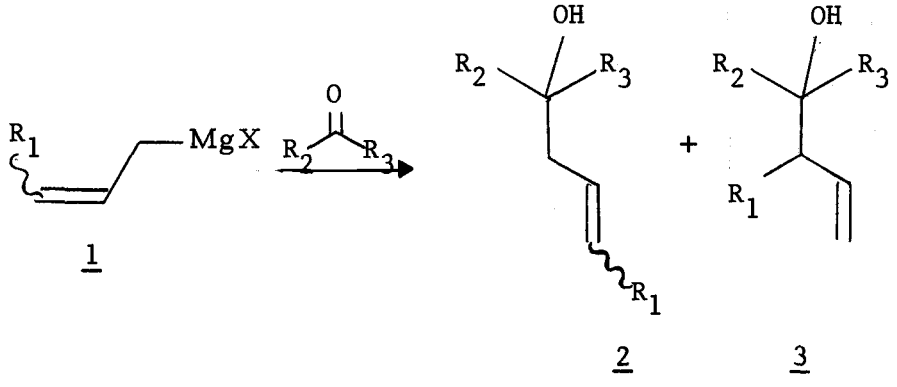
When 1-benzyl-2-chlorocyclopropane is treated with potassium t-butoxide in HMPT, E-1-phenylbutadiene is produced rapidly and quantitatively. The stereochemistry of the ring opening has been shown to be consistent with the thermally allowed ring opening process.

The potassium salt of 6,6-dimethylcyclohexa-2,4-dien-1-ol was shown to undergo a suprafacial [1,5] hydrogen shift faster than that of the parent alcohol. The stereochemistries and possible mechanisms of these rearrangements are discussed in the following pages.

II. HISTORICAL

One of the most studied anionic rearrangements is the transformation of allyl Grignard adducts. The reaction of the allyl Grignard 1 with a carbonyl can produce carbinols 2 and 3 (Scheme 1).

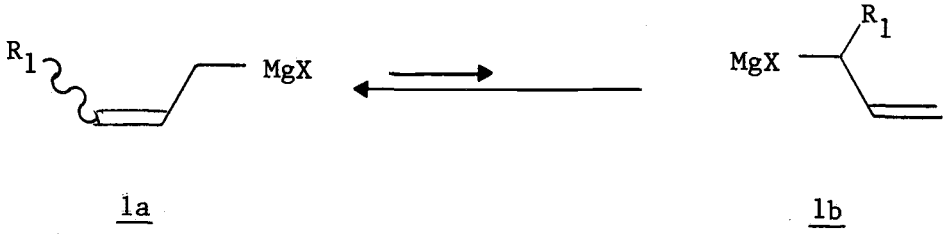
Scheme 1



1 2 3

The crotyl type of Grignard reagents have been shown to exist as a rapidly equilibrating mixture of primary 1a and secondary 1b forms in solution by NMR studies. The equilibrium generally lies heavily toward the side of the primary form 1a (Scheme 2).

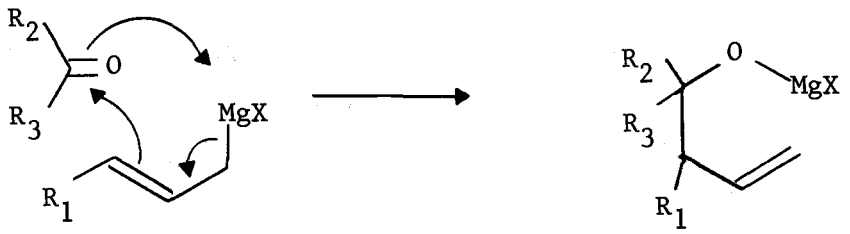
Scheme 2



1a 1b

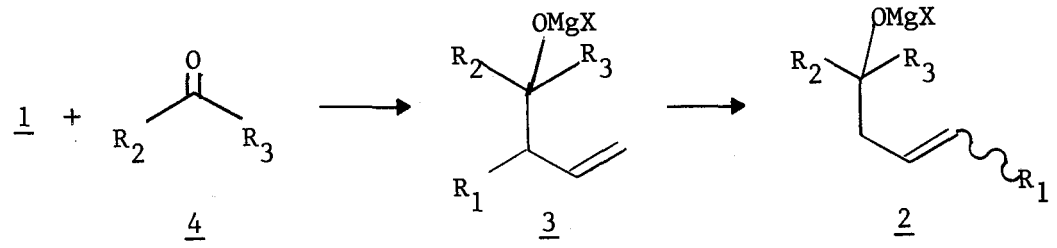
When an unhindered ketone is added to a solution of a crotyl type of Grignard reagent, the α-alkyl allyl adduct is generally found to be essentially the only product (50). The traditional explanation for this product formation involves a 6-membered transition state where the magnesium is coordinated to the carbonyl oxygen (Scheme 3).

Scheme 3



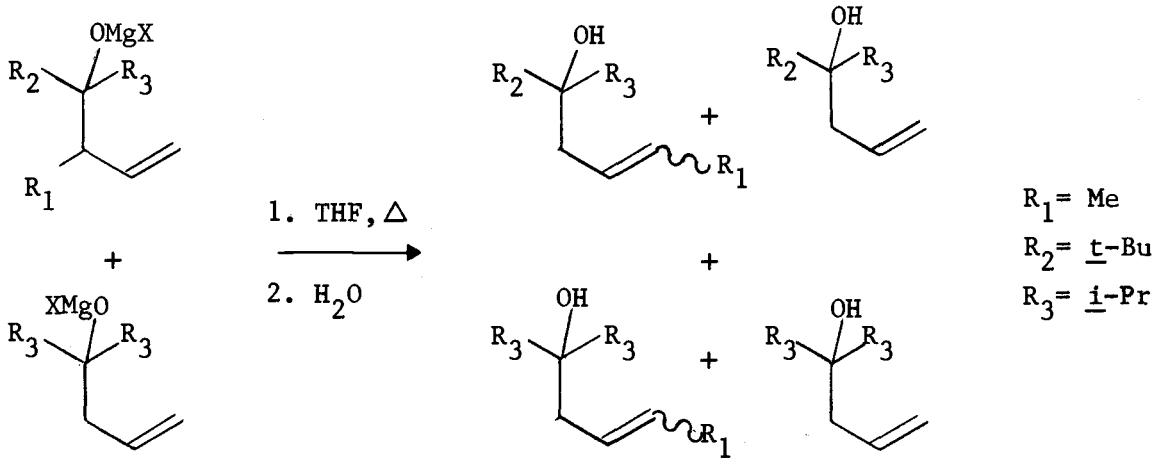
When the ketone 4 contains a great deal of steric bulk, carbinol 2 is generally found to be the major product. Benkeser and Broterman (51) showed that the most sterically hindered ketones generally give adduct 3 but subsequently rearrange to 2 (Scheme 4).

Scheme 4



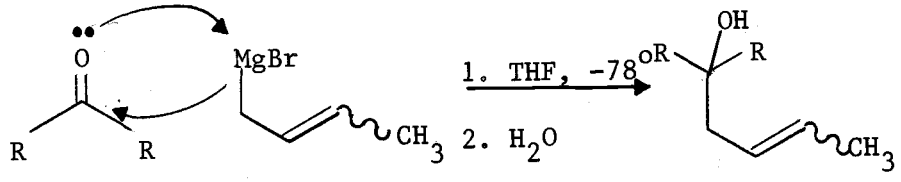
This rearrangement might be formally viewed as a [1, 3] sigmatropic shift. Benkeser has found evidence which indicates that the nature of the shift is not concerted (52). Crossover experiments were conducted and the products indicate that the magnesium salts fragment during the course of rearrangement (Scheme 5).

Scheme 5



Benkeser has also shown that the crotyl type products can be formed directly from the Grignard and the ketone via a four centered transition state (53) (Scheme 6). This information coupled with the fragmentation information strongly indicates that the [1, 3] shift for homoallyl alkoxy magnesium salts is not concerted. Lithium and zinc homoallyl alkoxides also rearrange and the rearrangement of the lithium alkoxides are about ten times as fast as the corresponding magnesium alkoxides.

Scheme 6



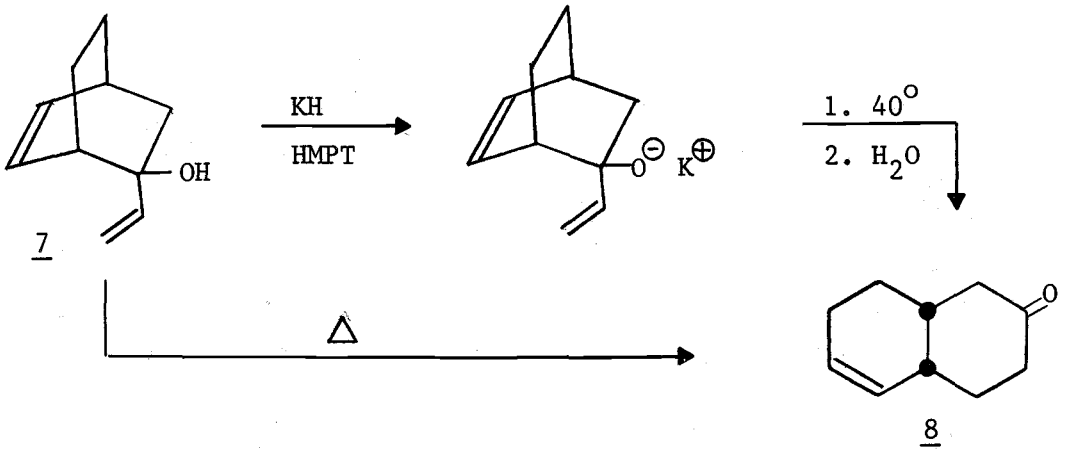
R = t-Bu

Very large rate enhancements have been observed for formally thermal rearrangements of compounds having a proximal negative charge over their neutral counterparts. Evans (54) among others has found that the alkoxy Cope rearrangement takes place much faster than its neutral counterpart. When dienol 7 is treated with potassium hydride in HMPT, it undergoes a [3,3] sigmatropic shift rendering 8 after neutralization. This is the same product obtained from the thermal rearrangement of 7 (Scheme 7). The magnitude of the rate acceleration due to alkoxide formation was assessed as 10^{12}. When the macropolyether 18-crown-6 was added to the alkoxide reaction, a rate enhancement of 10^{17} was noticed over the thermal counterpart.

