AN ABSTRACT OF THE THESIS OF

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Title: DIVALENT CARBON INTERMEDIATES IN SOME BRIDGED POLYCYCLIC COMPOUNDS

Abstract approved: Redacted for privacy
Dr. Peter K. Freeman

The generation and attempted generation of carbenes in several alicyclic systems is described.

Pyrolysis of the lithium salt of 6,6-dimethylnorbornan-2-one tosylhydrazone at 160-180° (0.1 torr) gave 5,5-dimethylnorbornene in 75% yield. Photolysis of the lithium salt in tetrahydrofuran gave 5,5-dimethylnorbornene in 50% yield. Decomposition of the lithium salt of <u>exo</u>-3- and <u>endo</u>-3-deuterio-6,6-dimethylnorbornan-2-one tosylhydrazone by both thermal and photolytic means yielded 2- and 3-deuterio-5,5-dimethylnorbornene, and the deuterium content at C-2 and C-3 was determined by mass spectral analysis of the alkene and nmr analysis of 2,3-epoxy-5,5-dimethylnorbornene formed by treating deuteriated alkene with peracetic acid. The ratio of <u>exo</u> to <u>endo</u> hydride (deuteride) migration was found to be ca. 20:1 for both thermal and photolytic de-

compositions. The rather large amount (ca. 5%) of *endo* migration was thought to preclude delocalization of the C-1-C-6 bond into the empty p orbital of the singlet carbene, and torsional interactions are suggested as the cause of the 20:1 *exo*:*endo* selectivity.

5,5-Dimethylnorbornene was formed in 70% and 27% yield from the decompositions of 6,6-dimethylnorbornan-2-one tosylhydrazone in diglyme, at 160°, with 12 equivalents of sodium methoxide, and 11 equivalents of silver carbonate, respectively. Treatment of *endo*-3-deuterio-6,6-dimethylnorbornan-2-one tosylhydrazone yielded a 20:1 ratio of *exo*:*endo* migration in both cases. Decomposition of 6,6-dimethylnorbornan-2-one tosylhydrazone in diglyme at 160° with 15.9 equivalents of aluminum *iso*-propoxide gave 26% 5,5-dimethylnorbornene and 47% *exo*-2-*iso*-propoxy-6,6-dimethylnorbornane. Treatment of *exo*-3- and *endo*-3-deuteriated tosylhydrazone with aluminum isopropoxide under the reaction conditions yielded 5,5-dimethylnorbornene with substantially less deuterium than the starting material, suggesting the possibility of an alumino-carbonium ion (aluminum complexed carbene).

Treatment of 3-bromobicyclo[3.2.1]oct-2-ene with potassium *tert*-butoxide in dimethylsulfoxide gave a 93:7 ratio of 3-*tert*-butoxybicyclo[3.2.1]oct-2-ene and 2-*tert*-butoxybicyclo[3.2.1]oct-2-ene in 64% overall yield. The enol ether products underwent a retro-ene reaction in the vpc injection port (>225°) to yield bicyclo[3.2.1]octan-3-one and bicyclo[3.2.1]octan-2-one. Treatment of the vinyl bromide with potassium *tert*-butoxide in perdeuteriodimethylsulfoxide yielded enol ethers with the vinyl proton ca. 85% replaced by deuterium.

Addition of dibromocarbene to *exo*-tricyclo[$3.2.1.0^{2,4}$]-oct-6-ene gave a 42% yield of 7,8-dibromo-*exo*-tricyclo-[$3.3.1.0^{2,4}$]non-6-ene, which, upon treatment with lithium aluminum hydride, gave a 40% yield of 7-bromo-*exo*-tricyclo-[$3.3.1.0^{2,4}$]non-6-ene. Treatment of the tricyclic vinyl bromide with potassium *tert*-butoxide in dimethylsulfoxide gave a 51% yield of a 97:3 ratio of 7-*tert*-butoxy-*exo*-tricyclo[$3.3.1.0^{2,4}$]non-6-ene and 6-*tert*-butoxy-*exo*-tricyclo-[$3.3.1.0^{2,4}$]non-6-ene. 7-*tert*-butoxy-*exo*-tricyclo[$3.3.1.0^{2,4}$]-non-6-ene readily underwent retro-ene reaction in the vpc injection port (180-200°) to yield tricyclo[$3.3.1.0^{2,4}$]nonan-7-one. When the tricyclic vinyl bromide was treated with potassium *tert*-butoxide in perdeuteriodimethylsulfoxide, the olefinic proton in the product *endo*-ether was ca. 85% replaced by deuterium, and nmr analysis of the ketone retro-ene product showed that the α-position of the ketone contained 3.1 ± 0.2 hydrogens.

Treatment of deltacyclene with dibromocarbene gave a 58% yield of 9,10-dibromotetracyclo[$4.4.0.0^{2,4}.0^{3,7}$]dec-8-ene, which was reduced by treatment with lithium aluminum hydride to 9-bromotetracyclo[$4.4.0.0^{2,4}.0^{3,7}$]dec-8-ene in

47% yield. Treatment of the tetracyclic vinyl bromide with potassium *tert*-butoxide in dimethylsulfoxide afforded a 53% yield of a 95:5 mixture of 9-*tert*-butoxytetracyclo-$[4.4.0.0^{2,4}.0^{3,7}]$dec-8-ene and 8-*tert*-butoxytetracyclo-$[4.4.0.0^{2,4}.0^{3,7}]$dec-8-ene, which underwent facile (180-200°) retro-ene reaction to tetracyclo$[4.4.0.0^{2,4}.0^{3,7}]$-decan-9-one and tetracyclo$[4.4.0.0^{2,4}.0^{3,7}]$decan-8-one.

exo-Tricyclo$[3.2.1.0^{2,4}]$non-6-ene and tetracyclo-$[4.4.0.0^{2,4}.0^{3,7}]$dec-8-ene were prepared in 83% and 76% yield respectively from reduction by sodium and *tert*-butyl alcohol in tetrahydrofuran of the corresponding vinyl bromides (above). The alkenes, along with cyclohexene and bicyclo[3.2.1]octa-2,6,diene were subjected to potassium *tert*-butoxide in perdeuteriodimethylsulfoxide (0.55 N) at 61°, and the rates of allylic hydrogen-deuterium exchange were followed by mass spectral analysis. The rates of disappearance of undeuteriated alkene were as follows: cyclohexene, 1.0×10^{-7} sec^{-1}; bicyclo[3.2.1]-octa-2,6-diene, 1.6×10^{-3}; tricyclo$[3.2.1.0^{2,4}]$non-6-ene, 5×10^{-8}; and tetracyclo$[4.4.0.0^{2,4}.0^{3,7}]$dec-8-ene, 5×10^{-8}. There is no evidence for transannular cyclopropyl participation with the allylic anion, in the last two cases, to form a trishomoaromatic intermediate.

Methoxide ion induced decomposition of *exo*-*exo*-6,7-dideuterio-*endo*-tricyclo$[3.2.1.0^{2,4}]$octan-8-one tosylhydrazone in diglyme, at 160°, gives an eight to one ratio of tetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane and tricyclo[3.3.0.0^{4,6}]oct-2-ene, both of which retain greater than 96% of the deuterium label. Formation of the tetracyclic hydrocarbon via base abstraction of a C-6 or C-7 proton is clearly ruled out. The proton nmr spectrum of the dideuteriated tetracyclic hydrocarbon seems to rule out formation by a concerted pathway involving bond formation between C-2 and C-8, fission at C-2-C-4, bonding between C-4 and C-6, and hydrogen migration from C-6 to C-8.

Diels-Alder addition of 1-methylcyclopropene to 5,5-dimethoxy-1,2,3,4-tetrachlorocyclopentadiene gave 8,8-dimethoxy-2-methyl-1,5,6,7-tetrachloro-*endo*-tricyclo[3.2.1.0^{2,4}]oct-6-ene in 95% yield. Dechlorination with sodium and *tert*-butyl alcohol in tetrahydrofuran gave a 56% yield of 8,8-dimethoxy-2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]-oct-6-ene. Hydrogenation gave 8,8-dimethoxy-2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octane, and hydrolysis yielded 2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one. 2-Methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one tosylhydrazone was prepared in 65% yield by hydrolysis of the ketal in aqueous methanol and *in situ* reaction with *p*-toluenesulfonylhydrazine.

Methoxide ion induced decomposition of 2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one tosylhydrazone in diglyme at 160° gave 3% 2-methyltetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane and 28% 2-methylenetricyclo[3.3.0.0^{4,6}]octane, along with a 10% total yield of three methyl ethers. The structure of the tetracyclic structure was established by an independent synthesis, and the structure of the tricyclic alkene was established by ozonolysis to tricyclo[3.3.0.0^{4,6}]-octan-2-one.

Sodium hydride induced thermal decomposition of *endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one tosylhydrazone produced the tetracyclic and tricyclic hydrocarbons in an 8:1 ratio, while sodium hydride induced decomposition of 2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one gave tetracyclic and tricyclic hydrocarbons in ratios as low as 1:1.5. Sodium hydride induced thermal decomposition in diglyme of 6,7-dideuterio-, 4-deuterio-, and 4,6,7-trideuterio-2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one tosylhydrazones yielded deuteriated 2-methyltetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane, along with deuteriated alkene. Mass spectral, proton nmr and deuterium nmr analyses of the deuteriated products were consistant with the intermediacy of 2-carbena-4-methyltricyclo[3.3.0.0^{4,6}]octane, the product of a formal carbene-carbene rearrangement from 8-carbena-2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octane.

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DIVALENT CARBON INTERMEDIATES
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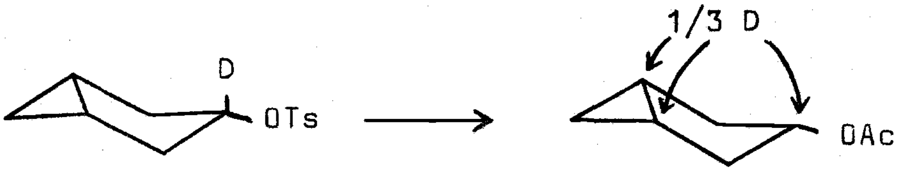
INTRODUCTION

This thesis describes the generation and attempted generation of carbenes in several alicyclic systems and investigations into possible non-classical behavior of the carbenes. In one sense, non-classical ions are examples of homoaromatic behavior, and this introduction will develop some of the background of homoaromatic intermediates which are pertinent to the work described herein. A homoaromatic system is merely an aromatic system in which the sigma backbone of the aromatic ring is disrupted, either by removing the sigma bond entirely or interposition of one or more methylene groups (1).

One of the earliest examples of homoaromaticity is



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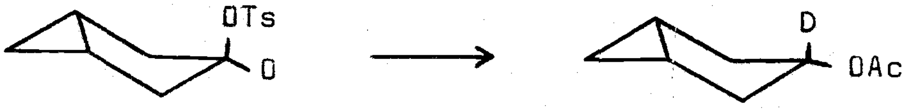

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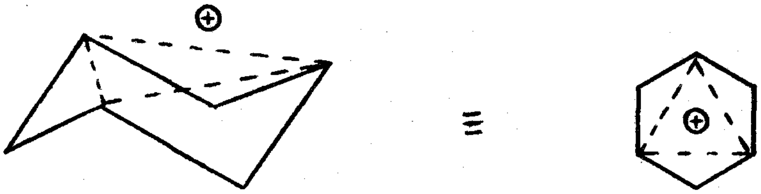
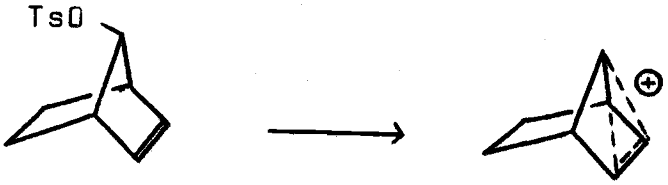
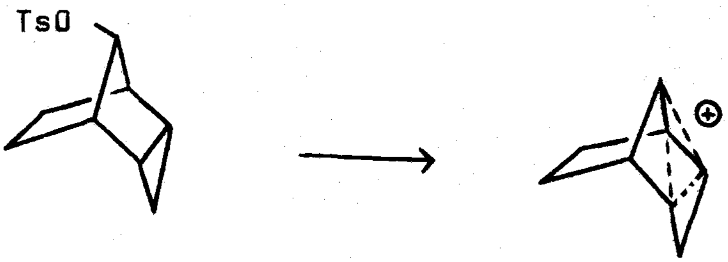
that of the trishomocyclopropenyl cation (2). Solvolysis of deuteriated 1 and 2 in acetic acid yields _cis_-acetate in both cases; however, during solvolysis of 1, the deuterium label was scrambled equally over C-1, C-3 and C-5, while solvolysis of 2 yielded very little deuterium scrambling and a large amount of olefin. The authors attribute these results to anchimeric assistance by the cyclopropyl "bent" bond with the developing p orbital of the carbonium ion during solvolysis of 1 to form a trishomocyclopropenyl cation. Solvolysis of 2, in which the leaving group is not in a position to be assisted, must then proceed via a classical carbonium ion.



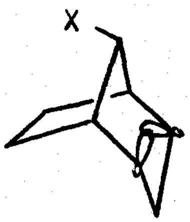
Overlap of pi electrons in the solvolysis of 7-norbornenyl tosylate (3) leads to the formation of a bishomocyclopropenyl cation. Dramatic evidence of this pi participation is provided by a rate enhancement for solvolysis of 10^{11} compared with 7-norbornyl tosylate.

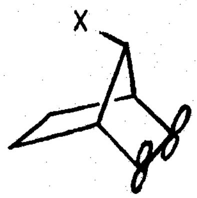


An even more dramatic rate enhancement is seen in the solvolysis of the p-nitrobenzoate of endo-tricyclo-[3.2.1.0^{2,4}]octan-8-ol (4-7). The trishomocyclopropenyl cation formed by overlap of the cyclopropyl "banana" bond enhances the rate of formation of the ion by a factor of

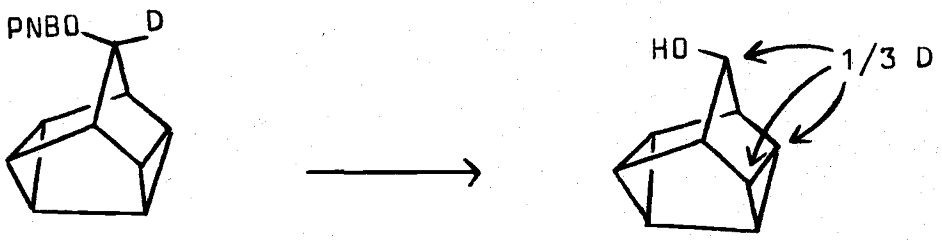


one thousand over even the greatly enhanced rate of formation of the bishomocyclopropenyl cation formed from the 7-norbornenyl derivative. This effect is possibly due to the orientation of the cyclopropyl electrons (directly toward the backside of the developing p orbital) compared with the orientation of the pi electrons of the norbornene double bond.





Solvolysis of the pentacyclic compound 3 proceeds 10^{11} times faster than 7-norbornyl p-nitrobenzoate, and the intermediate formed is 3-fold degenerate (8). Since the product is of the same ring system, ruled out is the possibility that these huge rate enhancements are due to relief of strain in the transition state.



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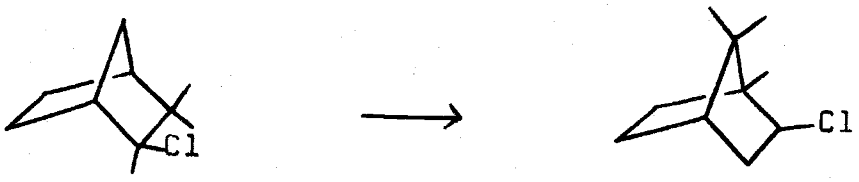
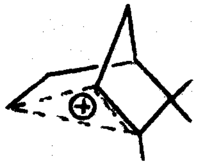
Cyclopropyl sigma bond and pi bond participation have been rather easily accepted, due in large part to the magnitude of the rate enhancements that have been observed. Of much greater controversy have been suggestions of non-cyclopropyl sigma bond participation. The concept of such a sigma bond participation was first proposed in 1939 by Nevell, de Salas and Wilson to explain the rearrangement of camphene hydrochloride to isobornyl chloride (9).

There was no explanation in "classical" organic chemistry

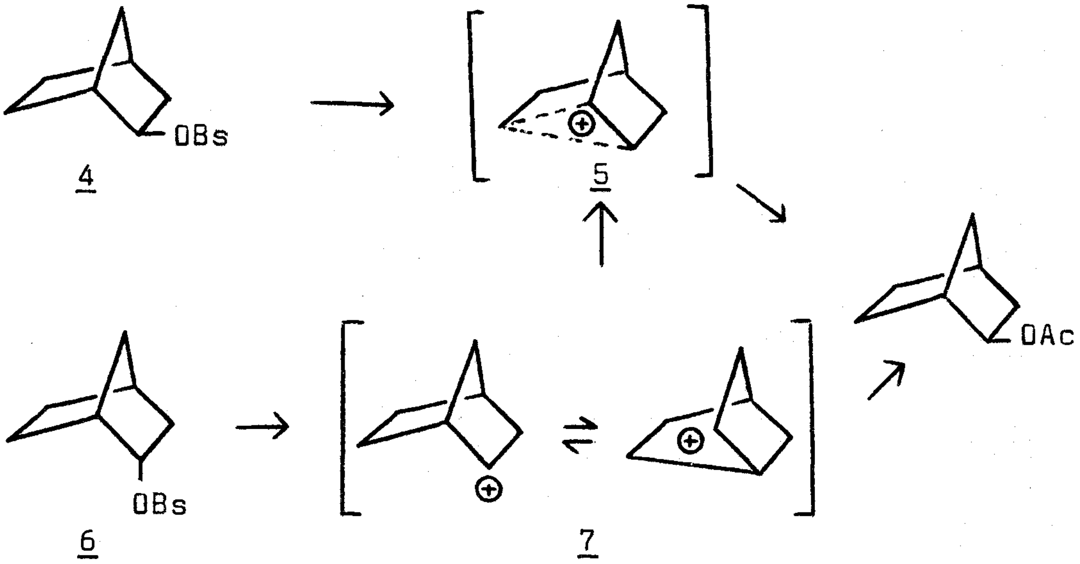


for this rearrangement. Why, upon ionization, should a tertiary carbonium ion rearrange to a secondary carbonium ion? The authors suggested an intermediate in which the C-1-C-6 bond participates, and collapse of the chloride



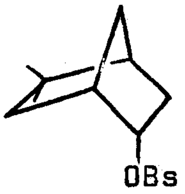
ion at C-1 generates the secondary chloride. The proposed intermediate is thus a homocyclopropenyl cation derivative in which two electrons are delocalized over three orbitals.

Further evidence for formation of a "non-classical" norbornyl ion was presented by Winstein and Trifan (10). Solvolysis of both exo- and endo-norbornylbrosylates 4 and 6 in acetic acid yielded exo-norbornyl acetate. However, 4 solvolyzed 350 times faster than 6 and was 99.9% racemized, whereas 6 was 92% racemized. The authors



attributed these results to formation of delocalized 5 from solvolysis of 4, and a classical carbonium ion from 6. The classical ion formed can then undergo degenerate 1,2 alkyl shifts 7, "leak" to ion 5, or react with solvent. These proposals have been severely criticized by H.C. Brown who contended that the experimental results could be equally well explained by assuming a rapidly equilibrating pair of classical ions 7 for solvolysis of both 4 and 6, and that the rate "enhancement" observed for solvolysis of 4 was actually due to an abnormally slow rate of ionization of 6 due to hindrance caused by the *endo* C-5 and C-6 hydrogens (11).

Solvolysis of *endo* brosylate 8 was found to occur at essentially the same rate as 6 (12). Further indications of a negligible steric deceleration due to groups at C-5 and C-6 were revealed by the solvolyses of 9 and 10.