Alkoxide 9 was found not to isomerize in THF after refluxing for 24 hours, whereas, its epimer 10 isomerizes quickly under these conditions giving 11 after hydrolysis (Scheme 8).

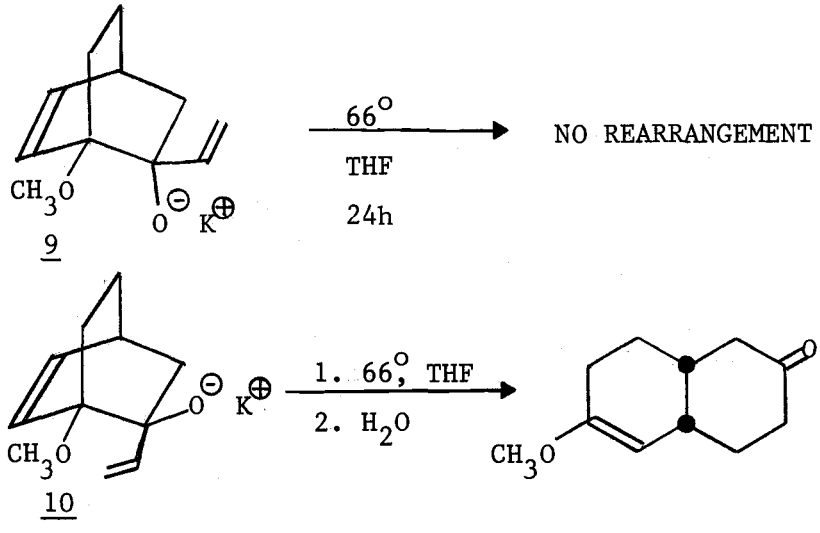
Alkoxide 9 is geometrically not set up for a concerted transformation, whereas, 10 is. Although diradicals or carbanions may intervene in the rearrangement, the failure of 9 to rearrange suggests that the transformation of 10 is concerted. Evans believes that ion-pair disassociation is the important factor in the rate enhancement and not the solvent dielectric constant because of the larger rate

Scheme 7



7 8

Scheme 8

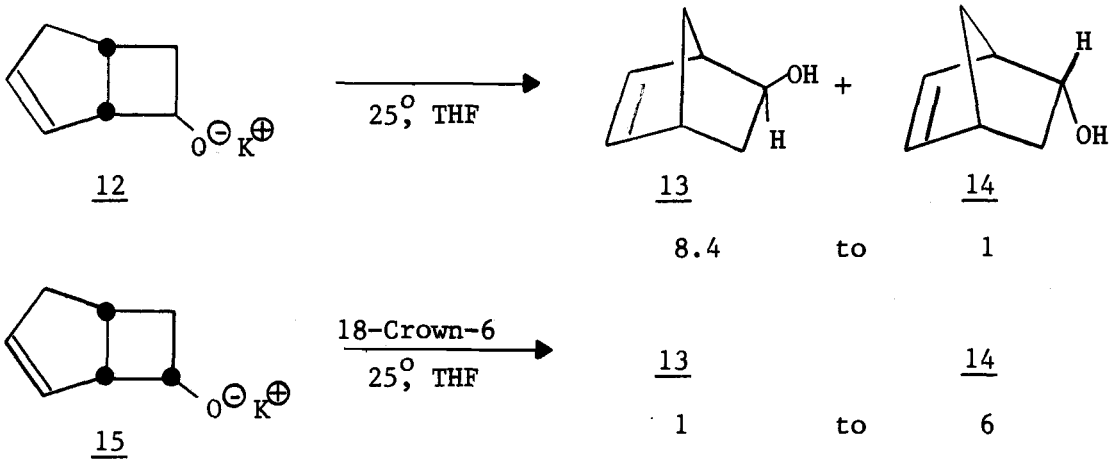


9 10

enhancements found when HMPT or crown ether was employed. The disassociation of the ion-pair produces a "naked" alkoxide anion which probably activates the carbon - carbon sigma bond which is broken when the rearrangement takes place.

S. R. Wilson has studied the stereochemistry of the rearrangement of a homoallyl alkoxide which gives products due to a [1,3] sigmatropic shift (55). The alkoxide 12 containing an exo-alkoxy substituent to the ring system isomerizes to give 13 and 14 in a ratio of 8.4 to 1 (Scheme 9). The epimer of 12 which contains an endo-alkoxy substituent did not undergo rearrangement under the same conditions as 12. However, rearrangement of 15 took place when 18-crown-6 was employed using the same experimental parameters. Alkoxide 15 rearranged to give two products, 13 and 14, when neutralized.

Scheme 9



12 13 14

8.4 to 1

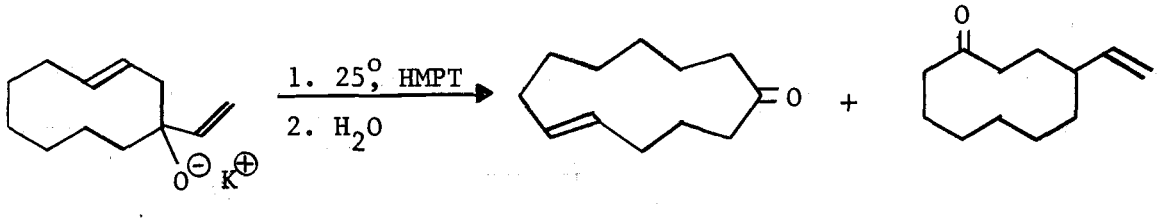
15 13 14

1 to 6

Both products from the rearrangements were stable under the reaction conditions. The main product from the rearrangement of 12 is consistent with a concerted reaction mechanism with inversion of configuration of the migrating group just as is the main product from the rearrangement of 15. The failure of 15 to isomerize under the same conditions as 12 is also consistent with a concerted rearrangement (56) but the production of two products from each alkoxide indicates the transformations are not completely concerted. However, two pathways may be operable, one being concerted and the other ionic or radical in nature.

Thies and coworkers (57) have also found that 3-alkoxy-1,5-dienes also undergo [1,3] sigmatropic shifts to produce ketones after hydrolysis. Dienol 16 rearranges to give ketone 17 a product of a [1,3] sigmatropic shift and ketone 18 a product from a [3,3] sigmatropic shift when treated with potassium hydride in HMPT at 60° (Scheme 10).

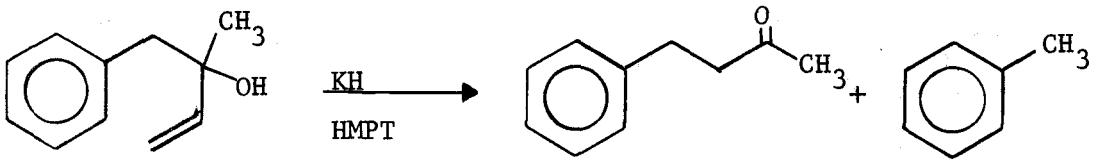
Scheme 10



16 17 18

Thies and coworkers (58) found fragmentation products from certain dienols which indicates that the rearrangement may not be totally concerted (Scheme 11).

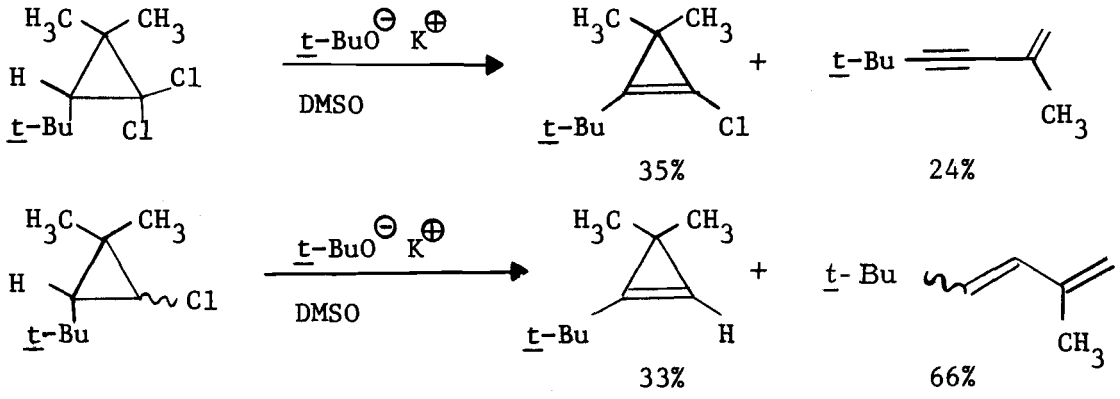
Scheme 11



III. RESULTS AND DISCUSSION

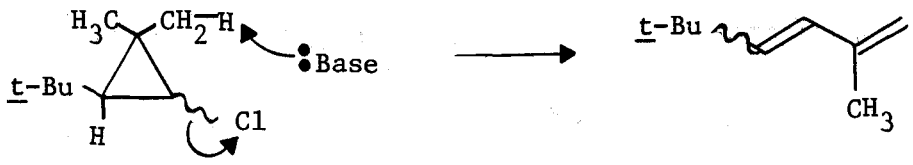
The elimination of hydrogen halide from halogenated cyclopropanes using a strong base usually proceeds to form cyclopropenes or products derived from cyclopropenes. However, a few examples of ring opened products have also been reported (59) (Scheme 12).

Scheme 12



The cyclopropyl protons are generally more acidic than the cyclopropylcarbinyl protons and ring opened products are produced only when the cyclopropyl protons are sterically hindered to approach by base. An explanation for the production of the ring opened products is abstraction of the cyclopropylcarbinyl proton followed by or concurrent with ring opening and loss of halide (Scheme 13).

Scheme 13

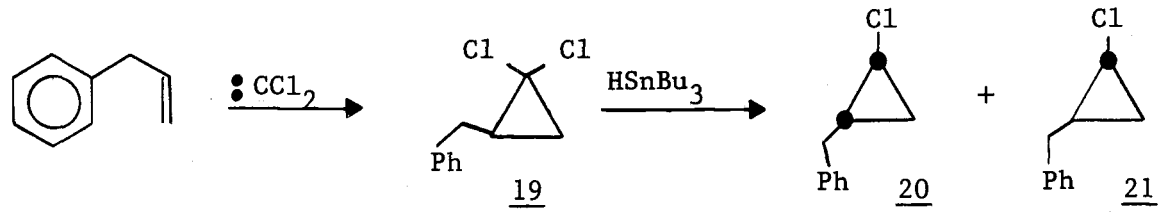


It was felt that if the cyclopropylcarbinyl protons were made more acidic by the addition of a group which would stabilize the resultant anion produced by the mentioned proton abstraction, ring opened products may be produced as the only products from the elimination reaction.

To test this hypothesis, cis- and trans-2-benzylchlorocyclopropane, 20 and 21, were prepared from a dichlorocarbene reaction (60) and selective reduction using tri-n-butyl tin hydride (61) (Scheme 14). The stereochemistries of the monochlorides 20 and 21 were determined by the method of production and NMR spectral analysis. The selective reduction using tri-n-butyl tin hydride is known to give products due to attack at least sterically hindered position preferentially. Trans coupling constants for adjacent hydrogens on a cyclopropane ring are generally larger than the corresponding cis coupling constants (62). The proton vicinyl to the chloride in 20 displayed a doublet of doublets of doublets with coupling constants of 4.0, 4.0, and 8.0 Hz. The vicinyl proton to the chloride in 21

produced a doublet of doublets of doublets splitting pattern with splitting constants of 4.0, 8.0, and 8.0 Hz.

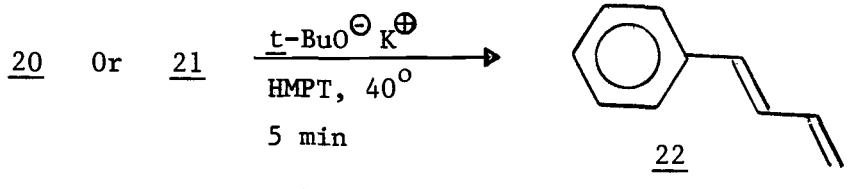
Scheme 14



1.2 to 1

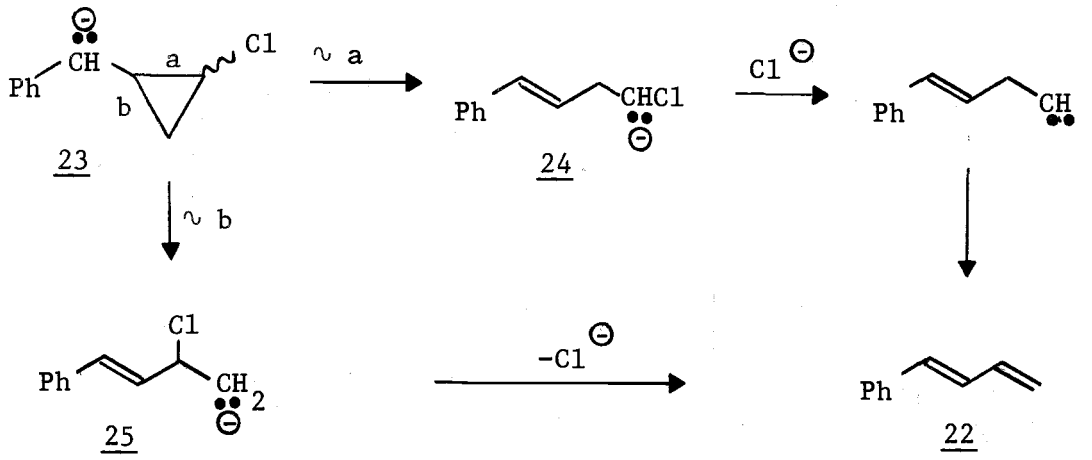
When either 20 or 21 was treated with potassium t-butoxide in HMPT, E-1-phenyl-1,3-butadiene (trans-1-phenyl-1,3-butadiene) (22) was produced as the only product (Scheme 15). The elimination of hydrogen chloride from 20 or 21 proceeded smoothly at temperatures from 25° to 40° and quantitatively gave E-1-phenyl-1,3-butadiene as the only product from elimination. The yield decreased upon long exposures of the product to the reaction conditions. This was apparently due to polymerization. A time period of five minutes was all that was required for maximum yield.

Scheme 15



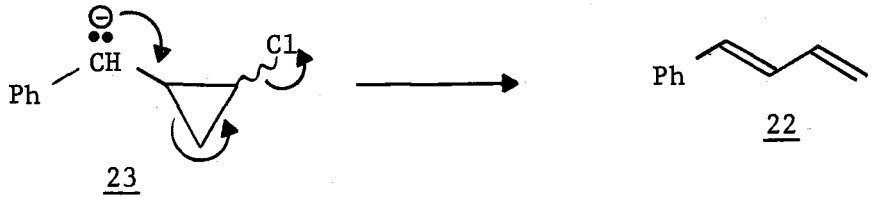
If it is assumed that the elimination proceeds through an initial formation of the benzyl anion 23, a mechanistic dichotomy emerges (Scheme 16).

Scheme 16



Considerable precedent exists for the rearrangement of cyclopropylcarbinyl anions to a homoallyl anion (19). Of the two possible homoallyl anions generated from 23, anion 24 (rupture of bond a) would have a thermodynamic advantage over anion 25 (rupture of bond b) due to the stabilizing influence of an electron withdrawing chlorine atom. On the other hand, cleavage of bond b would be expected from the normal concerted ring opening of cyclopropyl chlorides (63). In such a reaction profile, intermediate 25 would not intervene between 23 and 22 since the chloride would be departing concommitant with the carbon - carbon bond breakage (Scheme 17).

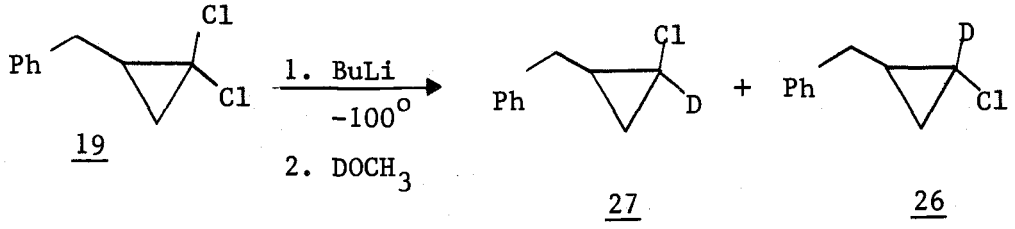
Scheme 17



23 22

Distinction between the two possible bond ruptures was found by appropriate deuterium labeling. Treatment of 1-benzyl-2,2-dichlorocyclopropane (19) with butyllithium at low temperature followed by an addition of a deuterium source provided cyclopropanes 26 and 27. The NMR spectrums of the cyclopropanes showed no absorption due to vicinyl hydrogens to the chloride (Scheme 18). Also, NMR analysis indicated that deuterium incorporation was greater than 95%.

Scheme 18

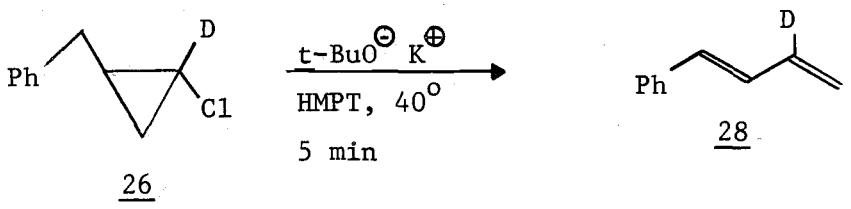


19 27 26

Exposure of 26 to the elimination reaction conditions led to the exclusive formation of E-1-phenyl-3-d_1-1,3-butadiene (28) (Scheme 19). The structure of 28 was determined by its NMR spectrum. The ratio of phenyl proton absorption to terminal vinyl proton absorption was 5 to 2. The absorption pattern for the terminal vinyl protons

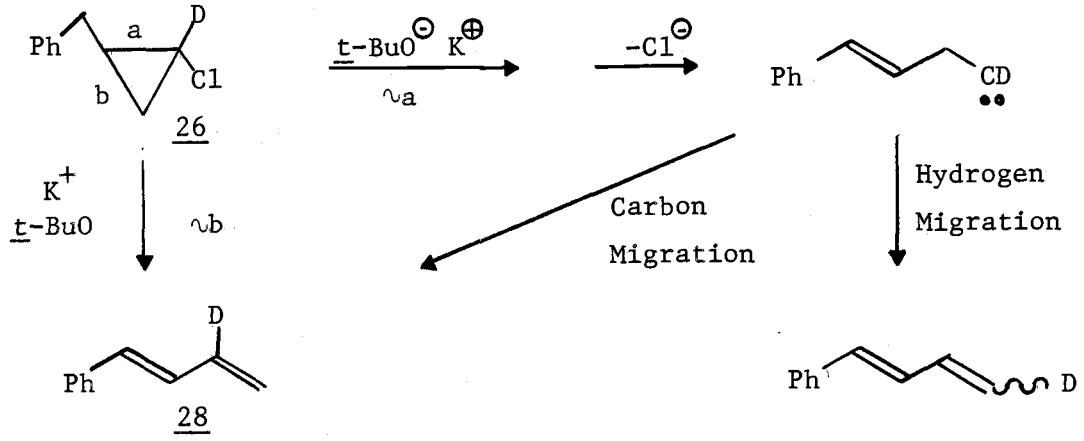
coupled with the ratio of phenyl proton absorption to terminal vinyl proton absorption was used to pinpoint the deuterium position. Since hydrogen migration is generally faster than carbon migration to a carbene center (72), the exclusive formation of 28 indicates that bond rupture of b is taking place in the elimination reaction (Scheme 20).