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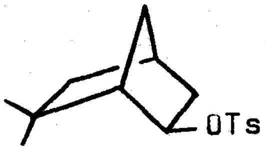

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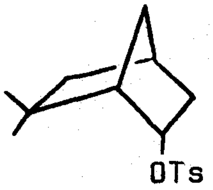

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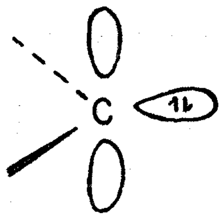
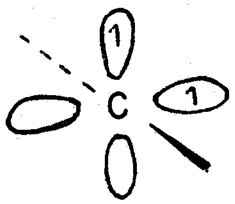
While it was found that 9 solvolyzes 20 times slower than 4, 10 only solvolyzes 16 times slower than 6 (13). Solvolysis of *endo*-norbornyl brosylate 6 would not seem to be abnormally slow due to steric interactions with *endo* hydrogens on C-5 and C-6, although in some cases dramatic decelerations attributable to steric interactions in norbornyl derivatives have been observed (14, 11c).

Clearly, homoaromatic cations are well documented. These delocalized ions are formed by the overlap of a pair of well-positioned electrons of a sigma or pi bond with the empty p orbital of a carbonium ion. An appealing concept which presents itself is the possibility of overlap of electrons from a suitably oriented sigma or pi bond with the empty p orbital of a singlet carbene.

A carbene is a divalent carbon atom which has two non-bonding orbitals inhabited by two electrons. A carbene can thus exist either in a singlet state, in which the electrons occupy the same orbital and are paired, or in a triplet state in which the electron spins are parallel and each orbital contains one electron (15a). A triplet carbene acts often as a diradical, undergoing typical abstraction reactions, while singlet carbenes typically undergo insertion into pi bonds and carbon-hydrogen sigma bonds.

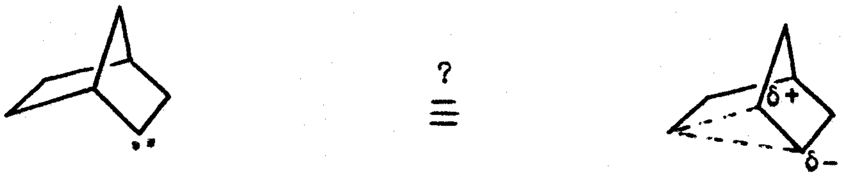


Singlet Carbene

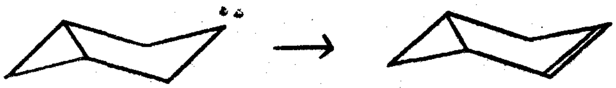


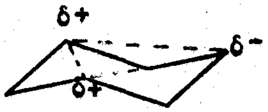
Triplet Carbene

Overlap of the empty p orbital of a singlet carbene with a pair of electrons from a suitably oriented bond would form a homoaromatic system similar to that formed by the corresponding carbonium ion. One logical candidate for a non-classical carbene would be 2-carbenanorbornane. The extensive amount of work on the cationic system points to a delocalized species; however, generation of the carbene leads to 99.5% nortricyclene and 0.5% norbornene (16). There is no evidence to confirm or rule out delocalization of sigma bond density from these results.



An attempt to demonstrate homoaromatic behavior of a carbene is seen in the work of Freeman and Kuper (17). Generation of 3-carbenabicyclo[3.1.0]hexane resulted in exclusive formation of the hydride shift product bicyclo[3.1.0]hex-2-ene. Again, no evidence of any trishomocyclopropenyl interaction of type 11 was revealed.





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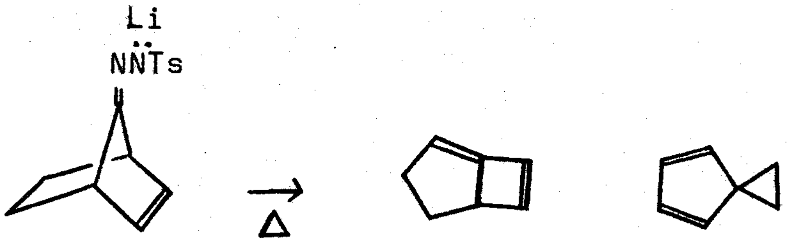
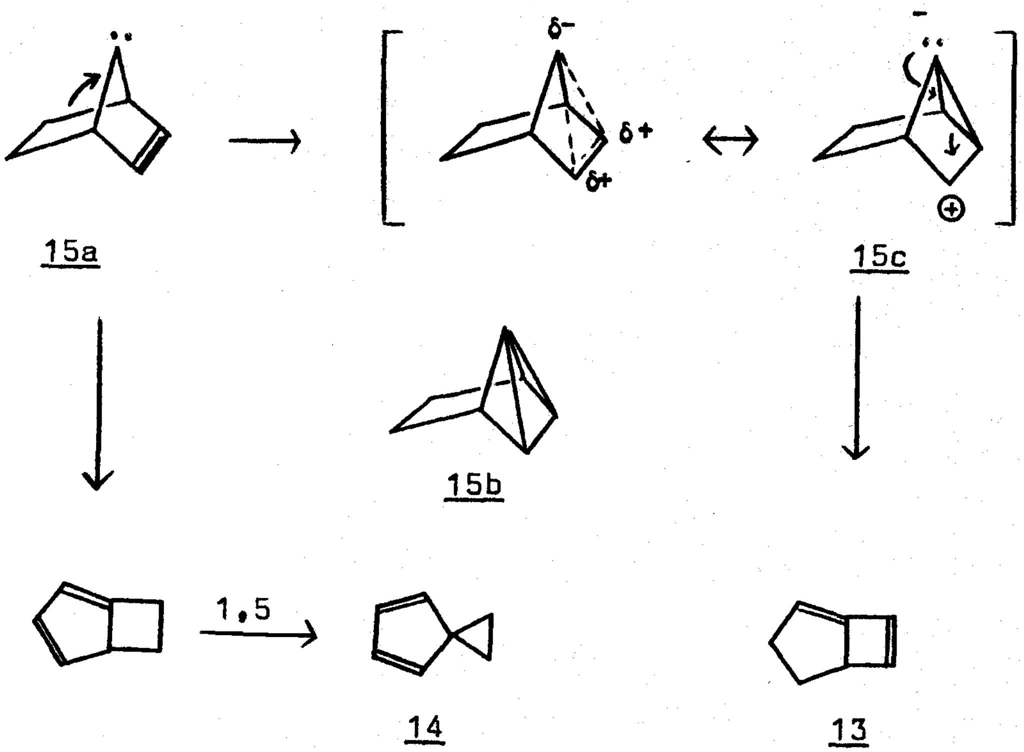
One of the thoughts that comes to mind is that in these two systems the non-classical stabilization of the corresponding carbonium ions, as indicated by their several hundredfold solvolysis rate enhancements, is modest at best. In order to observe non-classical stabilization of a carbene, possibly the systems which should be studied are those which are very effective in promoting carbonium ion stabilization.

Moss and his co-workers have recently reported on the generation of a divalent intermediate which has a large potential for non-classical delocalization. Pyrolysis of the lithium salt of the tosylhydrazone of 7-norbornenone, 12, was found to yield, along with assorted minor products, 13 in 67% yield and 14 in 7% yield (18). The authors suggest the possibility of bishomocyclopropenyl type participation, although the carbene cannot actually insert into

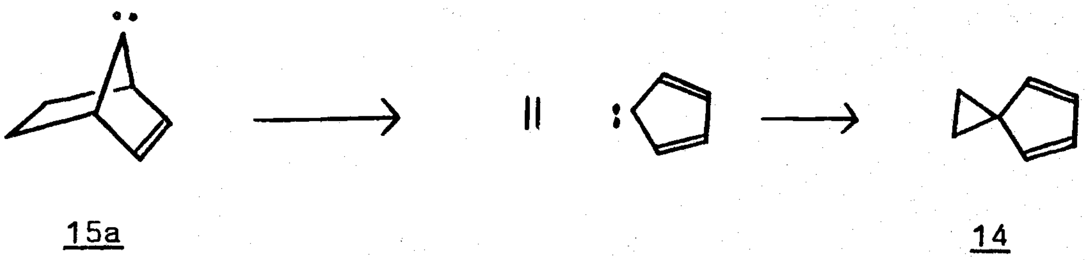


12 13 14

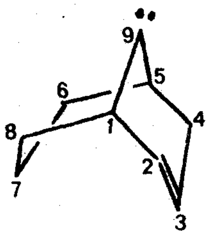
the double bond (a "foiled methylene"), as the tetracyclic compound which would be formed, 15b, would contain a carbon atom with all four bonds in one hemisphere. Formation of 13 could be visualized by bond reorganization of resonance structure 15c, while 14 might arise from thermal rearrangement of the product of a 1,5 alkyl migration of 15a. The authors also suggest the possibility of a retro Diels-



Alder reaction of intermediate 15a followed by carbene insertion to yield 14.



Suggestions of carbene delocalization can be more easily defended if it is obvious *a priori* that one set of products would be expected in the case of participation, while a different set of products would be expected if there were no delocalization. Fisch and Pierce have generated 9-carbenabicyclo[3.3.1]non-2-ene 16 by methoxide ion induced tosylhydrazone decomposition in diglyme (19).



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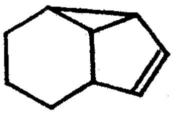
Although the carbene would not be expected to insert into the double bond, the authors feel that they have shown that there is interaction of the carbene with the double bond. Models indicate that the axial C-H bonds at C-4, C-6, and C-8 are all in the proper relationship to the carbene center for insertion. Assuming the allylic C-H bond to be the most reactive (20), 17 would be expected to be the major cyclopropyl olefin product. However, if there is interaction of the carbene with the double bond, it would be expected that the carbene center at C-9 would



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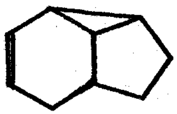

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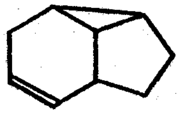

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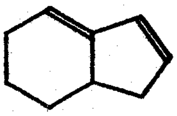
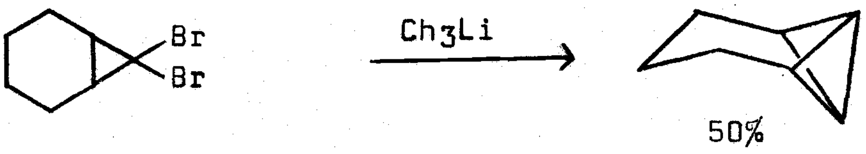


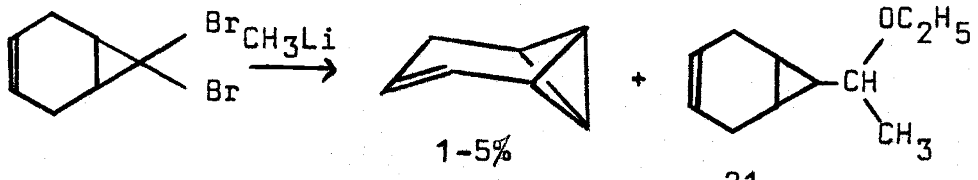
20

move closer to the double bond. Models show that the axial hydrogen at C-4 would then pivot into an equatorial position which would not be as favorable for insertion, thus promoting formation of cyclopropyl olefins 18 and 19. Generation of 16 yields 18 and 19 in an 18% yield each along with a 31% yield of 20. The yield of 17 was shown to be less than 1%.

A delocalized carbene would be expected to be of lower energy and hence more selective than a corresponding carbene with no delocalization. The reaction of 7,7-dibromobicyclo[4.1.0]heptane with methyllithium gives a 50% yield of tricyclo[3.1.1.0^{6,7}]heptane (21). There is no reason to expect any delocalization in this carbene

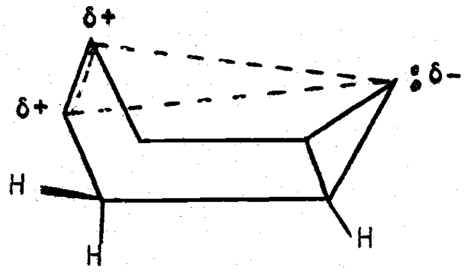


(carbenoid). Recently, Klumpp and Vrielink treated 7,7-dibromobicyclo[4.1.0]hept-3-ene with methyllithium in ether, and found only a 1-5% yield of tricyclo[3.1.1.0^{6,7}]-hept-2-ene (22). The rest of the products were intermolecular reaction products such as dimers, halogen containing compounds, and the major product 21. The authors suggest that interaction of the double bond with the empty p orbital of the carbene in the boat conformation stabi-



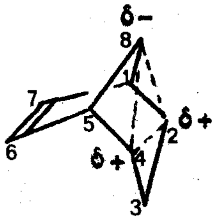
21

lizes the carbene making it more selective and allowing it to react intermolecularly. Also it will be noticed that the C-H bonds at C-2 and C-5 are not in the syn periplanar geometry believed to be favored in the transition state for carbon-hydrogen insertion (21, 23).

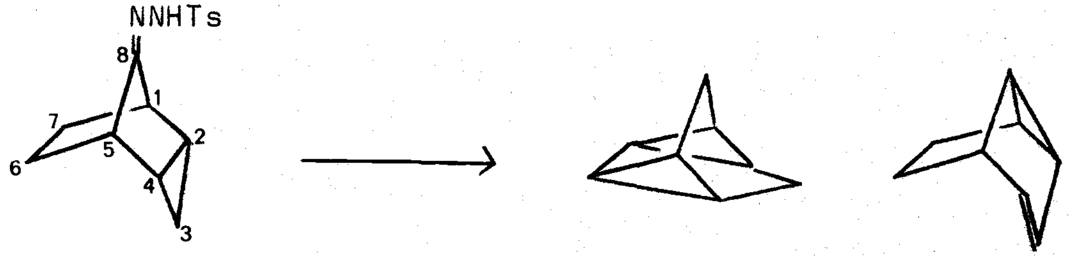


There seems to be some suggestive evidence for participation of the empty p orbital of a carbene with a suitably oriented pi bond. Recalling that the record holder for solvolysis rate enhancement is the endo-tricyclo-[3.2.1.0^{2,4}]octyl system, 8-carbena-endo-tricyclo[3.2.1.0^{2,4}] octane would be an obvious candidate for trishomocyclopropenyl type stabilization.

Extended Huckel calculations by Hoffman and Gleiter predict that in some favorable cases such as 7-carbenanorbornene, 12, there is a probability of a singlet delocalized carbene (24). It was also predicted that the interaction of a suitably oriented cyclopropane ring with the carbene would result in a deeper potential energy minimum, hence, greater stabilization. Thus the C-8 carbon would be expected to lean closer to the cyclopropyl "bent" bond rather than interact with the pi bond, since cyclopropyl interaction is predicted to be stronger.



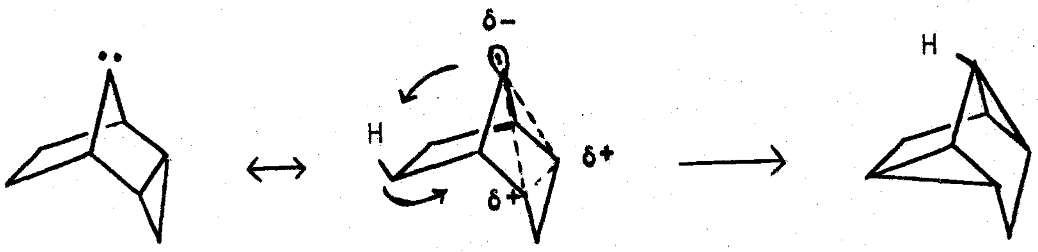
8-Carbena-endo-tricyclo[3.2.1.$0^{2,4}$]octane has now been studied by Freeman and Raghavan (25). Decomposition of the tosylhydrazone of endo-tricyclo[3.2.1.$0^{2,4}$]octan-8-one in diglyme in the presence of excess sodium methoxide at 150° yields two hydrocarbon products 22 and 23,



22

23

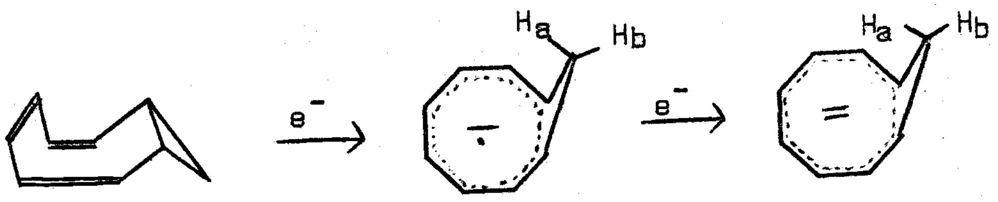
which were shown to be derived from the carbene in yields of 33% and 4% respectively. It was suggested that <u>22</u> could result from a concerted intramolecular pathway involving breakage of the C_2-C_4 bond, C_2-C_8 bond formation, hydrogen migration from C_6 to C_8 and bond formation between C_6 and C_4. This could be described as a $\sigma^2a\,\omega^0a\,\omega^2a$ process which is symmetry allowed thermally by the Woodward-Hoffman rules for pericyclic reactions (26a). Generation of the carbene from tosylhydrazone in which the hydrogen on nitrogen had been replaced by deuterium (>97% N-D) yielded <u>22</u> which had 23% deuterium incorporation, indicating that an intramolecular reaction pathway makes a large contribution to formation of <u>22</u>.



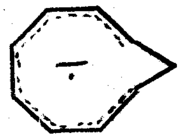
<u>22</u>

Another area of homoaromaticity which concerns work described in this thesis is that of homoaromatic anions. Before discussing the bishomocyclopentadienide anion <u>35</u>, which is the parent compound for work described here, it would be instructive to review some of the pertinent work done on some other homoaromatic anionic systems.

In 1966 two groups of workers presented evidence of formation of a homoaromatic nine electron system: the monohomocyclooctatetraene anion radical. Reaction of 24 with potassium metal in diglyme at -80° (27a) or electrolysis of 24 in liquid ammonia (27b) yielded a radical anion



24 25 26



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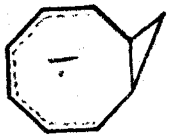

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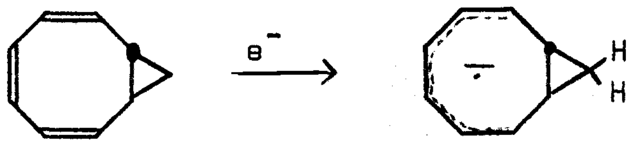
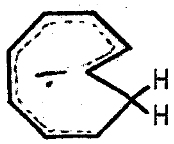
whose esr spectra was consistent with 25 but not 27 or 28. In tetrahydrofuran at -80° 25 is further reduced by potassium metal to dianion 26. Nmr of the stable dianion showed H_a shielded (δ 0.0) and H_b deshielded (δ 2.0) by the ring current compared with the parent hydrocarbon (28).

In contrast to the reduction of 24, reaction of the *trans* fused monomethylene adduct of cyclooctatetraene, 29, with potassium at -90° yielded a radical anion whose esr spectrum was consistant with that expected for 30 (29).



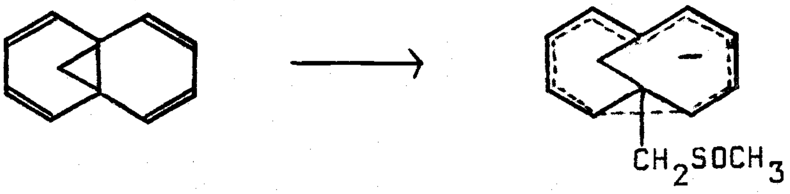
29 30



31

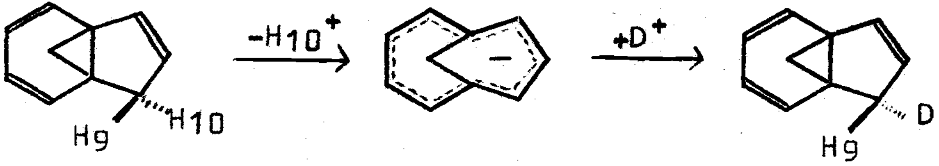
The reaction of 24 to yield 25 and the reaction of 29 to yield 30 can be understood in terms of orbital symmetry rules for electrocyclic reactions (26b, 29). The conversion of a bicyclic hexatriene anion radical 28 into a cyclononatetraene anion radical 27 is predicted to be disrotatory. The opening of the anion radical from 24 leads to the all *cis* cyclononatetraene with favorable geometry for a planar delocalized electron system. *trans*-29 already has the hexatriene system in a nearly planar arrangement which is favorable for conjugation (ie, 30). Disrotatory opening of anion radical 30 would lead to the very unfavorable *trans*-*cis*-*cis*-*cis* radical anion 31.