Scheme 19



26 28

Scheme 20

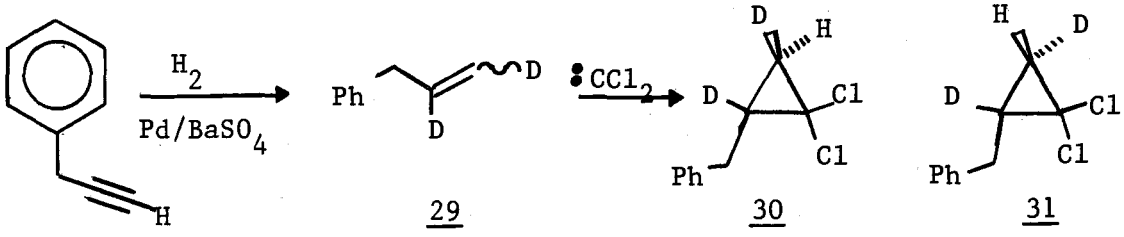


26 28

An attempt was made to determine the stereochemistry of the ring opening since the disrotatory mode of ring opening is well established for the concerted ring opening of halocyclopropanes (63).

Propargylbenzene was reduced to the dideuterated allyl benzene 29 using deuterium gas and a poisoned palladium catalyst (Scheme 21). Low voltage mass spectral analysis revealed that 29 was at least 95% dideuterated. However, NMR spectral analysis failed to show the stereochemistry of the olefinic unit. Dichlorocarbene reacted with 29 to produce two inseparable dichlorides, 30 and 31 in a calculated ratio of 1 to 7.5. The stereochemistries of the dichlorides 30 and 31 were determined from the NMR spectrum of the mixture and the NMR spectrums of their derivatives formed from selective reduction of the dichlorides with tri-n-butyl tin hydride. The NMR spectrum of the mixture revealed a proton absorption at a chemical shift of 1.28 δ and a hydrogen absorption at a chemical shift of 1.72 δ in a corresponding ratio of 7.5 to 1.

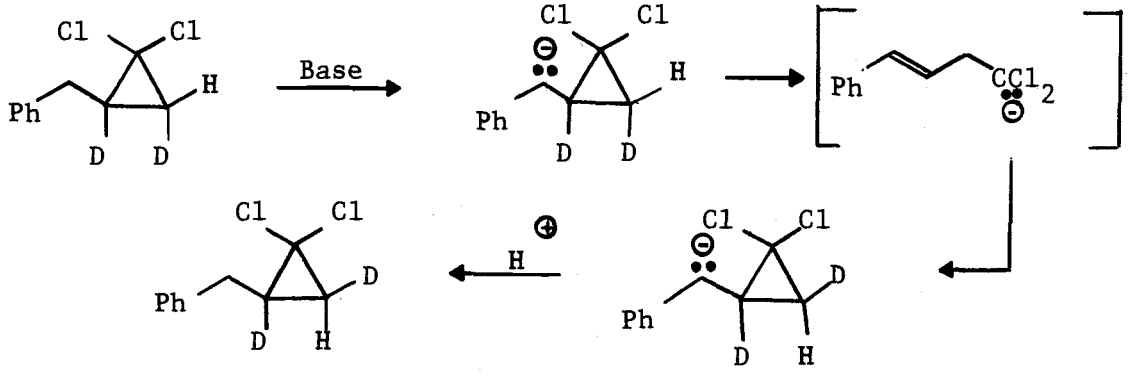
Scheme 21



It was hoped that only one cyclopropane 30 would be produced from the reaction sequence. The dichlorocarbene reaction is known to be stereospecific (64). The production of 30 and 31 implies that the reduction of propargylbenzene was not completely stereospecific (71)

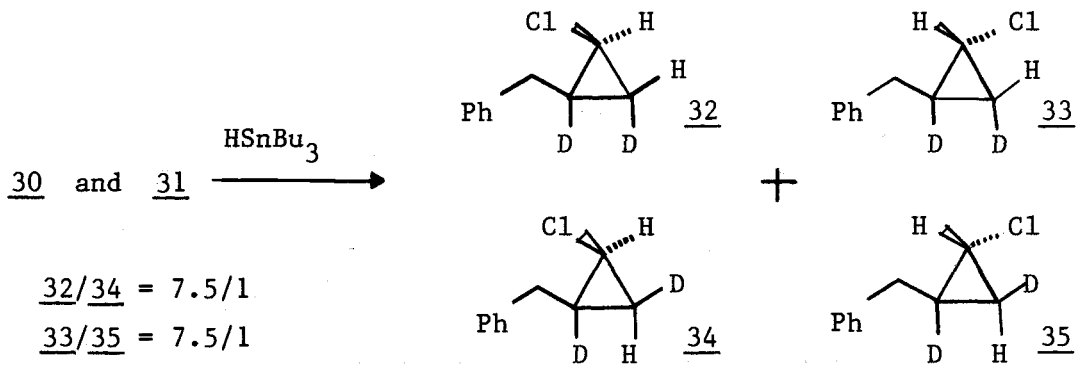
or that the basic media used in the carbene reaction was responsible for epimer production (Scheme 22).

Scheme 22



Treatment of the mixture of dichlorides 30 and 31 with tri-n-butyl tin hydride produced the four monochlorides 32, 33, 34, and 35 (Scheme 23). The two chlorides 32 and 34 were inseparable as were 33 and 35. NMR spectral analysis indicated that the epimer ratios of the two mixtures were the same, 7.5 to 1. This is the same ratio found for the mixture of dichlorides 27 and 28. This was expected since the benzyl substituent would have a far greater influence on epimer production due to its greater steric bulk when compared to either hydrogen or deuterium.

Scheme 23

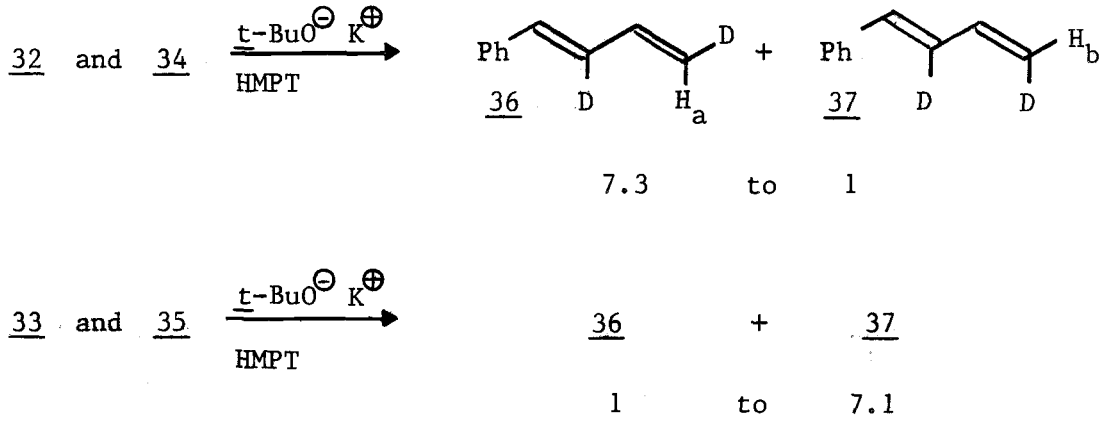


The NMR spectra of the mixtures of the monochlorides were also used to determine the stereochemistries of the dichlorides 30 and 31. The NMR spectrum of the mixtures of epimers 32 and 34 displayed a cyclopropyl proton absorption, a doublet, at a chemical shift of 0.76 δ (J=8.0 Hz) and a broad absorption peak at a chemical shift of 0.94 δ . The corresponding ratios of the areas of absorption was approximately 7.5 to 1. The NMR spectrum of the mixture of 33 and 35 revealed a cyclopropyl proton absorption, a doublet, at a chemical shift of 0.50 δ (J=4.0 Hz) and another doublet at a chemical shift of 0.98δ (J=8.0 Hz). The corresponding ratio of areas of absorption was found to be approximately 7.5 to 1. The splitting constants from the cyclopropyl protons were used to establish the stereochemistries of the two dichlorides.

Each mixture of epimers were separated using preparative gas chromatography. When either mixture (32 and 34) or (33 and 35) was subjected to the elimination reaction conditions, both E,E-1 and E,Z-1-phenyl-2,4-d_2-1,3-butadiene (36 and 37) were produced

(Scheme 24).

Scheme 24



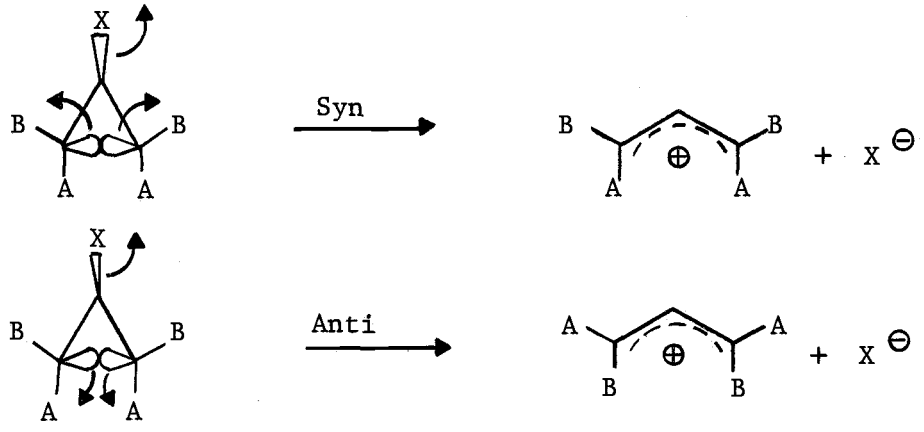
Upon prolonged exposure of the butadiene mixtures to air, an equilibrium of E,E and E,Z isomers was achieved. The terminal vinyl proton in the E,E isomer has a different chemical shift than corresponding proton in the E,Z isomer. The downfield peak for the doublet of H_a was found to have the same area as the upfield peak for the doublet of H_b for the equilibrium mixture. The upfield peak for H_b and the downfield peak for H_a did not overlap with any other absorption peaks. The relative areas for these peaks were used to calculate the ratio of isomer production. The information for H_a and H_b is shown in Table 3.