W. A. Böll has generated anion 32 by the reaction with potassium *tert*-butoxide in dimethysulfoxide of 9,10-methanonaphthalene (30). Evidence for formation of 32 comes mainly from the value of approximately δ 0.2 for the methylene protons in the nmr of the stable anion.



32

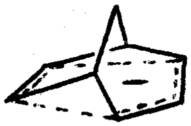
Radlick and Rosen have shown that treatment of 33 with dimsyl sodium generates the 10-electron anion 34 (31a). Remarkably, they found that both the abstraction and reprotonation occurred *anti* to the methylene bridge. It was found that the acidity of H_{10} was 10^4 that of H_9



33 34

(31b). The authors show that this cannot be due to steric requirements and suggest that H_{10} is more readily abstracted by base because the electron pair in the orbital between C_9 and H_{10} can overlap more effectively in the transition state with the electron pair in the zero carbon bridge. They also suggest that in anion 34 the orbitals of C_1 and C_6 are not of the p-pi type but are directed such that the face of the molecule opposite the methylene bridge has a higher electron density, rendering this face to be the preferable one for attack of proton or deuteron.

Probably the most well known and highly studied homoaromatic anion is the bishomocyclopentadienide anion 35. J.M. Brown first proposed intermediate 35 to account for



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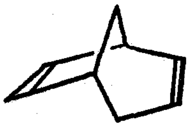

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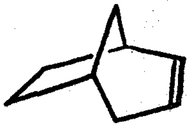
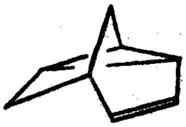


37

the fact that 36 undergoes allylic hydrogen-deuterium exchange with potassium tert-butoxide in d_6-dimethylsulfoxide $10^{4.5}$ times more rapidly than does monoene 37 (32). Reprotonation of 35 takes place only at the C-4 position and neither 38 or 22 were formed (1, 32). An actual equilibration of 36, 38 and 22 was found in the solvent system



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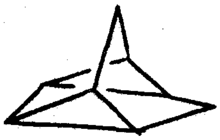

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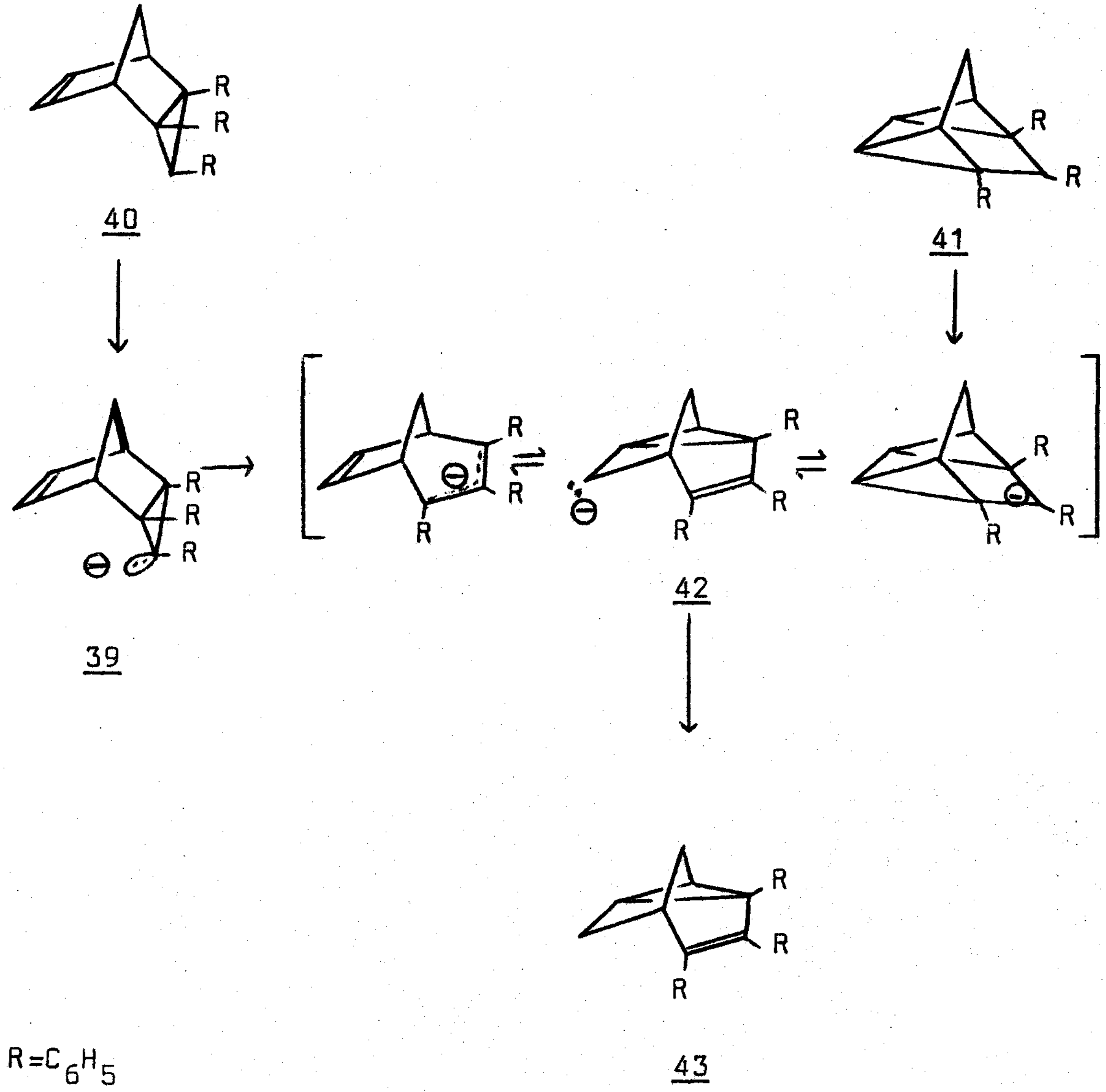
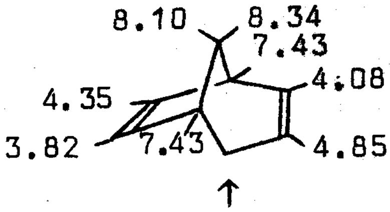
cesium cyclohexylamide in cyclohexylamine, which gives greater equilibration and exchange rates than potassium tert-butoxide in dimethylsulfoxide (1). The relative reactivities of the hydrocarbons to exchange was found to be

36>38≫22, while the thermodynamic stabilities of the hydrocarbons were found to be 38>36>22.

In a similar vein, treatment of 40 or 41 with a solution of lithium in ethylenediamine yields 43. The author suggests interconversion of anions 42 followed by reprotonation yields 43 (33).



The homoaromatic anion 35 is sufficiently stable to permit preparation of the potassium salt and observation of its nmr spectrum (34). Perhaps the most indicative feature of the nmr of the anion is the rather large upfield shift of both the C-8 methylene protons compared



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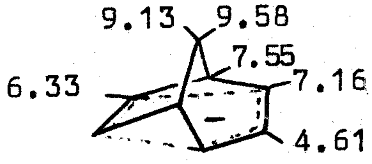

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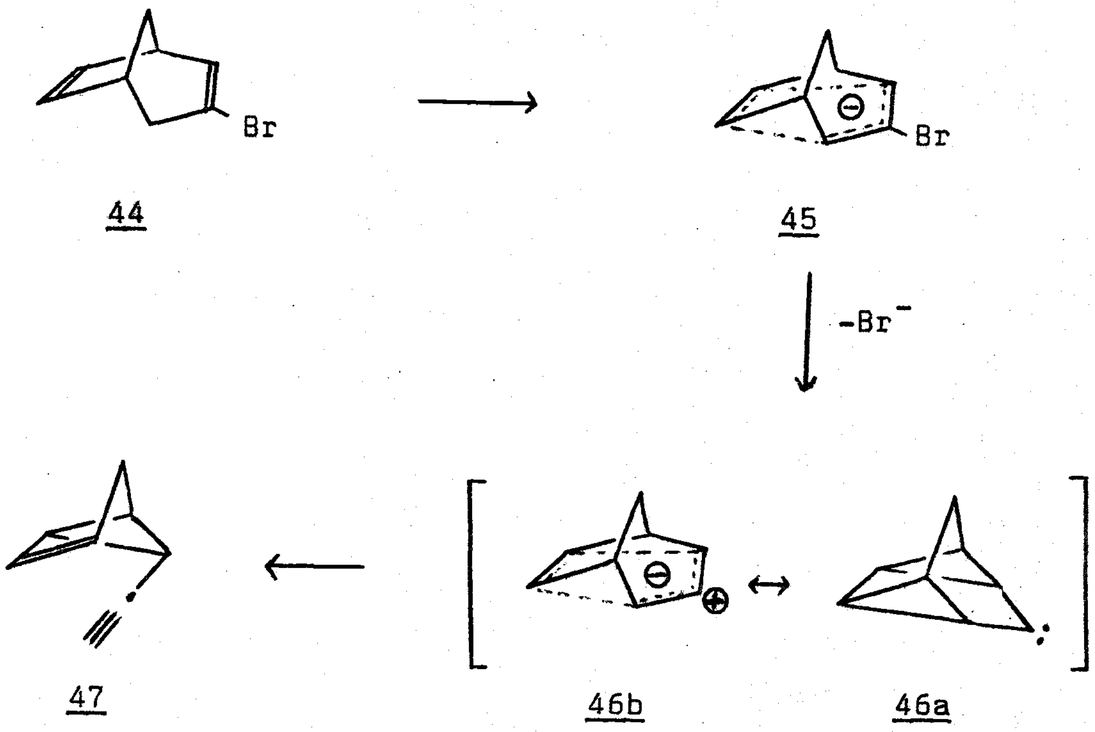
with the diene, due to the shielding effect of the ring current. It was originally thought that reprotonation at C-4 occurred with equal facility from either the exo or endo side of the system (32b, 34b); however, Brown has recently shown using 220 MHz nmr that quenching of anion 35 with dimethylsulfoxide-d_6 results in predominate 4-exo-deuterium incorporation, while reprotonation by methanol-O-d leads to endo deuterium incorporation (35). Brown suggests that hydrogen bonding by the methanol with the electron density on the endo side of the ring is followed by collapse to give endo-4-deuteriated 36. Reprotonation by dimethylsulfoxide would not be expected to be influenced by hydrogen bonding, and torsional effects are suggested as the cause for predominate _exo_-reprotonation. Stereoelectronic effects as suggested by Radlick and Rosen (31) are considered by Brown to be insignificant.

A fascinating mechanism has been proposed by Bergman for the reaction of _44_ with potassium _tert_-butoxide in dimethylsulfoxide (36). Loss of a proton would yield bishomocyclopentadienide anion _45_, which upon loss of bromide ion would yield "homoconjugated carbene" _46_. Typical cyclopropyl carbene ring opening (37) would then yield the observed product, _47_.

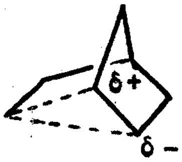


PART I

STEREOSPECIFICITY OF 3,2-HYDRIDE MIGRATION BY 2-CARBENA-6,6-DIMETHYLNORBORNANE

RESULTS AND DISCUSSION

As discussed in the introduction, there is a large body of evidence suggesting that formation of the 2-norbornyl carbonium ion is assisted by participation of the C-1-C-6 bond. A consideration of this chemistry suggests that characterization of 2-carbenanorbornane might be of considerable interest, since, in the singlet state, delocalization analogous to that found in the carbonium ion would be possible. Overlap of the empty p orbital at C-2 with the C-1-C-6 bond would lead to a non-classical carbene.



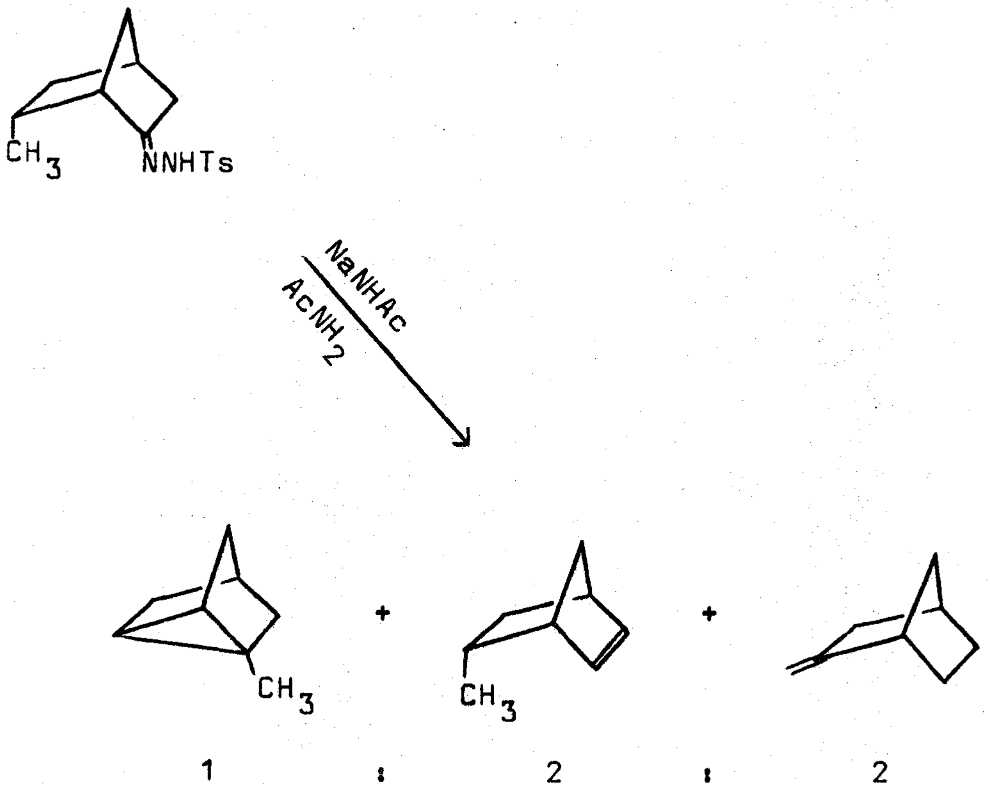
Since most alicyclic carbene intermediates react by way of intramolecular rather than intermolecular pathways (38a), characterization of 2-carbenanorbornane would appear to require the analysis of an insertion or hydride migration reaction.

Generation of 2-carbenanorbornane by base induced thermal tosylhydrazone decomposition leads predominantly to the C-6 carbon-hydrogen insertion product, nortricyclene (99.5%), with the C-3-C-2 hydrogen migration product, norbornene, present only in trace amounts (0.5%) (16a). This intramolecular pathway gives no clue as to whether there is delocalization of the C-1-C-6 bond.

One of the methods used to characterize the 2-norbornyl cation has been to study the stereospecificity of 3,2-hydride shifts (39, 40). It appeared that a study of the stereochemistry of the 3,2-hydride shift would help to characterize the bivalent intermediate with the carbene carbon at the 2-position of the norbornane skeleton.

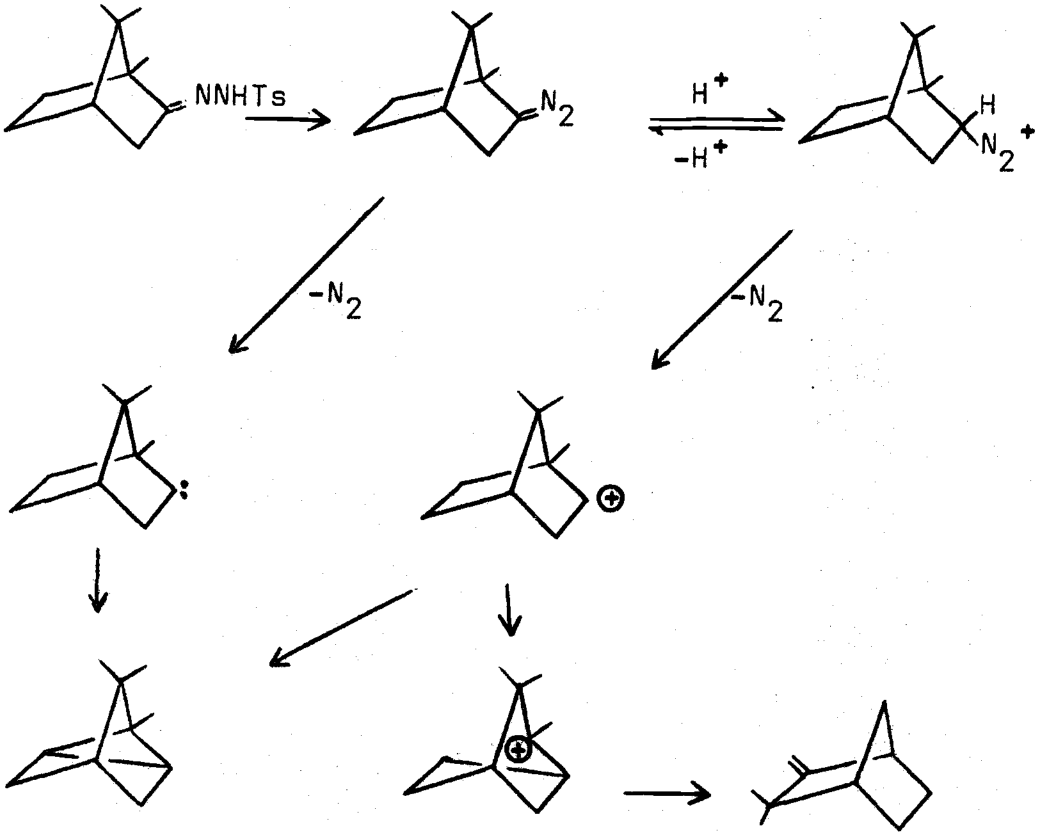
Because the major reaction pathway of 2-carbenanorbornane is insertion into the C-6 carbon-hydrogen bond to form nortricyclene, in order to study hydride migration it became necessary to block the C-6 position to encourage the carbene to undergo 3,2-hydride migration.

A 2-carbenanorbornane with the C-6 position blocked has been generated by Krieger and co-workers (41). As shown below, decomposition of <u>endo</u>-6-methylnorbornan-2-one tosylhydrazone in acetamide yields a mixture of hydrocarbons.



It would be appropriate at this point to digress and discuss the generation of the carbene. The method of choice was that of the Bamford-Stevens reaction which involves base catalyzed thermal decomposition of a p-toluenesulfonylhydrazone with loss of p-toluenesulfinate to give an intermediate diazo compound (42). Rapid loss of nitrogen yields a divalent carbon intermediate. Coordination with a Bronsted or Lewis acid would accordingly produce a diazonium or carbonium ion or both. Camphor tosylhydrazone has been used as a tool for distinguishing between carbenic and cationic solvent-base systems (43).

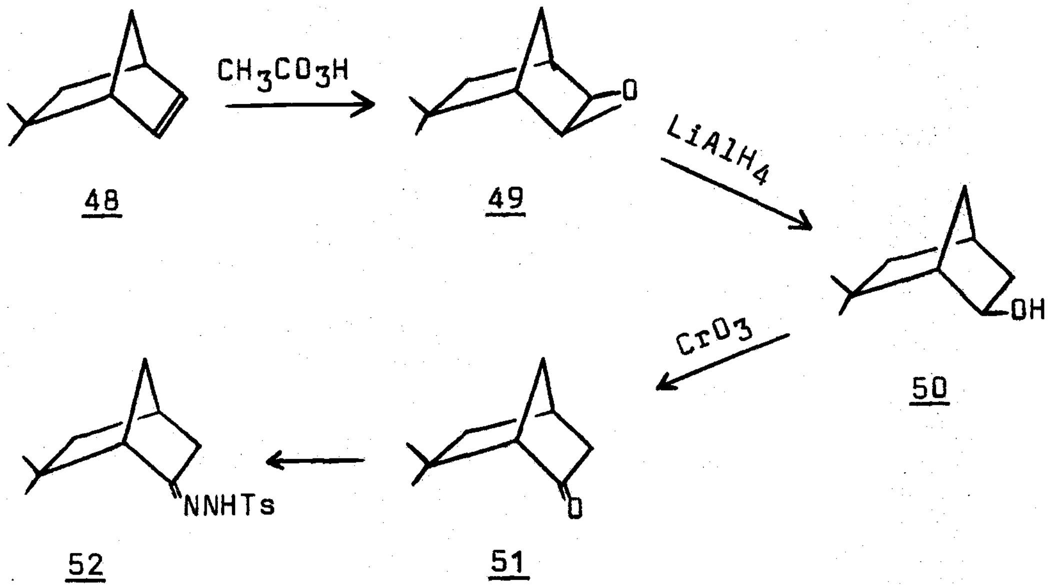
Scheme 1



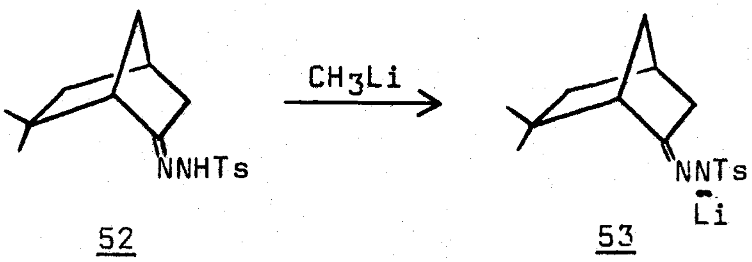
An excess of base and an aprotic solvent favor formation of tricyclene, a carbene product, while protic or polar solvents yield a mixture of camphene and tricyclene indicating cationic intermediates. Most diazoalkanes, however, are more sensitive toward protonation than diazocamphene (15b). For example, camphor tosylhydrazone decomposed in acetamide yields 97-99% tricyclene (44), while pinacolone tosylhydrazone gives about 50% carbonium ion rearrangement (45). Kirmse suggests that reactions run in acetamide and considered to be carbenoid should be regarded with some suspicion (15b).