Table 3

	Chemical Shift (δ)	Coupling Constant (Hz)
H_a	5.28	17
H_b	5.11	10

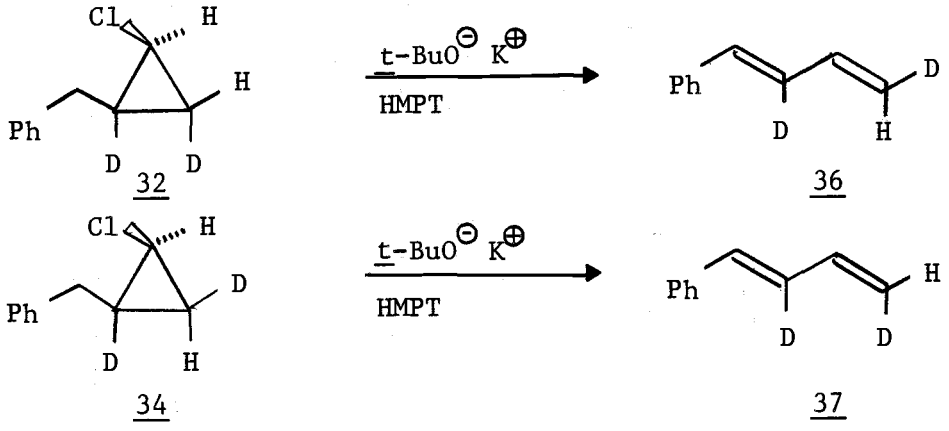
Theoretically, there exists two disrotatory modes for concerted ring opening of cyclopropylhalides, one being a disrotatory opening opposite (anti) to the direction of the leaving halide and the other in the same direction (syn) (Scheme 25) (63). Experimentally, the disrotatory process in the opposite direction of the leaving halide has been shown to be the preferred route (65). This preferred mode of ring opening is attributed to the stabilization of the developing empty p orbital due to the leaving halide by the electron rich orbitals of the breaking carbon - carbon sigma bond (65).

Scheme 25



The stereochemistries of the resulting products from the two mixtures (32 and 34) and (33 and 35) indicate that the elimination reaction follows the preferred mode of ring opening. When the mixture of 32 and 34 is subjected to the elimination conditions, both E,E- and E,Z-1-phenyl-2,4-d_2-1,3-butadiene is produced in a ratio of 7.3 to 1. Since the mixture contains a ratio of 32 of 34 of 7.5 to 1, the elimination of hydrogen chloride from these compounds is at least 97% stereospecific with 32 producing 37 and 34 producing 36 (Scheme 26).

Scheme 26

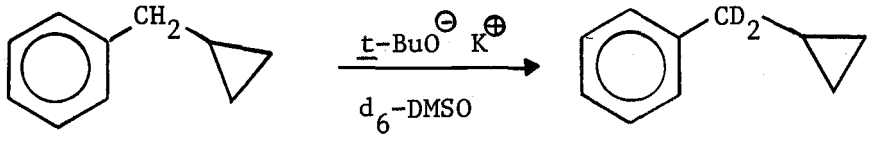


Similarly, the reaction of 33 to give 36 and 35 to give 37 is at least 93% stereospecific statistically.

A mechanistic question posed earlier concerns the existence of the intermediate carbanion 23. When compound 38 was treated with potassium t-butoxide in d_6-dimethylsulfoxide for twenty hours at room temperature, no ring opened product was observed

(Scheme 27) (21b).

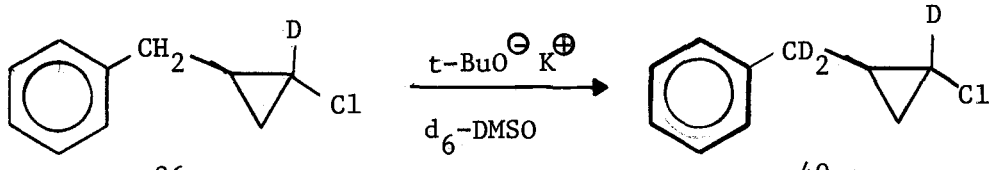
Scheme 27



38 39

However, hydrogen-deuterium exchange took place ultimately yielding the dideuterated 39. Utilizing this information, 26 was subjected to the same conditions. Under these conditions, a sizable amount of elimination took place but the isolated cyclic product's NMR spectrum showed no absorption in the benzylic region (Scheme 28).

Scheme 28



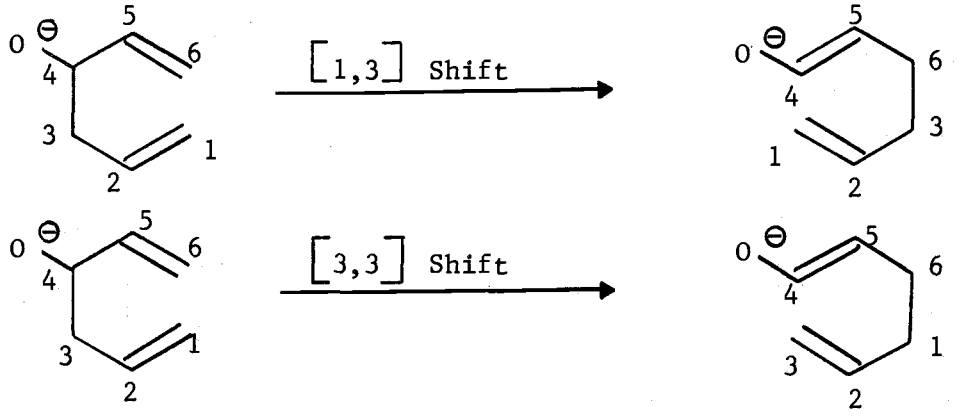
26 40

Cram (66) has found that in base-catalyzed hydrogen - deuterium exchange reactions run under these conditions the carbanion is a relatively long lived discrete intermediate. The deuterium incorporation into 26 lends strong support to the existence of carbanion 23 as a discrete intermediate in the elimination process.

The elimination reaction was found to proceed faster in HMPT than in DMSO, this suggests that ion pair disassociation promotes the reaction. The stereospecificity of the elimination reaction combined with the existence of 23 as a discrete intermediate places the elimination reaction in the class of accelerated thermal rearrangements facilated by a proximal negative charge.

Evans (68), Thies (57), Still (75), and Wilson (67) among others have observed exceptionally facile rearrangements of 3-alkoxy-1,5-hexadienes affording enolates due to [1, 3] and [3, 3] sigmatropic shifts (Scheme 29).

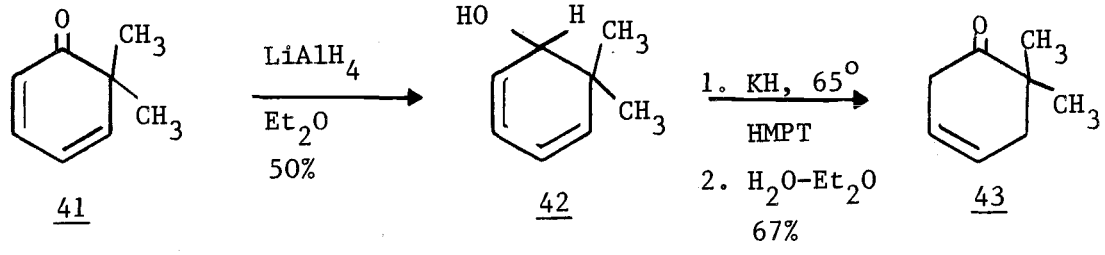
Scheme 29



Although there is some debate as to the concerted nature of these rearrangements (68), it was felt that a [1, 5] hydrogen shift from an alkoxy-1,5-diene may occur from a suitable model system if an enolate was produced from the hydrogen shift. It was also felt that the alkoxydiene would also give a rate enhancement over its

neutral counterpart for the [1, 5] hydrogen shift. To test this hypothesis, cyclohexadienone 41 was converted to the cyclohexadienol 42 by treatment with either diisobutylaluminum hydride or lithium aluminum hydride (Scheme 30).

Scheme 30



41 42 43

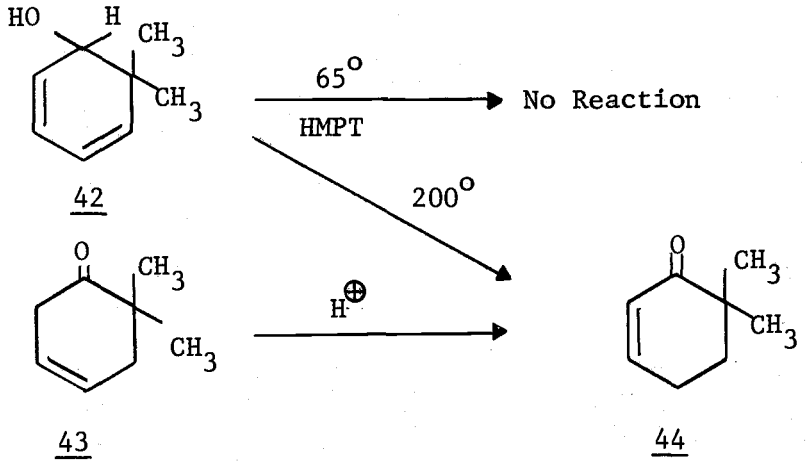
The dienol 42 was felt to be a suitable system for the study of the [1, 5] -hydride shift for three reasons, it is geometrically set up for a [1, 5] hydrogen shift, a very stable enolate would be produced from its alkoxy derivative if a [1, 5] hydrogen shift took place, and the ring structure would inhibit [1, 3] and [3, 3] sigmatropic shifts which would also produce stable enolates if a linear system was used.

The dienol was found to isomerize to give the unsaturated ketone 43, the kinetic product of [1, 5] hydrogen shift when treated with potassium hydride in HMPT at 65° for thirty minutes and quenched with an ether - water solution (Scheme 30).