The products formed in the acetamide decomposition of endo-6-methyl-2-norbornanone tosylhydrazone could be explained by a carbonium ion mechanism as well as by the carbenic mechanism proposed by the authors. The work cited above (15b, 45), along with the fact that C-C bond insertion is a rarely observed process (46), suggests that there is a fair degree of cationic character in the acetamide decomposition.

In order to observe a 3,2-hydride shift, 6,6-dimethylnorbornan-2-one tosylhydrazone was prepared and decomposed under rigorously aprotic conditions which would insure carbene formation. The synthesis of 6,6-dimethylnorbornan-2-one was carried out following the general procedure of M.M. Donaldson (13b). 5,5-Dimethylnorbornene, 48, was treated with 40% peracetic acid yielding 6,6-dimethyl-exo-2,3-epoxynorbornene in 75% yield. The epoxide was then heated at reflux with lithium aluminum hydride in 4-methylmorpholine for 12 hours yielding alcohol 50. Chromic acid oxidation of the crude alcohol gave 6,6-dimethylnorbornan-2-one in 51% overall yield from 49.



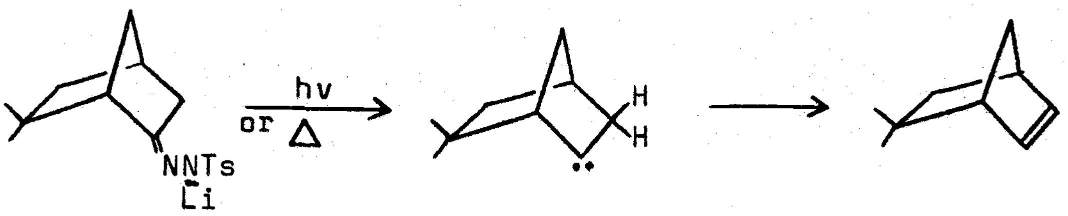
Tosylhydrazone 52 was produced in 51% yield by heating ketone 51 with *p*-toluenesulfonylhydrazine. The lithium salt 53 was formed by the addition of one equivalent of methyllithium followed by removal of the solvent. The dry lithium salt was then heated at 160-180° (0.1 torr) and the volatile hydrocarbon product was collected at -78°. Vpc,



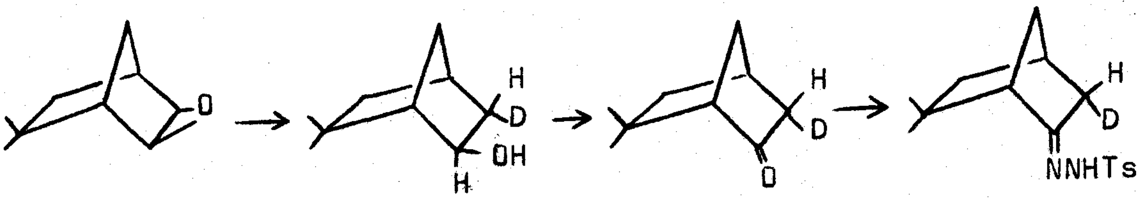
ir and nmr analysis demonstrated that the expected 5,5-dimethylnorbornene was produced in 75% yield.

In order to further our understanding of the carbene generated by this process, the lithium salt 53 was also decomposed by photolysis (47). Tosylhydrazone 52 was dissolved in tetrahydrofuran which had been freshly distilled from lithium aluminum hydride and exactly one equivalent of methyllithium was added. It was found that the reaction of excess methyllithium with the tosylhydrazone lithium salt (48) forming the lithiate of 5,5-dimethylnorbornene was quite facile in tetrahydrofuran, so before irradiation an aliquot was withdrawn, quenched and subjected to vpc analysis. There was no alkene formed by elimination. The soluble lithium salt was then irradiated through quartz with a 450 watt Hanovia high pressure mercury lamp until nitrogen evolution ceased. After workup, vpc analysis indicated a 50% yield of 5,5-dimethylnorbornene along with a small amount of toluene from decomposition of p-toluenesulfinate (47).

Thus carbene generation yielded, as the sole hydrocarbon product, the 3,2-hydride shift product, 5,5-dimethylnorbornene.

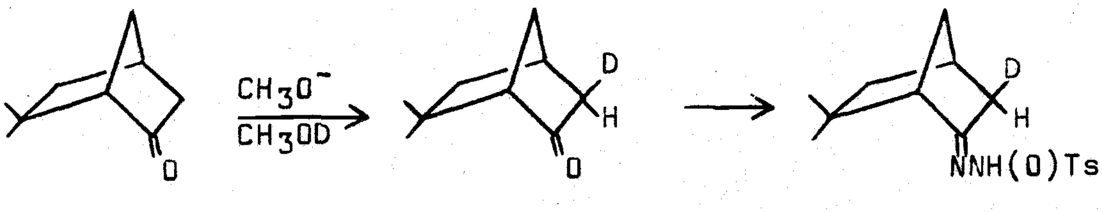


In order to study the stereochemistry of the 3,2-hydride migration it was necessary to synthesize tosylhydrazones which had been stereospecifically deuteriated *exo* and *endo* at the C-3 position. Treatment of epoxide 49 with lithium aluminum deuteride (99.5% d) produced *endo*-3-deuteriated alcohol 50n. Chromic acid oxidation to 51n followed by treatment with *p*-toluenesulfonylhydrazine yielded 52n.



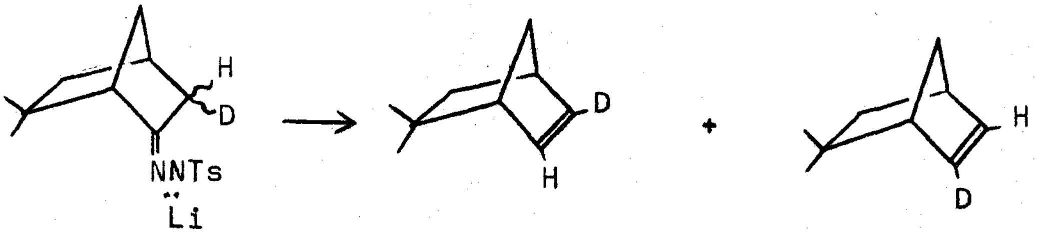
49 50n 51n 52n

exo-3-Deuteriated ketone 51x was produced by stirring 51 in methanol-O-d (99% d_1) with a catalytic amount of sodium methoxide, and 52x was generated by allowing 51x to react with tosylhydrazine in methanol-O-d.



51 51x 52x

Tosylhydrazones 52n and 52x were treated with methyllithium to generate lithium salts 53n and 53x. The lithium salts were decomposed both thermally and photolytically as described above to yield deuteriated 5,5-dimethylnorbornene.



48a

48b

In order to determine the stereospecificity of 3,2-hydride (deuteride) migration, it was necessary to be able to differentiate the two olefinic positions. Unfortunately, the nmr spectrum of 5,5-dimethylnorbornene in CCl_4 reveals a single absorption at δ 6.04 for the olefinic protons; however, the nmr spectrum of epoxide 49 reveals that the C-2 and C-3 protons are easily distinguished at δ 2.96 and 3.10, respectively.

After photolytic and thermal decompositions of lithium salts 53x and 53n, the resultant deuteriated alkene was subjected to mass spectral analysis. A portion of the deuteriated alkene was treated with peracetic acid and the resulting epoxide was subjected to nmr analysis at 100 MHz. Integration of the area in the nmr spectrum of the two protons at C-2 and C-3, together with mass spectral analysis, allowed calculation of the amount of *exo* and *endo* hydride (deuteride) migration.

Table I gives the results of the thermal and photolytic decompositions of 53x and 53n. From this data the amount of 48a and 48b can be calculated after correcting for the amount of undeuteriated and dideuteriated 48 (49).

Table I. Results of Decompositions of Tosylhydrazone Salts 53x and 53n

Run	Salt	Batch	Type	Mass Spectra of 48			Nmr Integration of 49	
				d_0	d_1	d_2	C-2	C-3
1	53x	A	Pyr.[a]	17.9±0.9[c]	78.3±2.1	3.8±1.5	0.938±0.097	0.222±0.090
2	53x	B	Pyr.	9.4±0.3	82.2±1.1	8.4±0.7	0.844±0.028	0.149±0.060
3	53n	C	Pyr	3.4±0.4	96.6±0.4	0.0	0.097±0.011	0.937±0.077
4	53x	D	Phot[b]	43.4±0.5	56.6±0.5	<0.5	0.979±0.071	0.456±0.046
5	53n	E	Phot.	5.2±0.2	94.8±0.2	0.0	0.104±0.030	0.947±0.039

a) Dry salt pyrolysis; b) Photolysis in THF; c) One standard deviation

Table II gives the results of these calculations, which indicate that the *exo:endo* selectivity favors exo-hydrogen (deuterium) migration by a factor of about 20:1.

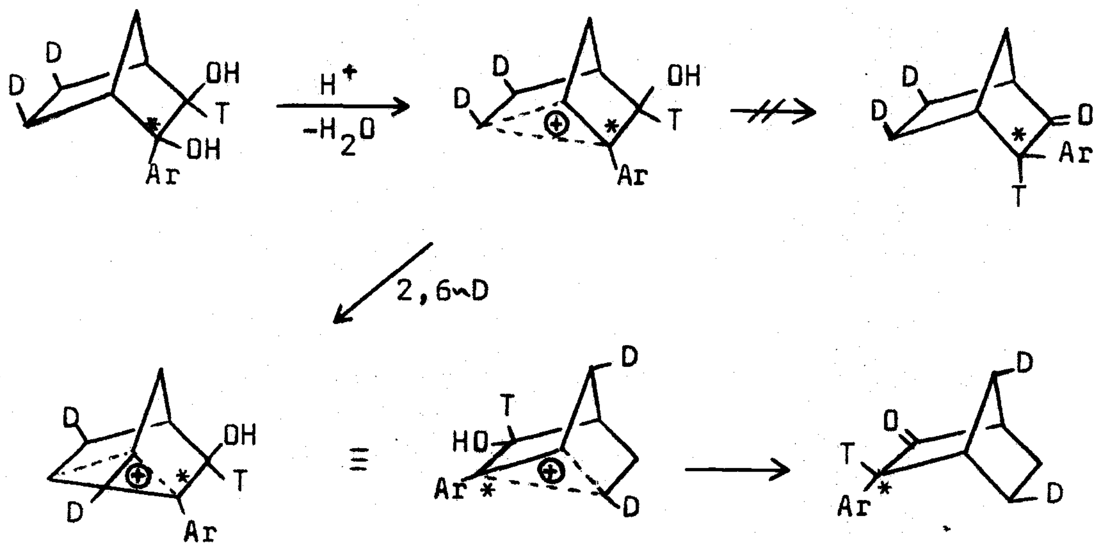
Table II. Decomposition of Tosylhydrazone Salts <u>53x</u> and <u>53n</u>

Tosylhydrazone	Type	<u>48a</u>	<u>48b</u>
<u>53x</u>	Dry Salt[a]	5.9±1.2	94.1±2.0
<u>53n</u>	Dry Salt	93.6±1.6	6.4±1.2
<u>53x</u>	Photolysis	3.9±1.4	96.1±2.7
<u>53n</u>	Photolysis	94.5±1.3	5.5±0.4

a) Average of two runs

How does this compare with the results in the norbornyl cationic system? Collins and co-workers have studied the acid catalyzed pinacol rearrangement of 2-arylnorbornan-<u>exo</u>-<u>cis</u>-2,3-diols to <u>endo</u>-3-aryl-2-norbornanones by using optically active compounds, carbon-14, tritium and deuterium labeling,and their results are summarized in Scheme 2 (39). Thus it can be seen that rather than undergo <u>endo</u>-<u>endo</u> migration by tritium (hydrogen), the molecule undergoes two Wagner-Meerwein shifts and a 6-2 hydride shift before the tritium is able to undergo an <u>exo</u>-<u>exo</u> migration. No <u>endo</u>-<u>endo</u> migration by tritium is observed.

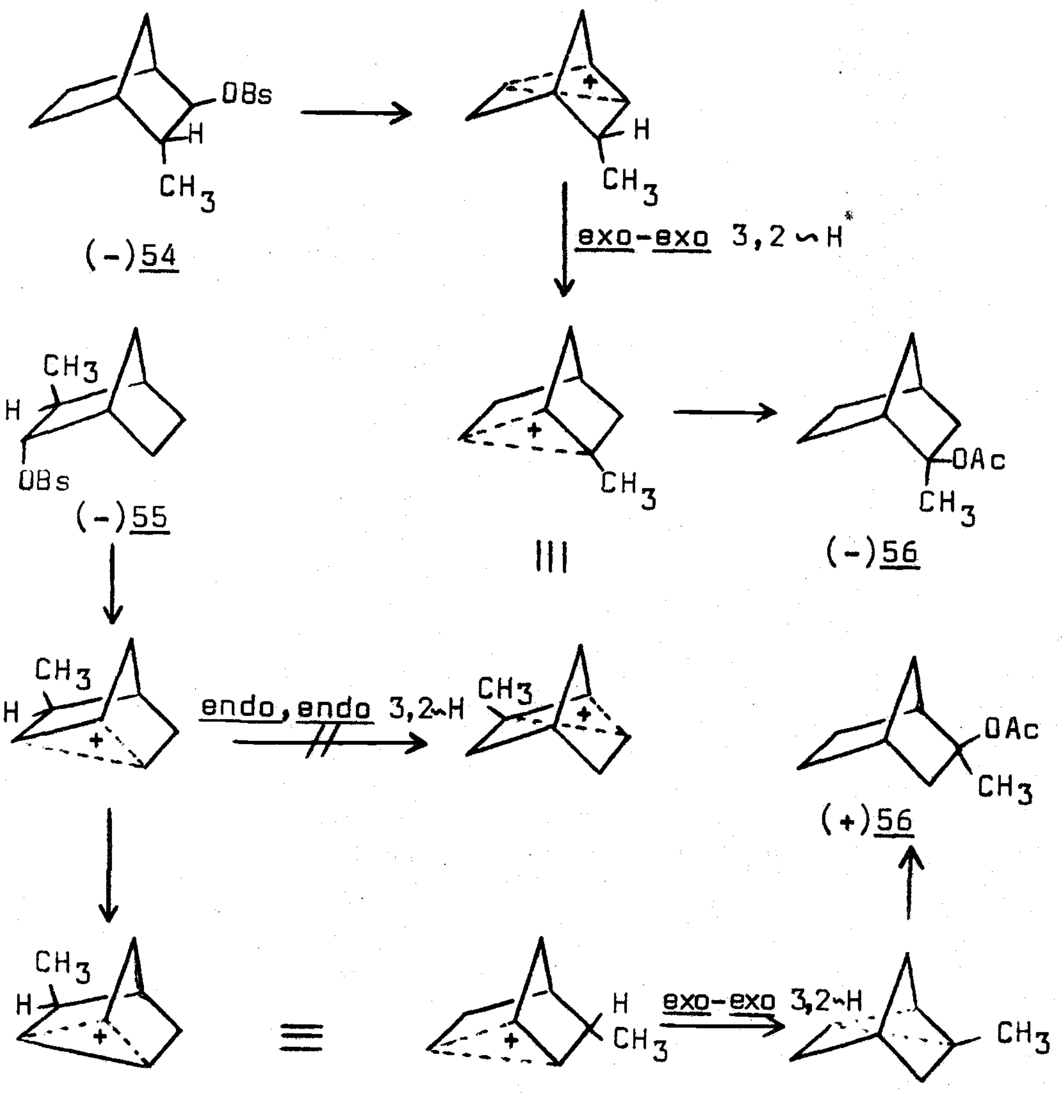
Scheme 2



Similar results were found by Berson and his co-workers in studies of the acetolysis of optically active endo-3-methyl-exo-2-norbornylbrosylate, 54, and exo-3-methyl-endo-2-norbornylbrosylate, 55 (40). Each yielded a complex mixture of products including a small amount of the hydride shift product endo-2-methyl-exo-2-norbornyl acetate, 56.

Scheme 3 outlines the conclusions reached based on the reactions of optically active (-)54 and (-)55. Solvolysis of (-)54 produced (-)56 via an exo-exo-3,2-hydride shift. Solvolysis of (-)55 could have generated (-)56 by a simple endo-endo-3,2-hydride shift; however, the carbonium ion

Scheme 3



instead underwent a Wagner-Meerwein and a 6,2-hydride shift, followed by another Wagner-Meerwein shift, and then an <u>exo</u>-<u>exo</u>-3,2-hydride shift to produce (+)<u>56</u>. It was calculated that an <u>exo</u>-<u>exo</u>-3,2-hydride shift is favored by at least a factor of 100 over an endo-endo-3,2-hydride shift.

While a selectivity of greater than 100:1 is found for hydride migration in the 2-norbornyl cation, our work shows a 20:1 preference for exo-hydride shift in 2-carbena-6,6-dimethylnorbornane. This must now be considered in light of the several proposals that have been made explaining the 100:1 selectivity found in the carbonium ion.

One explanation is based on the assumption of a non-classical ion (39, 40). A non-classical ion would be expected to undergo exo-hydrogen migration since attack on a bridged intermediate either by an external or internal nucleophile must necessarily come from the backside, by analogy with S_n2 reactions in other systems.

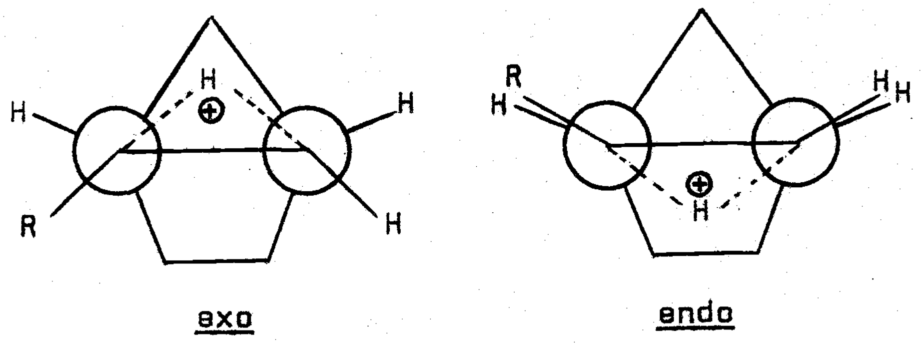
In order to discuss the possibility of a delocalized carbene, it is necessary to know whether we are dealing with a singlet or triplet species. Since irradiation and photolysis of tosylhydrazone salts 53x and 53n yield essentially the same hydride migration results, it would seem logical that carbenes formed by both methods have the same electronic state. Indications that the carbenes studied are in the singlet state come from the fact that when 53 is photolyzed in the presence of benzophenone, a triplet sensitizer, the yield of 5,5-dimethylnorbornene drops to less than 5%, although an equivalent of nitrogen is evolved as usual (albeit at a slower rate) during the photolysis. Carbene formation from the photolysis of tosylhydrazone salts yields the same products as does the direct photolysis of diazoalkanes (38b). A transient coloration was observed in the photolysis of <u>53</u> and of the sodium salt of camphor tosylhydrazone, supporting the intermediacy of a diazoalkane (47). Direct irradiation of diazoalkanes in the liquid phase proceeds via a singlet carbene while sensitized irradiation yields products suggestive of triplet carbene formation (50).