A control experiment was performed without the presence of potassium hydride. In the absence of potassium hydride, 42 was found not to isomerize at 65° in HMPT. However, 42 isomerized

readily at 200° to give 44. The enone 43 also isomerized to 44 when subjected to acidic conditions (Scheme 31). Apparently, the [1,5] hydrogen shift took place in the thermal rearrangement of 42, but the thermodynamic product 44 was eventually produced from the shift instead of the kinetic product 43.

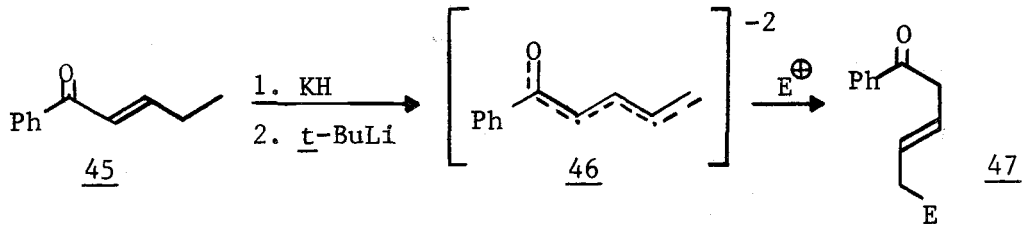
Scheme 31



42 43 44

Although the alkoxide rearrangement of 42 is consistent with a thermally allowed process, a dianionic intermediate may be responsible for the observed transformation. D. Seebach (69) has prepared dianions from unsaturated ketones. When the unsaturated ketone 45 is treated with potassium hydride followed by t-butyllithium, dianion 46 is produced. When this dianion is treated with an electrophile (one equivalent), the unconjugated enone 47 is produced (Scheme 32).

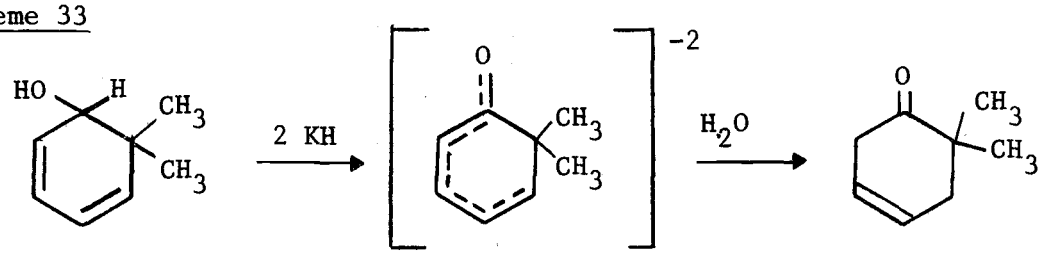
Scheme 32



45 46 47

The reaction of potassium hydride with proton donors to produce an anionic species and hydrogen gas is an irreversible reaction. The temperature required for the transformation of 42 to produce 43 may be sufficient for dianion formation although it seems unlikely (Scheme 33).

Scheme 33

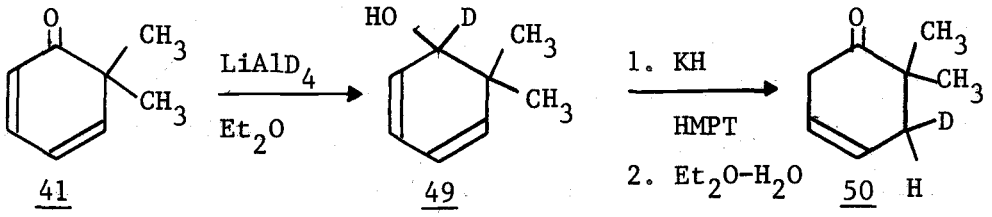


42 48 43

If the dianion 48 is produced, quenching should also produce 43, the same product from a [1, 5] hydrogen shift, analogous to Seebach's results.

Information about this possible process was found by appropriate deuterium labeling. Deuteriodienol 49 was prepared from 41 by reduction using lithium aluminum deuteride (Scheme 34).

Scheme 34

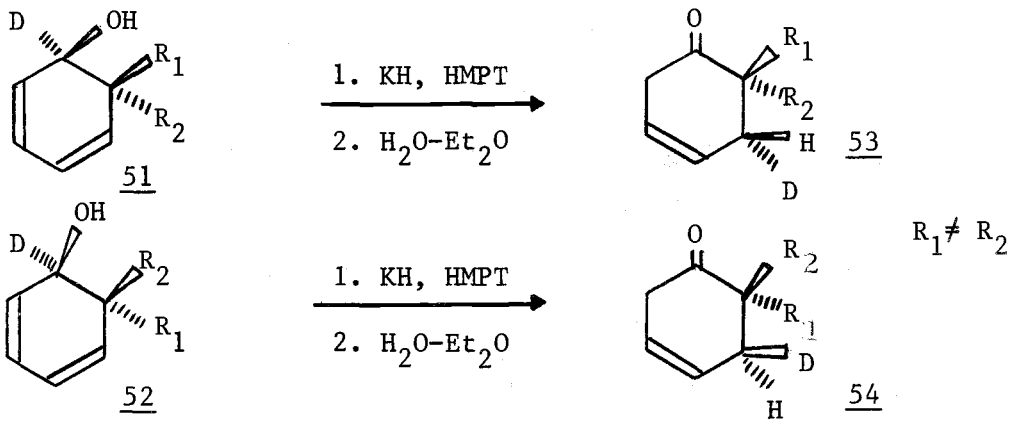


41 49 50

When 49 was subjected to the rearrangement conditions, the NMR spectrum of the resulting enone 50 indicated that the product was monodeuterated and the deuterium was in the 5-position. Mass spectral analysis indicated that the product was at least 98% monodeuterated. Clearly, this negates the possibility of a dianionic intermediate. The deuterium incorporation into the 5-position also shows that a [1,5] hydrogen shift is indeed taking place in the transformation of 42 into 43 under the basic conditions.

The observed [1,5] hydrogen shift from 42 has been shown to give the same product as that expected from a thermally allowed process. However, more work is necessary to see if the reaction is indeed stereochemically consistent with the thermally allowed transformation. Two simple dienols, 51 and 52, would be appropriate to study the stereochemistry of the rearrangement (Scheme 35).

Scheme 35



If the rearrangement is indeed concerted, the [1, 5] hydrogen shift should proceed suprafacially and 53 would be the expected from 51 and 54 from 52. An isotope effect would also be expected from this rearrangement process. One was found for the model studied, however, the isotope effect was not calculated, it was only observed. Compound 42 was found to rearrange more quickly than the deuterated 49.

Evans and Goddard (70) have calculated that the carbon - hydrogen bond energy in methanol is reduced by 16.5 kcal/mol when the alcohol is transformed into the disassociated potassium alkoxide (methoxide) using ab initio generalized valence bond and configuration theoretical methods. If this calculation is indeed valid, the observed rate acceleration for the [1, 5] hydrogen shift found in the model system may be rationalized by a ground state argument. If the transition states for the alcohol and the alkoxide have comparable energies,

the enhanced acceleration of the alkoxide over the alcohol rearrangement would be due to their ground state energy differences. However, the transition state energies may not be comparable due to the influence of the negative charge. Since the effect of the negative charge on the transition state is not known, it is inappropriate to justify the observed rate enhancement on ground state arguments alone.

The observed rate enhancement for the [1, 5] hydrogen shift due to alkoxide formation also places this reaction in the class of accelerated thermal rearrangements facilitated by a proximal negative charge.

IV. EXPERIMENTAL

1-Benzyl-2,2-dichlorocyclopropane (19)

To 48.0 g (0.412 moles) of chloroform and 32.0 g (0.25 moles) of allylbenzene was placed 5 mL of benzyltriethylammonium chloride. The flask was immersed in an ice bath and 75 mL of 50% aqueous sodium hydroxide solution was added over a period of 20 minutes to the chloroform solution. The flask was removed from the ice bath and was stirred at room temperature for 24 hours. The resulting brown mixture was poured into 100 mL of ice and the resulting solution was washed twice with 100 mL portions of diethyl ether. The ethereal washings were combined and in turn was washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, most of the ether was removed using a rotarory evaporator. The resulting liquid was subjected to vacuum distillation. A clear liquid (21.3 g, 51% yield, b.p. 70-72°/0.3 mm) was collected which exhibited a NMR spectrum consistent with that expected for 1-benzyl-2,2-dichlorocyclopropane (19)α NMR(CCl_4) δ 6.8-7.3 (m, 5H), 2.4-3.0 (m, 2H), 1.2-1.86 (m, 2H), 0.90-1.10 (m, 1H). Anal. Calcd for $C_{10}H_{10}Cl_2$: C, 59.72; H, 5.01; Cl, 35.26. Found: C, 55.85; H, 4.96; Cl, 35.55

cis- and trans-2-Benzylchlorocyclopropane (20 and 21)

To 10.0 g (0.05 moles) of 1-benzyl-2,2-dichlorocyclopropane (19) maintained under a positive nitrogen atmosphere was placed 15.0 g (0.05 moles) of tri-n-butyl tin hydride. The flask was heated to 100° for three hours while the contents were stirred by the means of a magnetic stirring bar. The flask was allowed to cool to room temperature and the flask was connected to a short path distillation apparatus and the contents of the flask were subjected to simple vacuum distillation. A clear liquid (7.5 g, % yield, b.p. 60-64°/ 0.2-0.3 mm) was collected. The liquid was subjected to g.l.p.c. analysis using column R at 140° column temperature. The chromatogram indicated the presence of two components in a calculated ratio of 12. to 1. The components were isolated by preparative scale g.l.p.c. using the same column and conditions. The smaller component which had a shorter retention time was assigned the structure of trans-2-benzylchlorocyclopropane (21) by its NMR spectrum; NMR(CCl_4) δ 7.1-7.36 (m, 5H), 2.78 (d of d of d, J=8, 4, and 4Hz, 1H), 2.71 (d of d, J=6.5 and 16Hz, 1H), 2.54 (d of d, J=6.5 and 16Hz, 1H), 1.14-1.61 (m, 1H), 0.64-1.10 (m, 2H). The larger component which had a longer retention time was assigned the structure of cis-2-benzylchlorocyclopropane (20) by comparison of its NMR spectrum to that of the trans isomer; NMR(CCl_4) δ 7.1-7.36 (m, 5H), 3.18 (d

of d of d, J=4, 8, and 8Hz, 1H), 2.98 (d of d, J=6.5 and 16Hz, 1H), 2.72 (d of d, J=6.5 and 16Hz, 1H), 1.0-1.48 (m, 2H), 0.50-0.76 (m, 1H).