Thus assuming a singlet carbene, the formation of a significant (about 5%) amount of <u>endo</u>-hydride migration product argues against delocalization of the C-1-C-6 bond into the empty p orbital, as this would require a front side displacement at C-2 in the hydride migration transition state.

Another proposal explaining the 100:1 selectivity for the C-3-C-2 hydride migration observed in the 2-norbornyl cation has been proposed by H.C. Brown, who suggests that <u>exo</u>-hydride migration is favored because <u>endo</u>-hydride migration is sterically hindered by interactions between the migrating hydrogen and the <u>endo</u> hydrogens on C-5 and C-6 (11d).

A third proposal has been presented by Schleyer. Using models of the presumed 3,2-hydride shift transition state of the 2-norbornyl cation (approximated by <u>exo</u> and <u>endo</u> isomers of tricyclo[3.2.1.0^{2,4}]octane) Schleyer has pointed out that in the exo-conformation the arrangements around bonds C-1-C-2 and C-3-C-4 are nearly ideally skewed, while in the *endo* conformation the arrangements around the same bonds are almost exactly eclipsed (51). Assumption of the usual 3 kcal/mole barrier to C-C rotation leads to the realization that the transition state for *endo*-*endo* migration could be up to 6 kcal/mole less stable than the transition state for *exo*-*exo* migration! This alone would more than account for the 100:1 selectivity found for the norbornyl cation.

Hydride Migration Transition State



The torsional interactions in the transition state of hydride migration of a 2-carbenanorbornane would be expected to be considerably less than 6 kcal/mole, since the isotope effect (k_H/k_D=0.96±0.18 for thermolysis and k_H/k_D= 0.84±0.18 for photolysis) (52), for this reaction, along with the small isotope effects found for other diazoalkane decompositions (k_H/k_D for β C-H insertion ranges from 1.1 to 1.4) (53), suggest that hydrogen bridging is not well developed in the transition state (54).

Although endo migration in the cationic transition state (R=H) has two ethane like eclipsing interactions, an endo hydride migration in the carbene transition state (R=electron pair) contains only one ethane like eclipsing, with the other being more like a methylamine eclipsing (one non-bonding electron pair eclipsed with a C-H). Although the eclipsing of a non-bonding electron pair with a C-H moiety would be expected to be associated with an energy maximum, it does not seem that it can be predicted with certainty whether this electronic repulsion would be greater than, or less than, the corresponding repulsion associated with the interactions between a pair of carbon-hydrogen units (55). Thus it seems that differences in torsional interactions in the transition state for exo and endo hydride migration, rather than sigma-bond delocalization, are responsible for the stereoselectivity observed for 2 carbena-6,6-dimethylnorbornane.

In order to provide additional characterization of this 2-carbenanorbornane, tosylhydrazone 52 was decomposed in diglyme at 160° with several different bases. Table III summarizes the data realized from the thermal decompositions of 52n and 52x in diglyme with several different bases, as described below.

Table III. Results of Decompositions of 52n and 52x with Several Bases

Run	Thz[a]	Batch	Base	Mass Spectra of 48			Nmr Integration of 49	
				d_0	d_1	d_2	C-2	C-3
6	52n	C	$NaOCH_3$ (12.0 eq)	3.4±0.5[b]	96.6±1.3	0.0	0.064±0.005	0.970±0.019
7	52n	C	Ag_2CO_3 (11.0 eq)	3.4±0.5	96.5±1.3	0.0	0.086±0.004	0.945±0.013
8	52n	C	$Al(OiPr)_3$ (15.9 eq)	11.5±0.8	89.4±1.5	0.0	0.116±0.015	1.008±0.010
9	52x	B	$Al(OiPr)_3$ (15.9 eq)	39.4±0.5	58.4±1.6	5.8±0.4	0.788±0.023	0.548±0.019

a) Tosylhydrazone; b) One standard deviation

Table IV indicates the amounts of 48, 48a and 48b formed from decomposition of 52n with various bases after correcting for the amount of undeuteriated tosylhydrazone as determined from the amount of undeuteriated 48 from runs 2 and 3.

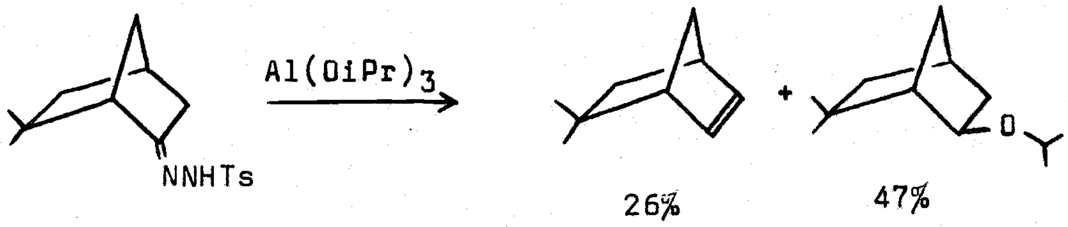
Table IV. Distribution of Deuterium in 48 from 52n

Base	48a	48b	48
$NaOCH_3$	96.8±1.1	3.2±0.7	-
Ag_2CO_3	94.6±1.4	5.4±0.7	-
$Al(OiPr)_3$	91.7±1.5	-	8.3±1.1

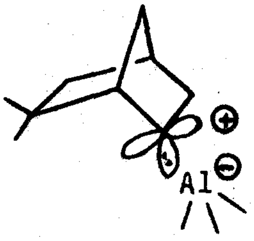
Reaction of tosylhydrazone 52 with twelve equivalents of sodium methoxide yielded 5,5-dimethylnorbornene in 70% yield. Decomposition of endo deuteriated tosylhydrazone 52n, using the same reaction conditions, yielded 5,5-dimethylnorbornene, with the ratio of exo:endo hydride shift calculated to be 96.8:3.2 (Table IV). This is similar to that found for the lithium salt (53x and 53n) decompositions and indicates that the same carbenic intermediate is probably involved.

Tosylhydrazone 52 was treated with eleven equivalents of silver carbonate in diglyme. Even with this large excess of base and a reaction time of eleven hours, unreacted tosylhydrazone was recovered, and along with a 5% yield of toluene, 5,5-dimethylnorbornene was produced in only 27% yield (56). Reaction of endo-deuteriated 52n, using the same reaction conditions, yielded 5,5-dimethylnorbornene with a calculated ratio of exo to endo insertion of 94.6 to 5.4 (Table IV). Thus, the silver gegenion seems to have little effect on the carbene intermediate formed.

Much more interesting was the reaction of tosylhydrazone 52 with 5.3 moles (15.9 equivalents) of freshly distilled aluminum iso-propoxide in diglyme. Treatment for eight hours yielded two products in 26% and 47% yield. The 26% product was identified as 5,5-dimethylnorbornene, while the 47% component was tentatively identified as exo-2-iso-propoxy-6,6-dimethylnorbornane from its mass spectrum, with parent ion m/e=182, and nmr spectrum (CCl_4, 100 MHz), which showed two methyl singlets at δ 0.98 and 0.96, an isopropyl doublet at δ 1.13 with J=6 Hz and two protons alpha to oxygen: a heptet with J=6 Hz at δ 3.50 and an unresolved absorption at δ 3.74. This structural assignment was confirmed by solvolysis of <u>exo</u>-6,6-dimethylnorbornyl tosylate in isopropyl alcohol, which yielded 40% (calculated from <u>exo</u>-alcohol) of a compound with identical ir, nmr and vpc retention time as those exhibited by the 47% component. Solvolysis of 6,6-dimethyl-<u>exo</u>-2-norbornyl tosylate in acetic acid yields 6,6-dimethyl-<u>exo</u>-2-norbornyl acetate (13).



The formation of isopropyl ether from the aluminum isopropoxide decomposition was unique as it was the only product formed other than 5,5-dimethylnorbornene in any of the tosylhydrazone decompositions studied herein. Ether products have been shown to arise from diazonium or carbonium ion intermediates in methoxide induced tosylhydrazone decompositions in diglyme (25b, 57), and it was thought that decomposition of <u>52</u> in the presence of aluminum alkoxide might lead to an alumino-carbonium ion (aluminum complexed carbene), as suggested by Shapiro and co-workers for the corresponding decomposition of camphor tosylhydrazone (43b). In order to characterize the intermediate further, endo-deuteriated tosylhydrazone 52n was



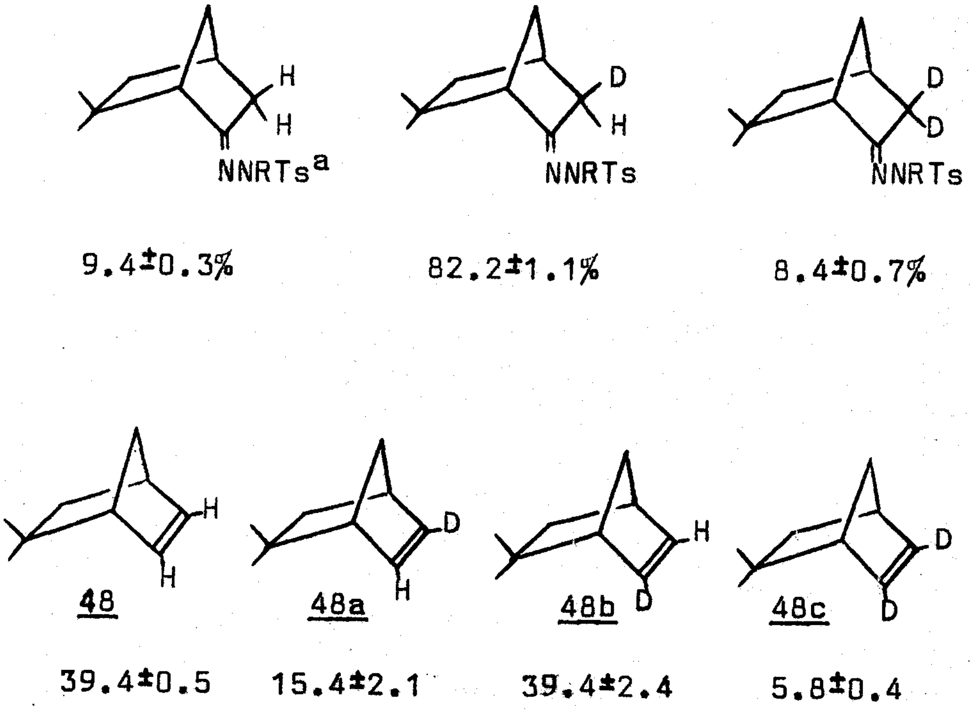
decomposed in diglyme with aluminum isopropoxide under the same reaction conditions. Mass spectral and nmr analysis, as presented in Table III, indicate that 48a and 48 are formed in a ratio of 89.4:11.5. After correcting for the amount of undeuteriated tosylhydrazone (determined from the alkene formed in dry salt pyrolysis of batch C), it seems that the 6,6-dimethylnorbornene formed in the aluminum alkoxide induced decomposition of 52 stems from an elimination reaction, with exo-3 and endo-3 proton (deuteron) abstraction occurring in a ratio of 92:8 (Table IV).

Elimination reactions of 2-norbornyl derivatives proceed predominantly via exo hydrogen abstraction. exo-2-Bromo-exo-3-deuterionorbornane forms norbornene with 94% of the deuterium label lost (58a). Even more important, Hoffman elimination of exo-2-N,N,N-trimethylammonio-exo-

3-deuterionorbornane also forms norbornene with 94% of the deuterium label lost, in spite of the fact that Hoffman eliminations almost always undergo anti elimination (58b).

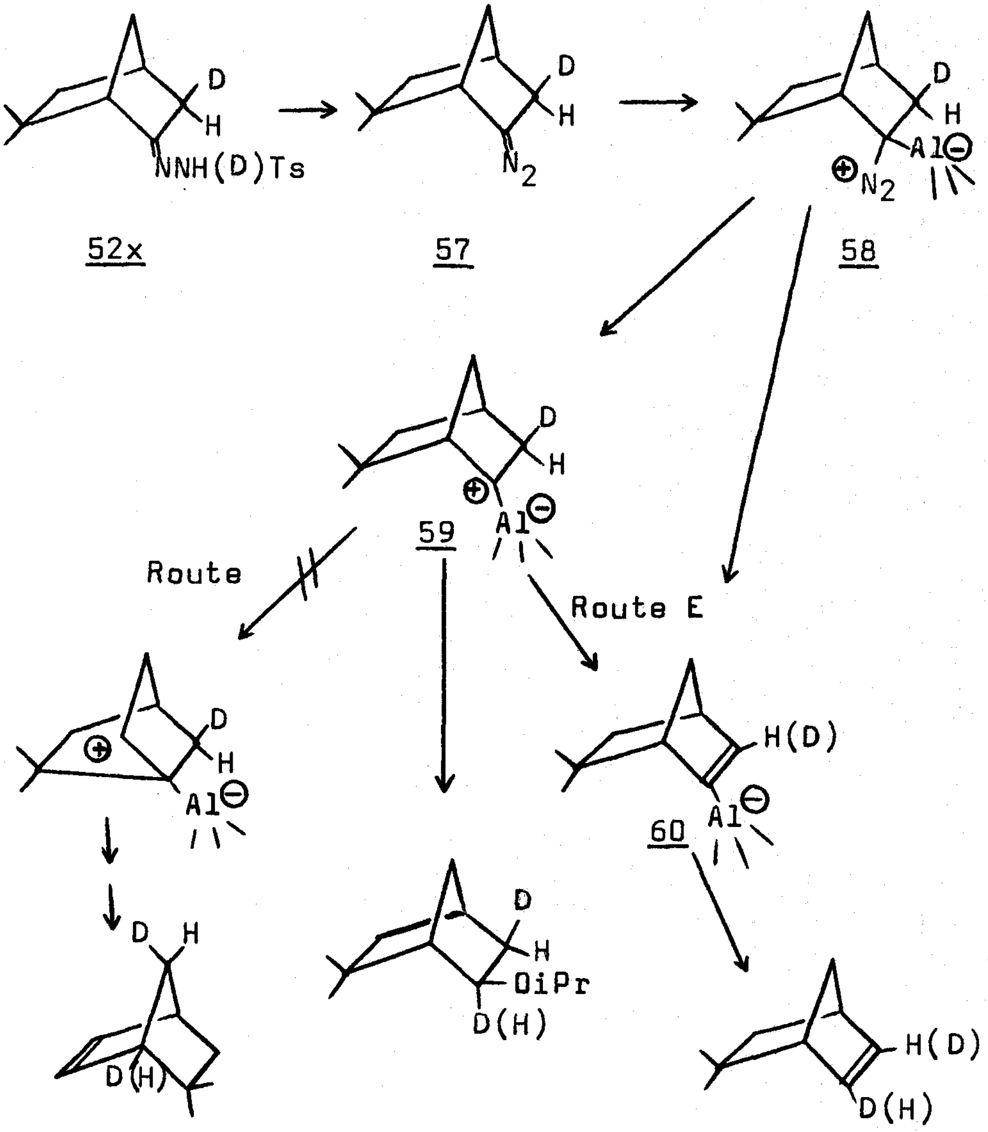
It seemed that further evidence for an elimination reaction would be provided by treatment of exo-deuteriated 52x with aluminum isopropoxide in diglyme at 160°. Since proton abstraction occurs predominantly from the exo side of the norbornyl skeleton, a large amount of deuterium should be lost from 52x, even with a substantial isotope effect. The situation is complicated somewhat since formation of exo-3-deuterio-6,6-dimethylnorbornan-2-one tosylhydrazone is accompanied by incorporation of deuterium on the nitrogen. Infrared studies on batch B of 52x (used in runs 2 and 9) indicate 50% N-H and 50% N-D. 52x (batch B) was treated with aluminum isopropoxide in diglyme at 160° for 8 hours. The resulting alkene product was subjected to mass spectral and nmr analysis as described above, and the results are tabulated in Scheme 4. The deuterium distribution at C-3 of 52x, as determined by analysis of the product of the dry salt pyrolysis of 53x (run 2), is also included in Scheme 4.

Scheme 4



These results are in reasonably good agreement with a mechanism similar to that proposed by Shapiro for the aluminum iso-propoxide induced decomposition of camphor tosylhydrazone (43b). ∝-Elimination of p-toluenesulfonic acid from 52x would lead to diazo compound 57 (Scheme 5). Coordination of the Lewis acid aluminum would lead to zwitterion 58. Loss of nitrogen could then lead to aluminum complexed carbene 59. It is significant that all the deuterium is found in the olefinic position of the

Scheme 5



alkene formed; this fact was revealed by europium chemical shift studies on the epoxide formed from the product 5,5-dimethylnorbornene. The intermediate 59 therefore does not undergo Wagner-Meerwein rearrangement before elimination (route R). Intermediate 59 does, however, undergo an E1 type elimination leading to 60 (route E). Electrophilic substitution of hydrogen or deuterium for aluminum would lead to a 48, 48a, 48b or 48c.

The significant loss of deuterium from the starting material, while consistant with an E1 type elimination, could be equally well explained by an E2 elimination of diazo compound 58 leading directly to 60. Deuterium loss could also come about from hydrogen deuterium exchange of 52x, 57 and/or 58, or any combination of the above.

In summary, pyrolysis and thermolysis of the lithium salt 53 generates what is probably a singlet carbene. The carbene then undergoes hydrogen migration yielding 5,5-dimethylnorbornene as the sole volatile product. Migration of the exo hydrogen is preferred over endo migration by a ratio of approximately 20:1. The rather large amount of endo hydride migration (about 5%) compared with the carbonium ion (<1%) would tend to preclude delocalization of the C-1-C-6 bond. Torsional effects in the hydride migration transition state would seem to offer an explanation for the 20:1 exo:endo selectivity that is observed.

Thermolysis of tosylhydrazone 52 in diglyme with several bases also yields 5,5-dimethylnorbornene as the sole hydrocarbon product. Sodium and silver bases seem to have little effect upon the exo:endo selectivity, while thermolysis in the presence of an aluminum base proceeds through an aluminum complexed carbene or diazonium ion.

EXPERIMENTAL SECTION

Melting points were determined using a Büchi melting point apparatus and are uncorrected. All boiling points are also uncorrected. Infrared spectra were recorded on either a Beckman IR-9 infrared spectrophotometer or a Perkin-Elmer 621 infrared spectrophotometer. Proton nmr spectra were recorded on a Varian Associates A-60 or HA-100 nmr spectrometer and deuterium nmr were recorded on a Varian Associates XL-100 nmr spectrometer. Mass spectra were run on an Atlas CH-7 or Finnigan 1015 S/L mass spectrometer. Elemental analyses were performed by Alfred Bernhardt, Mikroanalytisches Laboratorium, 5251 Elback Uber Engelskirchen, Fritz-pregl-strasse 14-26, West Germany. High resolution mass spectra were carried out by the University of Oregon chemistry department. Vpc analyses were carried out with an F and M Model 700 Chromatograph equipped with dual columns and thermal conductivity detectors. The following columns were used:

1. 10 ft x 0.25 in aluminum containing 10% Carbowax 20M on Anakrom 70-80 ABS.
2. 9 ft x 0.25 in aluminum containing 10% Carbowax 20M and 1% XF-1150 on Anakrom 70-80 ABS.
3. 18 ft x 0.125 in stainless steel containing 10% UCW-98 on 80-100 Diatoport S.

4. 15 ft x 0.375 in aluminum containing 20% Carbowax 1500 on 30-60 Chromosorb W.
5. 20 ft x 0.125 in aluminum containing 5% QF-1 on Anakrom 70-80 ABS.
6. 29 ft x 0.25 in aluminum containing 13% TCEP on 30-60 Chromosorb PAW.
7. 10 ft x 0.25 in aluminum containing 10% SE-30 on Anakrom 110-120 AS.
8. 10 ft x 0.25 in aluminum containing 10% UCON water soluble on 30-60 Chromosorb W.

Product ratios and percentage yields calculated from chromatographic data are based on relative peak areas as measured by a Hewlett Packard 3373B Integrator and are uncorrected for variations of thermal conductivity with molecular weight.