The cis and trans isomers of 2-benzylchlorocyclopropanes were also prepared by an alternate procedure. To 50 mL of dry deoxygenated THF maintained under a positive nitrogen atmosphere was placed 4.0 g (0.02 moles) of 1-benzyl-2,2-dichlorocyclopropane. The flask was immersed in a liquid nitrogen - hexane slush bath and after temperature equilibration was obtained, 0.04 moles of butyllithium (16.5 mL, 2.5 M in hexane) was added to the reaction flask over a period of 10 minutes through an addition funnel while the flask was stirred by the means of a glass covered magnetic stirring bar. The contents of the flask turned a dark red color. After the flask was stirred for 4.5 hours in the slush bath, the solution was quenched by the addition of 3.5 mL of methanol. The reaction mixture was poured into 50 mL of diethyl ether and the resulting solution was washed with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration procedure, most of the solvent was removed using a rotarory evaporator. The resulting light yellow liquid was subjected to simple distillation. A clear liquid was collected, 1.3 g, over a broad boiling range, b.p. 103-110°/7 mm. The liquid was analyzed by g.l.p.c. using column R at 140° column temperature. The chromatogram indicated that

four components were present. The first two components were purified by preparative scale g.l.p.c. using the same column and conditions. The two components produced NMR spectra and retention times identical to those of cis- and trans-2-benzylchlorocyclopropane. The ratio of trans to cis isomers was calculated to be 15 to 1.

E-1-D_1-chloro-2-benzylcyclopropane (26)

The second procedure for the preparation of cis- and trans-2-benzylchlorocyclopropane was employed exactly except that the reaction was quenched with deuterated methanol instead of methanol. A clear liquid, 2.3 g, was isolated by distillation, b.p. 96-105°/6.0 mm. The component having the same retention time as that of trans-2-benzylchlorocyclopropane (21) was isolated by preparative g.l.p.c. using column A at 135°. The isolated component exhibited a NMR spectrum consistent with that expected for E-1-d_1-1-chloro-2-benzylcyclopropane (26); NMR(CCl_4) δ 7.0-7.4 (m, 5H), 2.70 (d of d, J=6.5 and 14Hz, 1H), 2.52 (d of d, J=6.5 and 14Hz, 1H), 1.2-1.6 (m, 1H), 0.65-1.10 (m, 2H). The NMR spectrum indicated that the product was at least 95% monodeuterated.

cis-1,2-D_2-3-benzylpropene (29)

To 50 mL of spectral grade cyclohexane was placed a magnetic

stirring bar. The flask was fitted with a septum and connected to an atmospheric pressure hydrogenation apparatus. The atmosphere of the flask was flushed three times by forming a negative atmosphere using vacuum and releasing deuterium gas into the flask's atmosphere until a positive pressure of deuterium gas existed. Lindlar's catalyst was added, 1.0 g, by syringing a mixture of catalyst and cycohexane into the flask. After the catalyst was saturated with deuterium, 10.0 g (0.86 moles) of propargylbenzene and 40 μL of quinoline were syringed into the reaction flask. After 2.22 L (0.095 moles) of deuterium gas was consumed, the contents of the flask were filtered and subjected to simple distillation. During distillation, a clear liquid was collected (8.25 g, 81% yield, b.p. 47-49°/14 mm) which was subjected to analysis by g.l.p.c. using column Q at 100°. The chromatogram indicated that three components were present. The major component, 95% of the product mixture was isolated by preparative scale g.l.p.c. using the same column and conditions. Its NMR spectrum was consistent with that expected for cis-1,2-d_2-3-benzylpropene (29); NMR(CCl_4) δ 7.0-7.36 (m, 5H), 4.96-5.16 (m, 1H), 3.36 (s, 2H). Low voltage mass spectral analysis indicated the incorporation of 98% d_2.

cis- and trans-1,2-D_2-1-benzyl-3,3-dichlorocyclopropane (30 and 31)

The procedure for the preparation of 1-benzyl-2,2-dichloro-

cyclopropane was employed using 8.0 g (0.067 moles) of 1,2-d_2-3-benzylpropene (29), and 14.0 g (0.167 moles) of chloroform. The resulting light brown solution was subjected to simple vacuum distillation. A clear liquid (5.9 g, 44% yield, b.p. 72-74°/3.0 mm) was collected during distillation. This material was further purified by preparative scale g.l.p.c. using column Q at 110°. The chromatogram indicated that only one compound was present. The component was isolated and exhibited a NMR spectrum consistent with that expected for cis-1,2-d_2-1-benzyl-3,3-dichlorocyclopropane (30); NMR(CCl_4) δ 7.02-7.35 (m, 5H), 3.10 (d, J=15Hz, 1H), 2.78 (d, J=15Hz, 1H), 1.28 (s, 1H). However, the spectrum also indicated that some impurity was also present. There was a small absorption at a chemical shift of 1.72 δ. The ratio of this peak area to that at 1.28 δ was 1 to 7.5. This impurity was attributed to trans-1,2-d_2-1-benzyl-3,3-dichlorocyclopropane (31).

Selective Reduction of cis- and trans-1,2-D_2-1-benzyl-3,3-Dichloropropane (30 and 31)

The procedure for the preparation of 2-benzylchlorocyclopropanes was employed using 4.0 g (0.020 moles) of the mixture of cis- and trans-1,2-d_2-1-benzyl-3,3-dichlorocyclopropane (30 and 31) and 6.0 g (0.020 moles) of tri-n-butyltin hydride. During distillation, a clear liquid was collected (2.0 g, 60% yield, b.p. 60-64°/0.2 mm).

The liquid was subjected to g.l.p.c. analysis using column R at 140°. The chromatogram indicated to components were present in a ratio of 1.2 to 1. The smaller component which produced a shorter retention time displayed an NMR spectrum consistent with that expected for cis-1,2-d_2-trans-1-benzyl-3-chlorocyclopropane (33); NMR(CCl_4) δ 7.04-7.4 (m, 5H), 2.72 (d, J=8.0Hz, 1H), 2.70 (d, J=16.0Hz, 1H), 2.53 (d, J=16.0Hz, 1H), 0.76 (d, J=8.0Hz, 1H). However, the NMR spectrum indicated that there was an impurity present. The spectrum produced a small absorption at 0.96δ whose ratio to the absorption at 0.76δ was calculated to be 1 to 7.5. This impurity was attributed to trans-1,2-d_2-trans-1-benzyl-3-chlorocyclopropane (35). The larger component was also isolated and its NMR spectrum also revealed that it was a mixture of two epimers. The predominant epimer was identified by the NMR spectrum of the mixture. This epimer was assigned the structure cis-1,2-d_2-cis-1-benzyl-3-chlorocyclopropane (32); NMR(CCl_4) δ 7.0-7.3 (m, 5H), 3.07 (d, J=4.0Hz, 1H), 2.88 (d, J=16.0Hz, 1H), 2.66 (d, J=16.0Hz, 1H), 0.50 (d, J=4.0Hz, 1H). A small absorption at a chemical shift of 1.0 δ (d, J=8.0Hz) was used to identify the minor epimer as trans-1,2-d_2-cis-1-benzyl-3-chlorochyclopropane (34) as the minor epimer and the ratio of absorption at 1.0δ to that at 0.50δ was used to determine the epimer ratio as 1 to 7.5.

General Procedure for the Reaction of Benzylchlorocyclopropanes with Potassium t-Butoxide in HMPT

To approximately 10 mL of dry HMPT maintained under a positive nitrogen atmosphere was placed the benzylchlorocyclopropane and potassium t-butoxide. The reaction flask was immersed in a pre-heated oil bath (40°) and the contents of the flask were stirred for 5 minutes. At the end of this period, the reaction solution turned a deep blue color. Pentane, 20 mL was added to the reaction flask and the reaction was quenched by slow addition of water. The reaction flask contents were poured into 10 mL of water and the organic layer was separated and washed four times with 10 mL portions of water, 10 mL of saturated aqueous sodium chloride and dried using anhydrous magnesium sulfate. After a filtration process, most of the solvent was removed using a rotarory evaporator and the solution was analyzed by preparative g.l.p.c.

Reaction of trans-2-Benzylchlorocyclopropane (21) with Potassium t-Butoxide in HMPT

The general procedure for the reaction of benzylchlorocyclopropanes with potassium t-butoxide in HMPT was followed using 0.93 g (0.0056 moles) of trans-2-benzylchlorocyclopropane (21), 0.27 g (0.0024 moles) of potassium t-butoxide, 5 mL of HMPT and 0.27 g (0.0020 moles) of t-butylbenzene as an internal standard.

Preparative scale g.l.p.c. using column L at 150° indicated only one product was present in a calculated yield of 97%. The material was isolated and produced a NMR spectrum and retention time as that of E-1-phenyl-1,3-butadiene (22).

Reaction of cis-2-Benzylchlorocyclopropane (20) with Potassium t-Butoxide in HMPT

The general procedure for the reaction of benzylchlorocyclopropanes with potassium t-butoxide was followed using 0.320 g (0.00194 moles) of cis-2-benzylchlorocyclopropane, 0.30 g (0.0027 moles) of potassium t-butoxide and 10 mL of HMPT along with 0.30 g (0.0022 moles) of t-butylbenzene which was used as an internal standard. Preparative g.l.p.c. analysis using column L at 150° indicated only one product was present in a yield of 95%. This product was isolated and produced the same NMR spectrum and retention time as that of E-1-benzyl-1,3-butadiene (22).