Preparation of 5,5-Dimethyl-2,3-*exo*-epoxynorbornene **49**. The procedure of M.M. Donaldson (13b) was used with only minor modifications. Sublimation of the resulting product (20 torr, pot temperature 70^0) yielded the title compound in 75% yield; nmr (CCl_4, 100 MHz); δ 3.10 (doublet of doublets, J=3.5, 0.7 Hz, 1H, C-3 proton), 2.96 (doublet of doublets, J=3.5, 0.7 Hz, 1H, C-2 proton), 2.34 (unresolved, 1H, bridgehead C-1 proton), 1.90 (broadened singlet, 1H, bridgehead C-4 proton), 1.34 (broadened doublet, J=4 Hz, 1H, *exo*-C-6 proton), 1.22 (broadened doublet, J=4 Hz, 1H, *endo*-C-6 proton), 1.15 to 0.80 (complex signals including two singlets for the two methyl groups on C-5 at δ 1.05 and 1.02, 8H).

Preparation of 6,6-Dimethylnorbornan-2-ol 50. The procedure of M.M. Donaldson (13b) was used. Purification by preparative vpc yielded nmr (CCl_4, 100 MHz): δ 4.07 (doublet, J=6 Hz, 1H, proton α to hydroxyl), 2.20 (multiplet, 1H, proton on C-4), 1.68 (singlet, 1H, C-1 bridgehead proton), 1.63 to 0.73 (complex series of absorptions including methyl singlets at δ 1.00 and 0.97, 12H).

Preparation of endo-3-Deuterio-6,6-dimethylnorbornan-2-ol 50n. The reaction was run as described (23b) except that 3 equivalents of lithium aluminum deuteride (99.5% d) was heated at reflux with 49 for three days. After workup, vpc analysis on column 1 showed the product to consist of a mixture of alcohol and epoxide in a ratio of 70:30.

Preparation of 6,6-Dimethylnorbornan-2-one 51. Alcohol 50 was oxidized by the procedure of M.M. Donaldson (13b). Distillation of the title ketone (bp 80-83°, 18 torr; lit bp 74-75°, 12 torr) yielded 51.5% (calculated from epoxide 49); nmr (CCl_4, 100 MHz): δ 2.75 (unresolved, 1H, bridgehead proton at C-4), 2.02 (slightly, broadened singlet, C-1 bridgehead), 1.97-0.80 (complex absorptions including methyl singlets at δ 1.07 and 0.96, 12H).

Oxidation of endo-3-Deuterio-exo-6,6-Dimethylnorbornan-2-ol. The crude mixture of 50n and 49 was treated with chromic acid in acetone as described (13b). Distillation yielded 51n.

Deuteriation of 6,6-Dimethylnorbornan-2-one. The title ketone (1.0 g) was dissolved in 25 ml of methanol-O-d (99% d_1) with a catalytic amount of sodium methoxide and stirred for 2 hr at room temperature. After quenching with D_2O and dilution with water, the solution was extracted with pentane. The pentane was washed with water and brine and dried over sodium sulfate. After removal of most of the pentane by distillation, the ketone was used without further purification.

Preparation of 6,6-Dimethyl-2-norbornanone p-Toluenesulfonylhydrazone 52. A mixture of 4.5 g (0.033 mol) of 6,6-dimethylnorbornan-2-one and 6.2 g (0.033 mol) of tosylhydrazine in 35 ml of 95% ethanol with 2 drops of concentrated hydrochloric acid was heated at reflux for 3 hr. Several ml of water was added, and the solution was cooled to room temperature, then placed in a refrigerator, yielding 5.1 g (0.017 mol) 51% mp 150-154°. Recrystallization from ethanol yielded mp 157.5-159°, ir (0.1 mm, $CHCl_3$): 3200 cm^{-1} (m, N-H stretching), 1662 (m, C=N stretching), 1598 (m, aromatic C=C stretching) and 1170 (s, SO_2-N stretching); nmr (100 MHz, $CDCl_3$): δ 7.89 (singlet, 1H, N-H), δ 7.84 and 7.26 (each a doublet, 2H each, aromatic protons), δ 2.38 (singlet, 3H, aromatic methyl), δ 2.34 (multiplet, 2H, C-1 and C-4 bridgehead protons), δ 2.2 to 1.2 (complex signals, 5H), δ 0.96 (1H, buried under methyl) δ 0.96 and 0.56 (singlets, 3H each, methyls on C-6).

Anal. Calcd. for $C_{16}H_{22}N_2O_2S$: C, 62.71; H, 7.24 Found: C, 62.70; H, 7.21.

Preparation of *endo*-3-Deuterio-6,6-dimethylnorbornan-2-one Tosylhydrazone 57n. This preparation was carried out in an identical manner to that described above for the undeuteriated tosylhydrazone. Recrystallization from methanol gave mp 156.5-158°.

Reaction of *exo*-3-Deuterio-6,6-dimethylnorbornan-2-one with Tosylhydrazine. The *exo* deuteriated ketone (about 1 g, 0.08 mol) was placed in 10 ml of methanol-O-d (99% d_1) with 1.5 g (0.08 mol) of tosylhydrazine (previously recrystallized from methanol-O-d) and a drop of DCl in D_2O. The solution was heated at reflux for 3 hr; D_2O was added, and the solution was allowed to cool to room temperature, then placed in a refrigerator. The crystalline product was recrystallized from methanol-O-d-D_2O yielding purified tosylhydrazone with mp 156-158°.

Dry Salt Pyrolysis of the Lithium Salt of 6,6-Dimethylnorbornan-2-one Tosylhydrazone. A 25 ml flask was charged with 306 mg (1.00 mmol) of tosylhydrazone. To this was added 10 ml of anhydrous ether, and then 450 μl of 2.2 M methyllithium in ether (1.0 mmol) was added to the solution with swirling. When gas evolution ceased, the ether was evaporated by blowing dry nitrogen over the solution while swirling. When most of the ether had evaporated, the white lithium salt covered the inside of the flask. The salt was then warmed to 40° and any remaining volatile material was pumped off with an oil pump at 0.1 torr. The dry salt was then placed in an oil bath maintained at 180° and the volatile products were pumped over and collected in a trap maintained at -78°. After one hour the volatile material in the trap was washed out with pentane, and the resulting pentane solution analyzed by vpc on columns 1,2 and 3. Only one product was detectable by vpc, and it had ir, nmr and vpc retention time identical to 5,5-dimethylnorbornene. The yield (internal vpc standard) was 75%.

<u>Irradiation of the Lithium Salt of 6,6-Dimethylnorbornan-2-one Tosylhydrazone</u>. In a 50 ml flask, 306 mg (1.00 mmol) of tosylhydrazone was dissolved in 25 ml of tetrahydrofuran (which had been freshly distilled from lithium aluminum hydride) and 95 mg of decane (for vpc internal standard). Methyllithium (460 μl of 2.2 M, 1.0 mmol) in ether was added with stirring at 0°. A small aliquot was withdrawn and the rest was irradiated with a 450 watt Hanovia high pressure mercury lamp until the theoretical amount of nitrogen was evolved and evolution stopped. The solution was then diluted with 200 ml of water and extracted with 5 x 15 ml of pentane. The pentane extracts were combined, washed with 5 x 250 ml of water and 1 x 100 ml of brine, and dried over anhydrous sodium sulfate. The solution was concentrated by distilling off most of the

solvent through a vigreaux column. Vpc analysis on column 3 showed there to be two peaks other than the decane internal standard. The peak with the shorter retention time, formed in variable yield, had vpc retention time and infrared identical with that of toluene. The other peak had vpc retention time, infrared and nmr identical with 5,5-dimethylnorbornene. Internal vpc standard indicated the yield to be 50%.

The aliquot was worked up in an identical manner as the irradiated mixture, and vpc analysis indicated there was no (<0.1%) alkene formed by methyllithium elimination (48).

Irradiation of the Lithium Salt of 6,6-Dimethylnorbornan-2-one Tosylhydrazone in the Presence of Benzophenone. To a solution of the lithium salt in tetrahydrofuran as described above, was added 1.0 equivalent of reagent grade benzophenone. The solution was irradiated through a pyrex filter until nitrogen evolution ceased. After workup similar to that described above, vpc analysis on column 3 gave a low yield (<5%) of 5,5-dimethylnorbornene as the only volatile product.

Decomposition of 6,6-Dimethylnorbornan-2-one Tosylhydrazone with Sodium Methoxide in Diglyme. Five ml of dry diglyme was added to a 20 ml flask. To this was added 45 mg (0.15 mmol) of tosylhydrazone and 100 mg (1.8 mmol) of sodium methoxide. The flask was then fitted with a reflux condensor and drying tube and placed in an oil bath maintained at 160° for two hours. After cooling to room temperature, the solution was diluted with 50 ml of water, and extracted with 4 x 5 ml of pentane. The pentane extracts were combined, washed with 3 x 50 ml of water and 1 x 20 ml of brine, dried over anhydrous sodium sulfate, and most of the solvent removed by distillation through a vigreaux column. Vpc analysis indicated only one product, which had vpc retention time, ir and nmr identical with 5,5-dimethylnorbornene. Internal standard indicated the yield to be 70%.

Decomposition of 6,6-Dimethylnorbornan-2-one Tosylhydrazone with Silver Carbonate. Into four ml of dry diglyme in a 10 ml flask was placed 30 mg (0.10 mmol) of tosylhydrazone and 300 mg of silver carbonate (1.1 mmol). After fitting with a reflux condensor and drying tube, the flask was placed in an oil bath, maintained at 165°, for 11 hr. After cooling to room temperature, the solution was diluted with 50 ml of water, and a white precipitate formed (unreacted tosylhydrazone). The solution was extracted with 4 x 5 ml of pentane, the pentane extracts were combined, washed with 3 x 100 ml of water and 1 x 25 ml of brine. Distillation of most of the solvent through a vigreaux column, followed by vpc analysis demonstrated that the reaction under consideration resulted in a 5% yield of toluene and a 27% yield of 5,5-dimethylnorbornene (uncorrected for unreacted tosylhydrazone).

Decomposition of 6,6-Dimethylnorbornan-2-one tosylhydrazone with Aluminum *iso*-Propoxide. Into a 10 ml flask equipped with reflux condensor and drying tube and containing 7 ml of dry diglyme, was placed 180 mg (0.59 mmol) of tosylhydrazone and 620 mg (3.2 mmol) of freshly distilled aluminum isopropoxide. The solution was stirred for 8 hr at 160°, cooled to room temperature, diluted with 100 ml of 5% hydrochloric acid and extracted with 4 x 10 ml of pentane. The pentane extracts were combined, washed with 100 ml of 10% sodium carbonate, 2 x 100 ml of water and 1 x 50 ml of brine. After drying with anhydrous sodium sulfate, and distilling most of the pentane through a vigreaux column, the solution was analyzed by vpc on columns 1 and 3. There were two peaks by vpc; the peak with the shorter retention time (in 26% yield) was identified as 5,5-dimethylnorbornene by ir, nmr and vpc retention time. The peak with the longer retention time, formed in 47% yield, was tentatively identified as *exo*-2-isopropoxy-6,6-dimethylnorbornane by its spectral data, and this was subsequently proved to be correct by an independent synthesis (see below); ir (0.1 mm, CCl_4): 1377 and 1366 cm^{-1} (m, doublet, gem-dimethyls) 1063 and 1040 (both s, attributable to C-O stretch); nmr (100 MHz, CCl_4): δ 3.74 (unresolved, 1H, *endo* proton on C-2, α to isopropoxy), 3.50

(heptet, J=6 Hz, 1H, α proton on isopropoxy group), 2.15 (unresolved, 1H, bridgehead proton on C-1), 1.75 (broadened singlet, 1H, bridgehead proton on C-4), 1.70 to 0.65 (complex, 18H including a doublet at 1.13, J=6 Hz, 6H, isopropyl methyls and two singlets at δ 0.98 and 0.96, 3H each due to gem-dimethyls on C-6).

Anal. Calcd for $C_{12}H_{22}O$: C, 79.06; H, 12.16. Found: C, 79.21; H, 12.05.

Synthesis of exo-2-Isopropoxy-6,6-dimethylnorbornane. To 25 mg (0.18 mmol) of exo-6,6-dimethylnorbornanol, purified by preparative vpc, in 300 μl of pyridine (previously dried over potassium hydroxide) in a small vial, was added 41 mg (0.18 mmol) of recrystallized p-toluenesulfonyl chloride. The solution was placed in a refrigerator. Crystals started appearing after four hr. After sitting in the cold for three days, the pyridine was removed with an oil pump. The tosylate was taken up in 0.5 ml of ether, which was decanted into a small tube. The ether was removed under vacuum, yielding 61 mg of crude tosylate. The crude tosylate was then placed in a small vial with 2.5 ml of reagent isopropyl alcohol and the solution was heated in an 80° oil bath for four days. The solution was then diluted with 25 ml of water and extracted with 3 x 5 ml of pentane. The pentane was washed with 3 x 50 ml of water and 1 x 25 ml of brine. Most of the solvent was removed by distillation through a vigreaux column and the residue was analyzed by vpc on column 1, which revealed a 40% yield (internal vpc standard, yield calculated from the alcohol) of a compound with identical vpc retention time, ir and nmr as the compound identified as exo-2-isopropoxy-6,6-dimethylnorbornane.

Decomposition of Deuteriated Tosylhydrazones. Deuteriated tosylhydrazones were decomposed in exactly the same manner as described above for undeuteriated tosylhydrazones.

Preparation of Deuteriated 49 for NMR Analysis. Deuteriated 5,5-dimethylnorbornene, formed from tosylhydrazone decompositions in runs 1-9, was collected by preparative vpc (usually ca. 20 mg), and placed in a small vial with 50 μl of chloroform, 250 μl of 40% peracetic acid and 5 mg of anhydrous sodium acetate. After warming to 40° for 5 min, the solution was diluted with 2 ml of water, and 250 μl of 40% sodium hydroxide was added with cooling. The solution was then extracted 3 times with 200 μl of pentane. The pentane extracts were washed with 500 μl of water and 200 μl of brine, and dried over anhydrous sodium sulfate. Epoxide 49 was then collected by preparative vpc and subjected to nmr analysis.

Nmr Analysis of Deuteriated 49. 49, generated as described above from the deuteriated alkene 48 produced in runs 1-9, was subjected to nmr analysis in CCl_4 at 100 MHz. Integration of the absorptions at δ 3.10 and 2.96

due to the protons at C-3 and C-2 was compared with the integration of the signals at δ 2.34 and 1.90 due to the C-1 and C-4 bridgehead protons. In all cases, the deuterium content was found to be, within experimental error, the same as the deuterium content determined by mass spectral analysis. This was further confirmed for the epoxide derived from the alkene products of runs 8 and 9. The corresponding epoxide nmr samples were treated with $Eu(fod)_3$ until the 2 protons at C-7 were isolated. Integration indicated no (<10%) deuterium at C-7 in alkene from runs 8 or 9.

The ratio of the areas under the peaks at δ 3.10 and 2.96 yielded, after correcting for the amount of undeuteriated alkene (available from mass spectral analysis), the ratio of products 48a and 48b. The integrals are given in Tables I and III, and the calculated ratios of products are given in Tables II and IV.

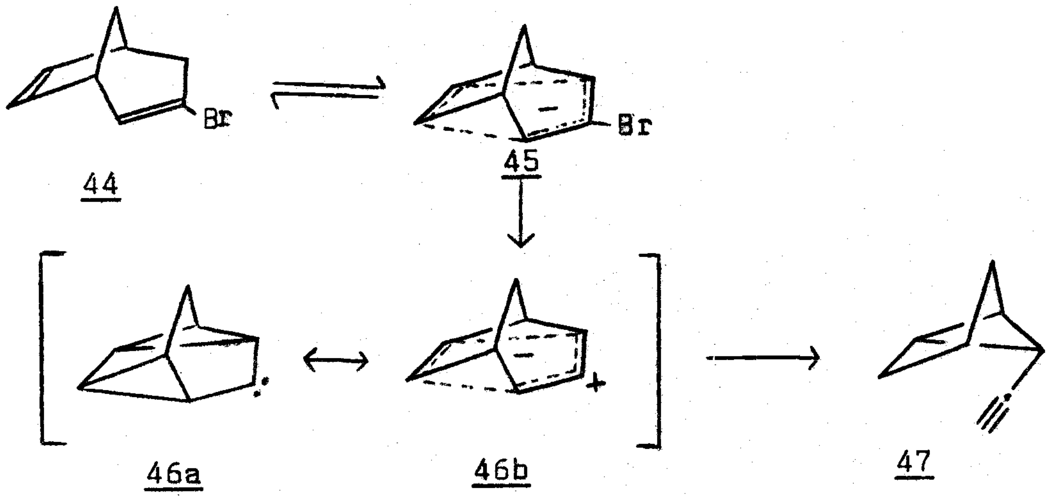
Mass Spectral Analysis of Deuteriated 48. Deuteriated 5,5-dimethylnorbornene from runs 1-9 was collected by preparative vpc and subjected to mass spectral analysis at low ionizing potentials. At 14 eV the parent-1 ion had been reduced to $<0.5\%$. The peak heights, after correcting for the natural abundance of C-13, yielded the amounts of d_0, d_1 and d_2 (62). These values are presented in Tables I and III.

PART II

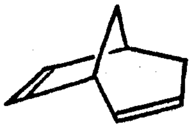
REACTIONS OF SOME ALICYCLIC VINYL BROMIDES WITH POTASSIUM *tert*-BUTOXIDE IN DIMETHYLSULFOXIDE

RESULTS AND DISCUSSION

The reaction of 3-bromobicyclo[3.2.1]octa-2,6-diene, 44, with potassium *tert*-butoxide in dimethyl sulfoxide proceeds via a deep-seated rearrangement yielding *endo*-6-ethynylbicyclo[3.1.0]hex-2-ene, 47 (36). It is found that optically active 44 undergoes loss of optical activity at a much faster rate than conversion to 47. The authors suggest that reversible loss of a proton to form bishomoaromatic anion 45 is followed by loss of bromide ion to give a "homoconjugated carbene" 46b. Typical cleavage of cyclopropyl carbene 46a (37) would then yield 47.



The ability of the electron rich "banana" bond of a cyclopropyl ring to donate electrons to a cationic center is well documented (4-7); however, at the time this work was begun, little was known of the ability of a cyclopropyl bond to interact with an anion to form a homoaromatic species (25-28). We were interested in observing the effect of replacing the double bond at C-6 in 36 with a cyclopropyl ring, as in such compounds as 61 and 62. Study of a



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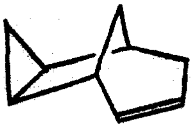

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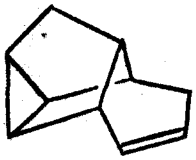
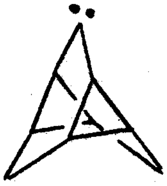


62

reaction similar to that reported by Bergman and Rajadhyaksha, as described above, seemed an ideal way to study the ability of a cyclopropyl ring to participate in formation of a homoaromatic anion, and at the time observe some interesting carbene chemistry, if 63 and 64 were formed (in analogy with the formation of 46).



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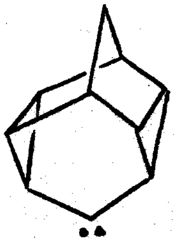

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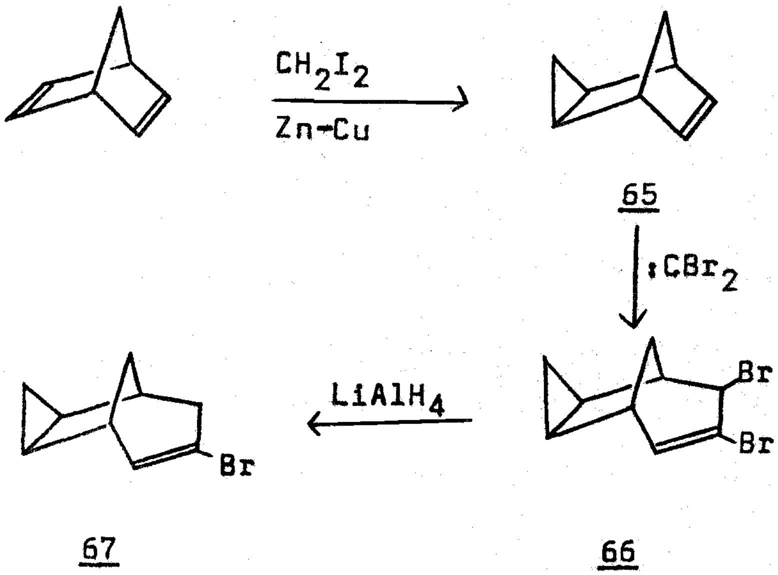
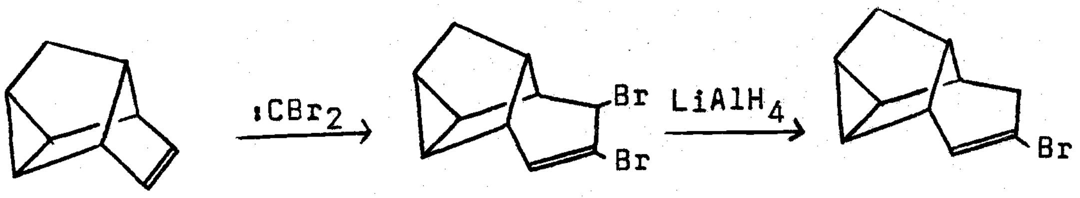
Simmons-Smith addition of methylene to norbornadiene produced tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, 65, in 14% yield (59).



Treatment of 65 with bromoform and potassium *tert*-butoxide afforded 66 in a 42% yield (60). Lithium aluminum hydride reduction of 66 gave a 50% crude yield of 67, which was found by vpc analysis to be 80% pure. Vinyl bromide 67 was purified by preparative vpc before further use.

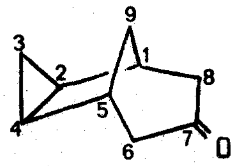
In order to study the effect of strain, and the importance of the angle of the cyclopropyl ring, vinyl bromide 70 was synthesized in a manner analogous to that of 67. Deltacyclene, 68, synthesized by the method of Coates and Kirkpatrick (8), was treated with bromoform and potassium tert-butoxide yielding dibromide 69 in 58% yield. Reduction to 70 with lithium aluminum hydride proceeded smoothly in 47% yield. Vinyl bromide 70 was collected by preparative vpc before use.



68 69 70

7-Bromotricyclo[3.3.1.$0^{2,4}$]non-6-ene, 67, was stirred in a solution of potassium *tert*-butoxide in dimethyl sulfoxide. Although reaction of 44 occurs "immediately" (36), workup of 67 after 15 minutes revealed only starting material. After stirring at room temperature for 48 hours, vpc analysis showed no peaks in the hydrocarbon region; however, two peaks, A and B, with retention times similar to that of 67, were observed in variable ratios. Collection of the shorter retention time component, A, followed by reinjection yielded again a mixture of A and B. Collection of the longer retention time component, B, followed by reinjection yielded only B. Thus, A was rearranging to B in the injection port and possibly the detector of the chromatograph.

The infrared spectrum of B showed a strong absorption at 1707 cm^{-1} indicative of a carbonyl function. Absorptions at 3030 cm^{-1} and 1028 cm^{-1} suggested the cyclopropyl ring was probably intact, and the mass spectrum showed a parent ion with m/e=136. The symmetry of the product, identified as 71, was revealed by the nmr (100 MHz, CCl_4) with an absorption at δ 2.29 integrating to six protons ($W_{\frac{1}{2}}$=5 Hz), corresponding to protons on C-1, C-5, C-6, and C-8, a singlet at δ 1.40 for protons at C-9, a two proton doublet of doublets (J=3.5, 7.5) at δ 1.13 for the protons at C-2 and C-4 and a two proton multiplet at ca. δ 0.35 for the cyclopropyl methylenes on C-3.

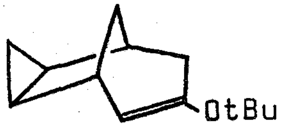


71

Infrared analysis of A, which had been collected by preparative vpc, showed it to be slightly contaminated with 71; however, there were strong absorptions at 1627 cm^{-1}, indicating an unsymmetrical double bond, and at 1175 cm^{-1}, indicating an ether linkage. In order to observe the nmr spectrum of A uncontaminated by 71, the dimethylsulfoxide reaction mixture was worked up by quenching with water, followed by extraction with a minimum amount of CCl_4. The crude CCl_4 solution was then washed with water and brine, dried over molecular sieves, and subjected to nmr analysis.

The crude nmr spectrum revealed a one proton doublet (J=6.5 Hz) at δ 5.20 and a nine proton singlet at δ 1.27. The remainder of the spectrum was very similar to that of 67. A parent peak in the mass spectrum of a mixture of A and 71 was found at m/e=192, confirming the assignment of

A as 7-tert-butoxytricyclo[3.3.1.$0^{2,4}$]non-6-ene, 72. Internal nmr standard showed the yield of 72 to be 51%.

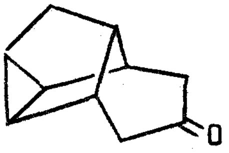


72

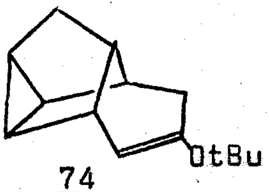
These were not the products expected on the basis of Bergman and Rajadhyaksha's work (36), and as a check on these results, we treated vinyl bromide 70 to the reaction conditions. After stirring at room temperature for 48 hours, vpc analysis revealed the same situation as in the reaction of 67: a component with a shorter retention time was rearranging to a component with a longer reaction time in the injection port, and detector, of the chromatograph.

The rearrangement product was assigned the structure 73 by analogy with the previous reaction, and its spectral data which included mass spectral parent ion m/e=148, infrared absorptions at 3080 cm^{-1} and 1029 cm^{-1}, a strong carbonyl absorption at 1717 cm^{-1}, and an nmr (60 MHz, CCl_4) which yielded a 4-proton doublet (J=3 Hz) at δ 2.30, a 4-proton multiplet at δ 1.98, and 2-proton singlets at δ 1.43 and at 1.12.

Thermally unstable primary product was subjected to spectral analysis after CCl_4 workup as described above. Assignment of structure 74 was based upon infrared: strong



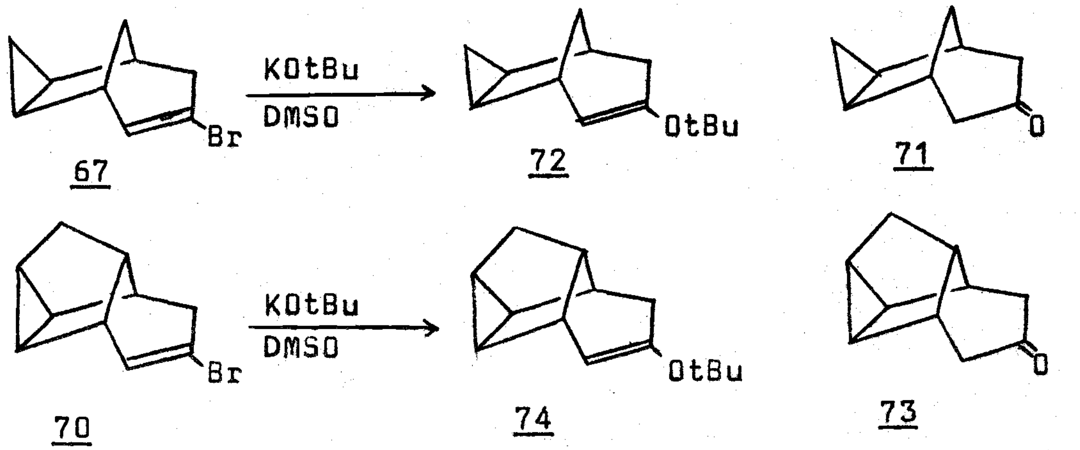
73



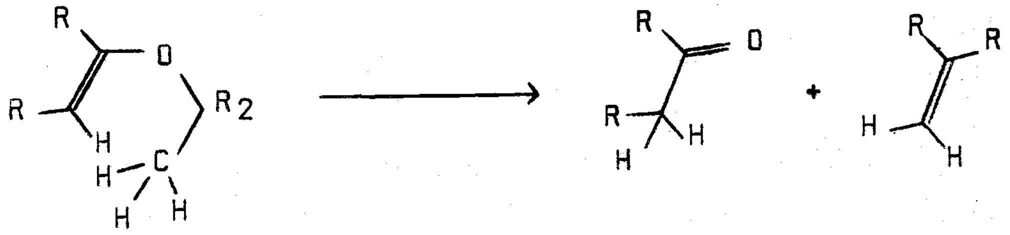
74

absorptions at 1644 cm^{-1} (C=C) and 1162 cm^{-1} (C-O); and upon the nmr (100 MHz, CCl$_4$), which revealed a doublet (J= 6.5 Hz) at δ 4.85 due to the lone olefinic proton, a nine proton singlet at δ 1.27; the rest of the spectrum was very similar to that of 70. Internal nmr standard determined the yield of 74 to be 53%.

The reactions of 67 and 70 with potassium *tert*-butoxide in dimethylsulfoxide, then, yield 72 and 74 respectively, which are thermally unstable under vpc injector and detector conditions and undergo retro-ene reactions yielding 71 and 73.

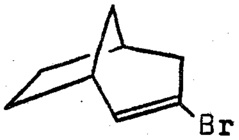


The formations of 71 from 72, and of 73 from 74, are examples of a retro-ene reaction (61a). Open chain ethers such as vinyl ethyl ether (61b) and vinyl propyl ether (61c) undergo retro-ene reactions at ca. 500°.



1-tert-Butoxycyclohexene (63a) and 3-tert-butoxybicyclo[3.2.1]oct-2-ene (64) can be subjected to vpc conditions with no difficulty, although the latter undergoes a retro-ene reaction at high injection port temperatures (vida infra). Vinyl ethers 72 and 74, however, undergo the retro-ene reaction quite easily in the vpc injector port and detector at 180-200°.

The question which presented itself was how these products are formed, and what, if any, role the cyclopropane ring plays in the reaction. In order to determine the effect of the cyclopropyl ring, 3-bromobicyclo[3.2.1]oct-2-ene, 75, was prepared by the method of Moore, Moser and LaPrade (65). If the formation of enol-ether products were due to either homoaromatic behavior or some other influence of the cyclopropyl ring, the treatment of 75 to the reaction conditions might show this. When 75 was treated with potassium tert-butoxide in dimethylsulfoxide for 48 hours, only one product was observed by vpc analysis. High injection port temperatures (>225°) resulted in a second peak with longer retention time. The primary product, formed in 64% yield, was identified as 3-*tert*-butoxybicyclo[3.2.1]-oct-2-ene, 76, from its spectral properties: the thermal pyrolysis product was identified as bicyclo[3.2.1]octan-3-one, 77 (65).



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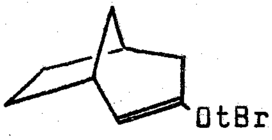

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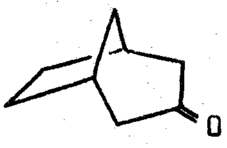
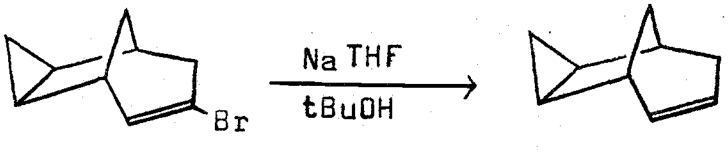
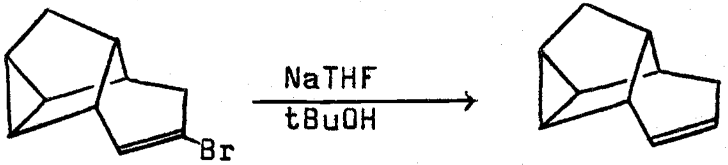


77

The cyclopropane ring in 67 and 70 are shown to have essentially no effect in the vinyl bromide reactions with potassium tert-butoxide in dimethylsulfoxide as revealed by product composition. Although the elimination reaction was the only process observed, we were still interested in whether there was interaction of the cyclopropyl ring with a genuine anion. To this end, hydrocarbons 61 and 62 were synthesized by treating the corresponding vinyl bromides, 67 and 70, with sodium and *tert*-butyl alcohol in tetrahy-



67 61



70 62

drofuran, yielding 83% and 76% respectively of <u>61</u> and <u>62</u>.

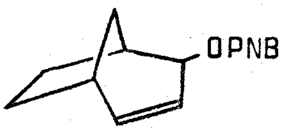
Hydrocarbons <u>61</u> and <u>62</u>, along with <u>36</u> and cyclohexene, were treated with potassium <u>tert</u>-butoxide in perdeuteriodimethylsulfoxide and the rates of deuterium incorporation were followed by mass spectral analysis. Table VI (pg 99) presents the mass spectral data, and Table V gives the calculated first order rate constants.

Table V. Calculated Rate Constants for Hydrogen Deuterium Exchange (0.55N KOtBu; 61°)

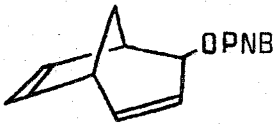
Compound	k(sec^{-1})[a]
C_6H_{12}	1.0×10^{-7}[b] (67×10^{-8})[d]
<u>36</u>	1.6×10^{-3}[b] (5.8×10^{-3})[d]
<u>61</u>	5×10^{-8}[c]
<u>62</u>	5×10^{-8}[c]

a) From first order plots of d_0 vs t. b) ±20% c) ±50%
d) 0.96N KOtBu, 60°, ref 32b.

It is clear from the rate data that there are no interactions of the cyclopropyl ring with the transannular allylic anion systems derived from the parent hydrocarbons <u>61</u> and <u>62</u>. That there was no cyclopropyl interaction was



<u>78</u>



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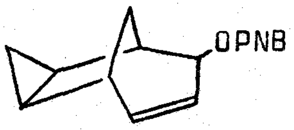
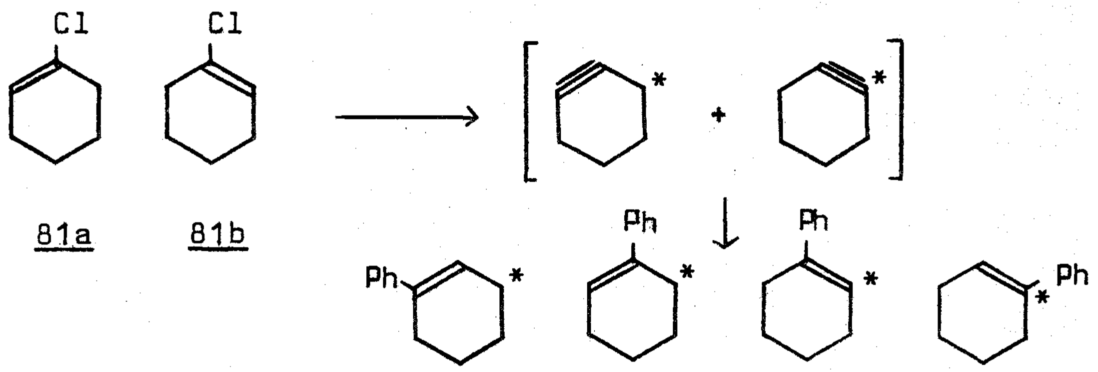


<u>80</u>

reinforced when neutralization of the exchange reaction mixture (0.55 N potassium tert-butoxide in dimethylsulfoxide at 155° for 15 hours) produced only starting substrates 61 and 62.

This complete lack of interaction of the cyclopropyl bond with the allylic anion formed is in good agreement with the lack of interaction of the cyclopropane ring with the analogous allylic carbonium ion (66). Specifically, 79 is found to solvolyze 235 times more slowly than 78, due to the antiaromatic nature of the 4-electron pi system produced (66a). In line with our observations, 80 only solvolyzed at 1/3 the rate of 78 (66b). Thus, in both the allylic cation and anion of 8-tricyclo[3.3.1.0^{2,4}]oct-6-ene, the cyclopropane ring has no effect other than induction, in contrast to the strong interaction of similarly positioned olefinic units in both cationic and anionic intermediates.

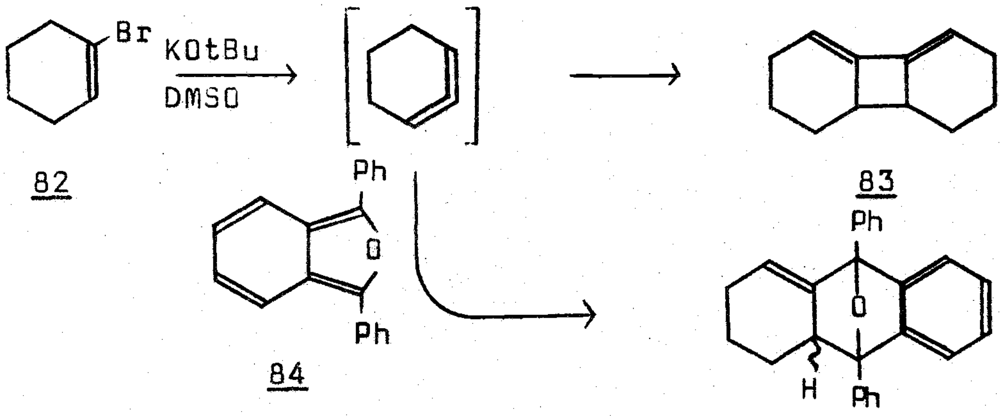
The formal substitution of a vinyl halide by an ether can be explained by a number of possible mechanisms, two of which, the formation of alkyne and allenic intermediates in 6-member rings, have been studied by a number of workers. 1-Phenylcyclohexene is formed from 1-chlorocyclohexene and phenyllithium (67). Reaction of an equimolar mixture of 81a and 81b with phenyllithium at 150° gave 1-phenylcyclohexene which had retained 23% of the label at C-1 (68). This is the expected result if an intermediate alkyne is formed, since this asymmetrical intermediate should yield phenylcyclohexenes with the label distributed as shown.



81a 81b

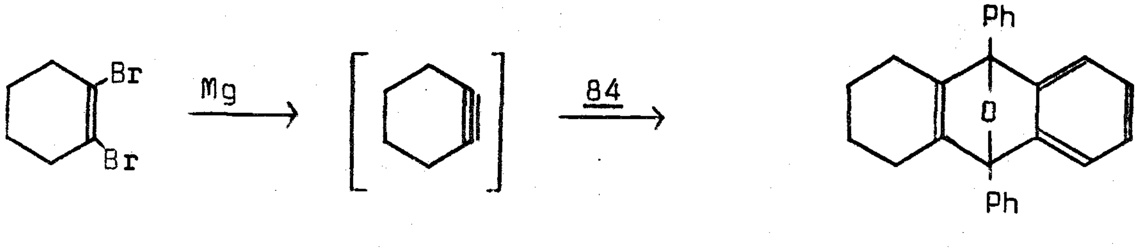
Similar results were found in the reaction with phenyllithium of labeled 1-chlorocyclopentene (68).

Allene formation in a 6-member ring has been demonstrated by Wittig and Fritze. Treatment of 1-bromocyclohexene, 82, with potassium tert-butoxide in dimethylsulfoxide affords a 7% yield of dimer 83 (69). Allene generation in the presence of 1,3-diphenylisobenzofuran, 84, afforded a 37% yield of 85. Generation of cyclohexyne by treatment



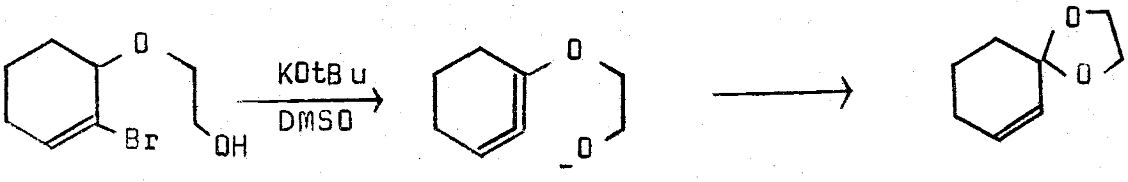
82 83 84 85

of 1,2-dibromocyclohexene, 86, with magnesium in the presence of 84 yields 87, which is not affected by treatment with potassium tert-butoxide in dimethylsulfoxide, indicating that 87 and 85 do not interconvert.