Reaction of E-1-D_1-1-chloro-2-benzylcyclopropane (26) with Potassium t-butoxide in HMPT

The general procedure for the reaction of benzylchlorocyclopropanes with potassium t-butoxide was employed using 0.331 g (0.00198 moles) of E-1-d_1-1-chloro-2-benzylcyclopropane (26), 15 mL of HMPT and 0.80 g (0.0071 moles) of potassium t-butoxide. The

product of the reaction was isolated by preparative scale g.l.p.c. using column L at 150°. The NMR spectrum was used to identify the material as E-1-phenyl-3-d_1-1,3-butadiene (28); NMR(CCl_4) δ 7.0-7.5 (m, 5H), 6.77 (broad d, J=8Hz, 1H), 6.45 (d, J=8Hz, 1H), 5.0-5.4 (m, 2H).

Reaction of E-1-D_1-1-chloro-2-benzylcyclopropane (26) with Potassium t-butoxide in Hexadeuterodimethylsulfoxide

Hexadeuterodimethylsulfoxide (2 mL) was placed into a NMR tube along with 0.1 g (0.008 moles) of potassium t-butoxide and 0.15 g (0.0008 moles) of 26. The reaction vessel was sealed and monitored by NMR. After 24 hours, the NMR spectrum of the reaction mixture showed no benzylic proton absorption. The reaction was quenched with water and extracted with pentane (15 mL). The pentane solution was washed three times with 10 mL portions of water and then with saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, most of the pentane was removed using a rotarory evaporator. The resulting light yellow solution was analyzed by g.l.p.c. using column L at 140°. About 40% of the product mixture was due to elimination to form phenylbutadiene. The component which had the same retention time as that of 26 was isolated by preparative scale g.l.p.c. The NMR spectrum showed no benzylic proton absorption; NMR(CCl_4) δ 7.0-7.4 (m, 5H),

0.65-1.4 (m, 3H).

Reaction of the Mixture of cis- and trans-1,2-D_2-trans-1-benzyl-3-chlorocyclopropane (33 and 35) with Potassium t-butoxide in HMPT

The general procedure for the reaction of benzylchlorocyclopropanes with potassium t-butoxide in HMPT was employed using 0.45 g (0.00268 moles) of the mixture of 33 and 35, 0.5 g (0.004 moles) of potassium t-butoxide and 15 mL of HMPT. The products of the reaction was isolated by preparative scale g.l.p.c. using column L at 150°. The NMR spectrum of the isolated products indicated that two products were present. The products were identified by the NMR spectrum of the mixture as E,E-1-phenyl-2,4-d_2-1,3-butadiene (37); NMR(CCl_4) δ 7.1-7.5 (m, 5H), 6.3-6.66 (m, 2H), 5.28 (d, J=17Hz, 1H) and as E,Z-1-phenyl-2,4-d_2-1,3-butadiene (36); NMR(CCl_4) 7.1-7.5 (m, 5H), 6.3-6.66 (m, 2H), 5.11 (d, J=10Hz, 1H). The ratio of the E,Z epimer to that of the E,E epimer was calculated to be 7.1 to 1. When the isolated products were allowed to sit undisturbed in the NMR tube for 3 hours, a 50:50 mixture of E,E and E,Z isomers was formed.

Reaction of the Mixture of cis- and trans-1,2-D_2-cis-1-benzyl-3-chloro cyclopropane (32 and 34) with Potassium t-butoxide in HMPT

The general procedure for the reaction of benzylchlorocyclopropanes with potassium t-butoxide in HMPT was employed using 0.285 g (0.0017 moles) of the mixture of 32 and 34, 0.40 g (0.003 moles) of potassium t-butoxide and 15 mL of HMPT. After the reaction was quenched, the products of the reaction were isolated by preparative scale g.l.p.c. using column L at 150°. The NMR spectrum of the isolated products indicated that two components were present. The products were identified as E,E- and E,Z-1-phenyl-2,4-d_2-1,3-butadiene (37 and 36) by NMR. The ratio of the E,E isomer to the E,Z isomer was calculated to be 7.3 to 1.

6,6-Dimethyl-2,4-cyclohexadien-1-ol (42)

Into a flask containing 50 mL of dry benzene and 20 mL of hexane was placed 3.0 g (0.024 moles) of 6,6-dimethyl-2,4-cyclohexadienone (41) and the flask was placed under a positive argon atmosphere and immersed in an ice bath. After temperature equilibration, 0.024 moles of diisobutylaluminum hydride was added slowly to the flask at such a rate that the temperature did not rise above 5° by the use of a syringe. The resulting solution was stirred at 0° for one hour and at room temperature for three hours. The reaction

vessel was again immersed in an ice bath and 50 mL of methanol was slowly added to the reaction. The reaction solution was stirred for one hour and 50 mL of water was added to the flask and after stirring for an additional hour, the solution was decanted away from the precipitate formed upon addition of the methanol. The methanolic solution was then added to 50 mL of pentane and washed three times with 50 mL portions of water and saturated aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, the liquid was concentrated using a rotarory evaporator and distilled. A clear liquid was collected during distillation (1.1 g, 36% yield, b.p. 54-56°/4.0 mm) which produced NMR spectrum consistent with that expected for 42; NMR(CCl_4) δ 5.45-5.94 (m, 4H), 3.8-3.94 (m, 1H), 2.04 (m, 1H), 1.02 (s, 6H).

Alcohol 42 was also prepared in a different fashion. To an addition funnel connected to a flask containing 2.0 g (0.05 moles) of lithium aluminum hydride and 100 mL of diethyl ether maintained at -17° was placed 3.0 g (0.024 moles) of 41 and 10 mL of ether. The contents of the addition funnel was added to the flask over a period of 30 minutes. Saturated aqueous ammonium chloride solution was then slowly added to the flask until a precipitate suitable for decanting was formed. The liquid was filtered from the precipitate and the aluminum salts were washed twice with 20 mL portions of ether. The mother liquor and the washings were combined and washed with saturated

aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process the ethereal solution was concentrated using a rotarory evaporator and distilled using vaccum. A clear liquid was obtained during distillation (1.5 g, 50% yield, b.p. 54-56°/4.0 mm) that produced an identical NMR spectrum and retention time as that of 42 produced from reduction using diisobutylaluminum hydride.

1-D_1-6,6-dimethyl-2,4-cyclohexadien-1-ol (49)

The second procedure for the preparation of 6,6-dimethyl-2,4-cyclohexadien-1-ol (42) was employed using 1.5 g (0.012 moles) of dienone 41 and 1.0 g (0.025 moles) of lithium aluminum deuteride. The product obtained from vacuum distillation (0.53 g) produced a NMR spectrum consistent with that expected from the reduction using a deuterium source; NMR(CCl_4) δ 5.44-5.95 (m, 4H), 1.0-1.4 (broad s, 1H), 1.06 (s, 3H), 1.02 (s, 3H).

Reaction of 6,6-Dimethyl-2,4-cyclohexadien-1-ol (42) with Potassium Hydride in HMPT

Into a flask containing approximately 2.0 g (0.05 moles) of potassium hydride was placed 10 mL of HMPT and the flask was placed under a positive argon atmosphere. To the contents of the flask was placed 0.30 g (0.0024 moles) of 42 and 0.310 g (0.0024

moles) of nonane as an internal standard. The flask was immersed in a preheated oil bath maintained at 65°. After a few minutes at that temperature, the contents of the flask turned blue. The reaction was quenched after 30 minutes by pouring the contents of the flask into a ice-ether mixture slowly. The resulting solution was added to 50 mL of pentane and the aqueous layer was separated and the organic layer was washed repetitively with water to rid it of HMPT and its decomposition products. The pentane solution was then washed with aqueous sodium chloride solution and dried using anhydrous magnesium sulfate. After a filtration process, the pentane solution was concentrated using a rotarory evaporator. The resulting light yellow solution was analyzed by g.l.p.c. using column A at 100°. The chromatogram of the reaction products indicated only one product was formed from the reaction in a yield of 67%. There existed more than one peak in the chromatogram but they were present also in the starting alcohol. They were responsible for only 5% of the reaction mixture. The major product was collected by preparative scale g.l.p.c. and produced a NMR spectrum that was consistent with a product of a rearrangement; NMR(CCl_4) δ 5.7-5.8 (m, 2H), 2.78-2.82 (m, 2H), 2.2-2.34 (m, 2H), 1.10 (s, 3H). The NMR spectrum was used to identify this product as 6,6-dimethyl-3-cyclohexen-1-one (43).

Reaction of 1-D_1-6,6-dimethyl-2,4-cyclohexadien-1-ol (49) with Potassium Hydride in HMPT

The procedure for the reaction of 6,6-dimethyl-2,4-cyclohexadien-1-ol (42) with potassium hydride in HMPT was employed using 10 mL of HMPT, 2.0 g (0.05 moles) of potassium hydride, and 0.150 g (0.0012 moles) of (49). The product isolated from the reaction by preparative g.l.p.c. using column A at 100° produced an NMR spectrum consistent with that expected; NMR(CCl_4) δ 5.75 (m, 2H), 2.78-2.90 (m, 2H), 1.18-1.32 (m, 1H), 1.10 (s, 6H). Low voltage mass spectral analysis indicated that the material was at least 98% monodeuterated. The material was assigned the structure 6,6-dimethyl-3-cyclohexen-1-one (50).

Thermal Rearrangement of 6,6-Dimethyl-2,4-cyclohexadien-1-ol (42)

Nonane (1.310 g, 0.0024 moles) and 0.30 g (0.0024 moles) of (42) were placed in a pyrex tube and sealed under a positive nitrogen atmosphere. The pyrex tube was heated to 220° for 2 hours. The products of the reaction were analyzed by preparative g.l.p.c. analysis. The main product from the reaction was found to be formed in 85% yield; NMR(CCl_4) δ 6.75 (t of d, J=4 and 10Hz, 1H), 5.81 (t of d, J=2 and 10Hz, 1H), 2.22-2.43 (m, 2H), 1.81 (t, J=6.0Hz, 2H), 1.08 (s, 6H). The compound was assigned the structure 6,6-dimethyl-2-cyclohexen-1-one (44).

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