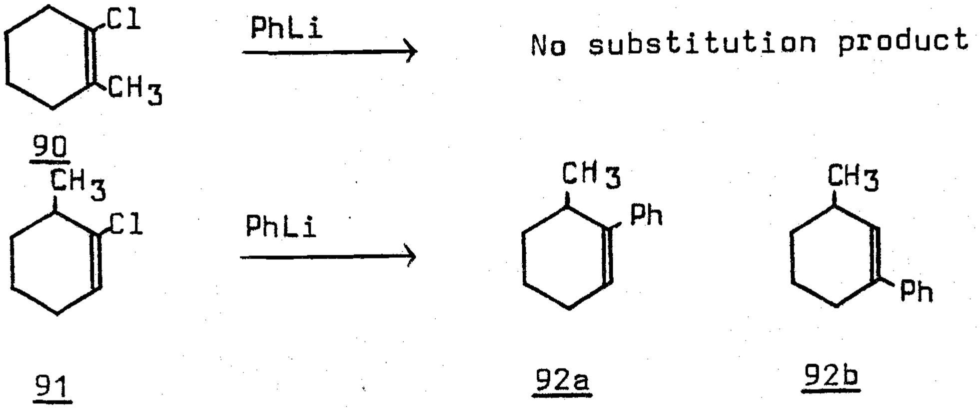
86 87

Further evidence for allenic intermediates in a 6-member ring was found by Bottini and co-workers in the reaction of 88 with potassium tert-butoxide in dimethylsulfoxide, which yielded 89 (70).



88 89

Montgomery and Applegate have found that 90, which is incapable of forming an alkyne, gave no substitution product, although an allenic product is not prohibited. It was found that isomeric 91, when treated with phenyllithium gave approximately equal amounts of 92a and 92b (71).



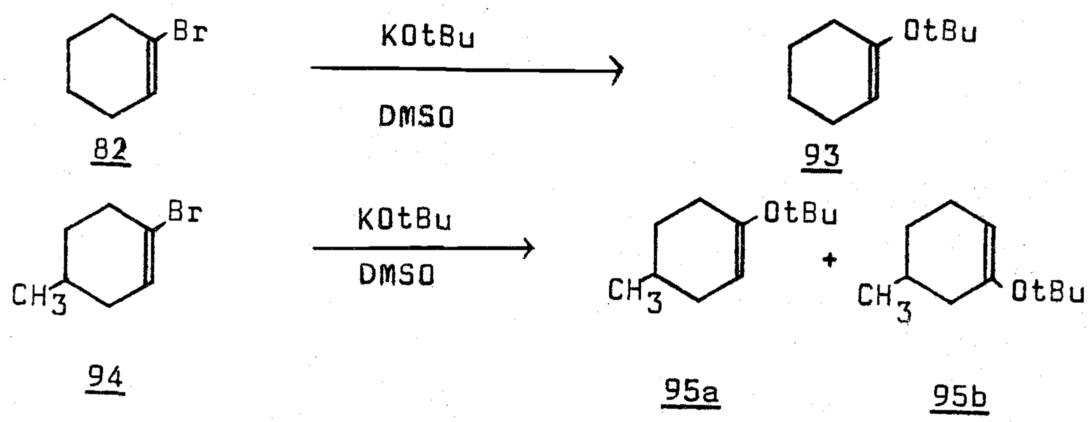
90

91

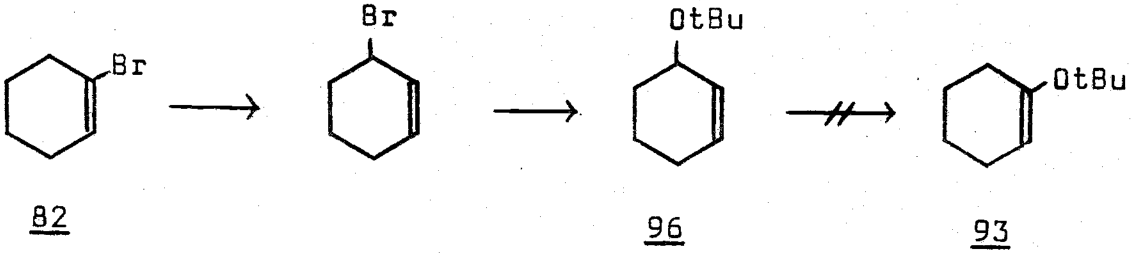
92a

92b

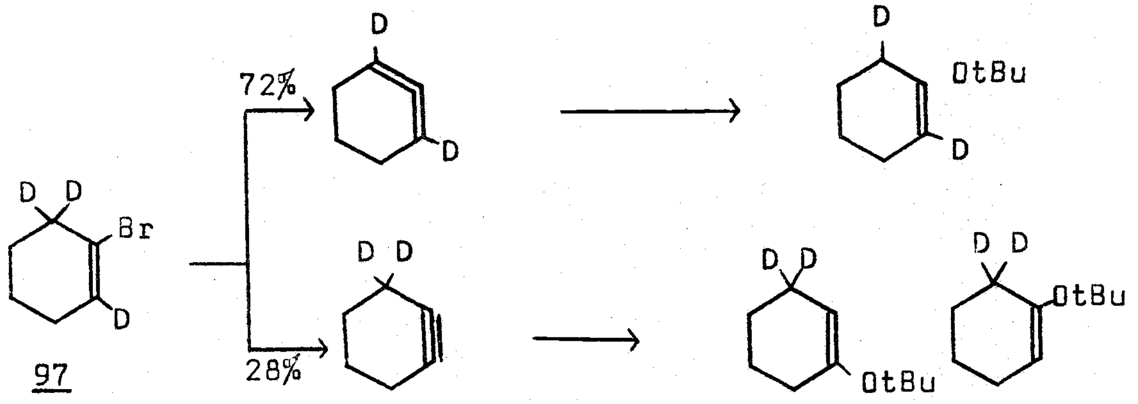
Whether an allenic or acetylenic intermediate is formed seems to be dependent, among other factors, on the base-solvent system used. Since reactions of vinyl bromides 67, 70 and 75 were carried out in potassium *tert*-butoxide-dimethylsulfoxide, the work described above in this solvent system (69, 70) is particularly relevant. While our studies were in progress, Bottini and his co-workers published a rather systematic study of the reactions of 1-halocyclohexenes with potassium *tert*-butoxide (63). Treatment of 82 with potassium *tert*-butoxide in dimethylsulfoxide afforded, in addition to a complex mixture of hydrocarbons, a 5-12% yield of 1-*t*-butoxycyclohexene, 93. 1-Bromo-4-methylcyclohexene, 94, yields 95a and 95b in a ratio of 86:14 upon treatment with KOtBu-DMSO. Varying the leaving group and the solvent changed the ratios of enol ethers significantly, which the authors felt indicated that there was more than one intermediate formed, although changes in the degree of association of the t-$BuO^{-}K^{+}$ with changes in the solvent might also yield different ratios of products.



A mechanism involving 96, such as that shown below, could be ruled out since it was shown that 96 is not converted to 93 under the reaction conditions.

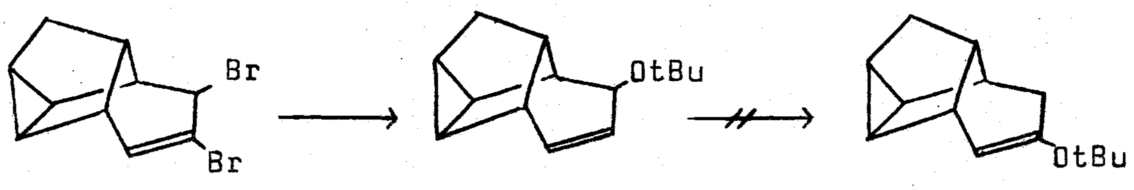


Treatment of 82 with potassium tert-butoxide in dimethylsulfoxide-d_6 yielded 93, which mass spectral analysis showed to consist of 93% d_1 and 7% d_2, with all the deuterium incorporated at C-2 or C-6 of the ether. Reaction of trideuteriated 97 yielded tert-butyl enol ethers as shown below as further proof that the reaction proceeds via a mixture of intermediates.



97

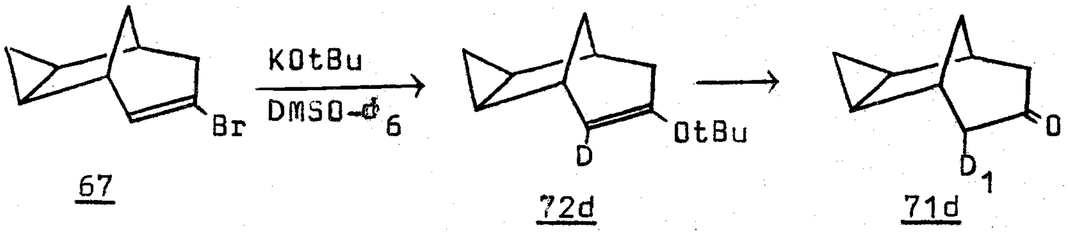
In order to determine the mechanism of the reactions of 67, 70 and 75 with potassium tert-butoxide in dimethylsulfoxide, it was necessary to show that the enol-ether formed was a primary product, and not a rearrangement product of an allyl ether. Ether 98 was synthesized by treating 69 with sodium and tert-butyl alcohol in tetrahydrofuran in 38% yield (along with an equal amount of 62). Treatment of 98 with potassium tert-butoxide in dimethylsulfoxide resulted in no isomerization to an enol-ether.



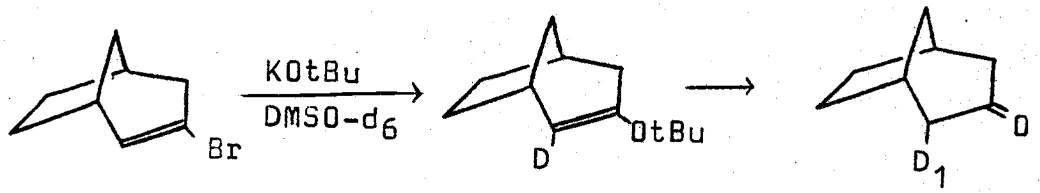
69 98 74

There are numerous possible mechanisms for the formal replacement of a vinyl halide by a vinyl ether. Several of the possibilities are direct substitution, S_n1, addition elimination, α,β elimination-addition (to form an alkyne) and

β,γ-elimination-addition (an allenic intermediate) (72). In order to sort through these possibilities, vinyl bromide 67 was treated with potassium *tert*-butoxide in perdeuteriodimethylsulfoxide (99.5% D). After 48 hours, the mixture was quenched with D_2O, and extracted with CCl_4 as described earlier. Nmr analysis showed that the doublet δ 5.20 due to the olefinic proton at C-6 had largely disappeared (ca. 15% H). Vpc collection of the deuteriated enol ether 72d yielded the corresponding ketone 71d. Nmr analysis of ketone 72d revealed that the broadened singlet at δ 2.29, assigned to the 4 protons α to the ketone plus the bridgehead protons integrated to 5.1±0.2 protons.



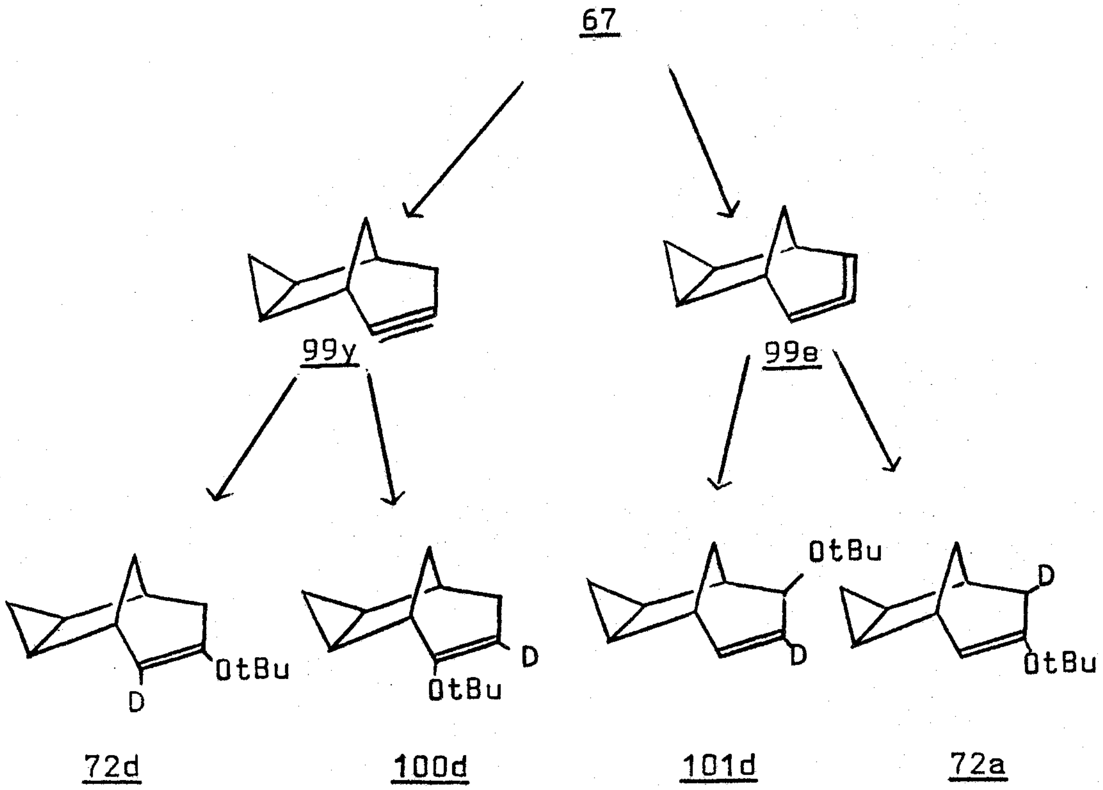
To confirm the lack of cyclopropyl interaction, 75 was allowed to react with potassium *tert*-butoxide in dimethylsulfoxide-d_6 and subjected to analysis as above, with the same results.



75 76d 77d

It was assumed that vinylic deuterium incorporation did not come about by hydrogen-deuterium exchange of 72, based on the fact that 93 does not undergo exchange under the reaction conditions (KOtBu in DMSO) (63), coupled with the similar slow exchange rates of cyclohexene and 61 as described above. In order to verify this, 72 was treated with potassium *tert*-butoxide in perdeuteriodimethylsulfoxide for 48 hours at room temperature. Mass spectral analysis of 71, the retro-ene product of the 72 which had been subjected to the exchange conditions, indicated no (<2%) deuterium incorporation. Incorporation of one deuterium from the solvent could be explained by either an α,β-elimination to form an acetylenic intermediate, 99y, or by a β,γ-elimination to yield an allene, 99e. Addition of *tert*-butyl alcohol-O-d would then yield in each case two possibilities as shown below.

An alkyne intermediate would be expected to add *tert*-butoxy at either end to yield a mixture of 72d and 100d. An allenic intermediate would be capable of undergoing addition of *tert*-butyl alcohol-O-d to yield either 101d

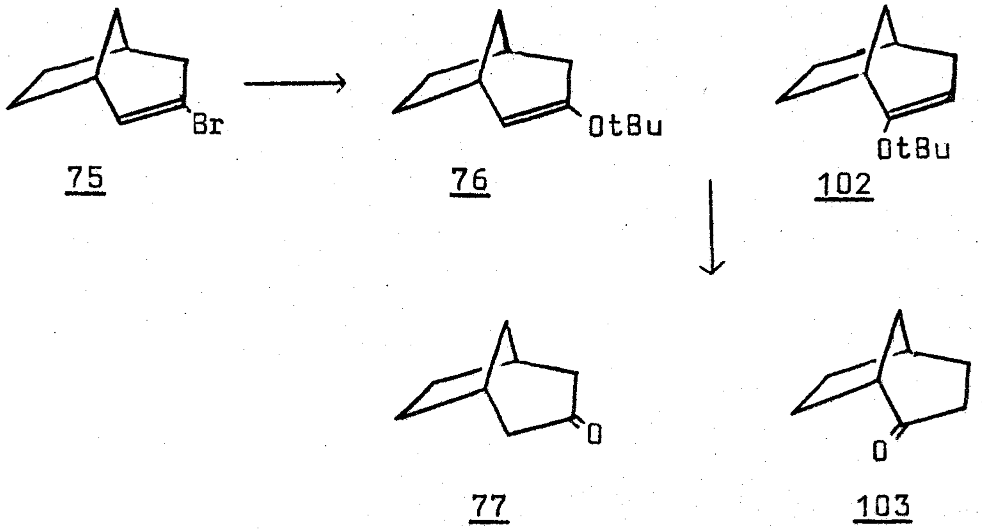


or 72a or both.

Deuteriated enol ethers formed from both 67 and 75 incorporated at least 85% of a deuterium into olefinic positions, as determined by nmr of the crude reaction mixture in CCl_4. The major product is then 72d; however, if an alkyne intermediate is formed, an a priori guess would be that 72d and 100d would be formed in equal amounts. They obviously are not, but is any 100d formed?

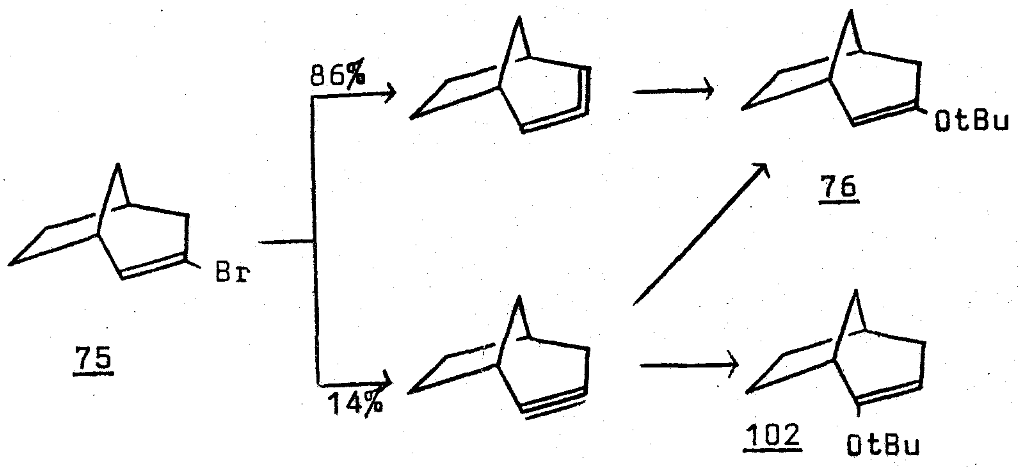
Vpc analysis of the ketone formed in the reaction of 75 showed a small peak (ca. 6-7%) with a slightly longer retention time than 77. The small peak, X, could not be separated by preparative vpc due to tailing of 77; however, mass spectral analysis yielded a parent m/e=124 which would make X isomeric with 77.

Attempted preparative vpc collection of the isomeric peak yielded a 70:30 mixture of 77 and X. This mixture was treated with methanol-O-d (99% d) and a catalytic amount of sodium methoxide and allowed to stir for 12 hours at room temperature. Mass spectral analysis revealed that 77 incorporated four deuteriums as expected, while X incorporated only two deuteriums, confirming the assignment of X as 103. The reaction of vinyl bromide 75 with potassium *tert*-butoxide in dimethylsulfoxide then must yield enol ethers 76 and 102 in a ratio of 93:7 which undergo a thermal retro-ene reaction to form 77 and 103 respectively.

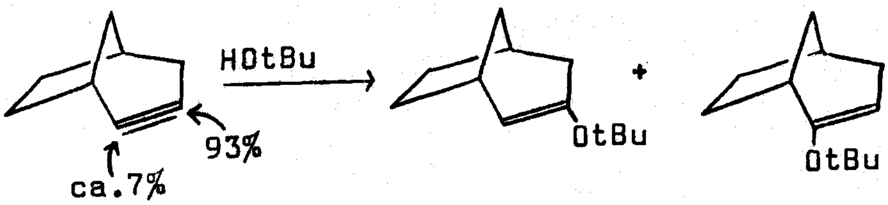


Vpc analysis of the ketones formed from 67 and 70 indicates, in each case, a small peak with slightly longer retention time than 71 and 73, in amounts of ca. 3% and ca. 5% respectively. These small peaks were not investigated further.

The reactions of 67, 70 and 75, which are constrained 6-membered rings, seem to proceed via a similar mixture of intermediates. Since 75 yields 77 and 103, which in turn yield 76 and 102 in a ratio of 93:7, making the assumption that an acetylenic intermediate can be attacked equally well from both ends, while an allenic intermediate is preferentially attacked at the middle carbon (68), suggests that a mixture of acetylenic and allenic intermediates in the ratio of 86:14 would explain the product ratios observed.

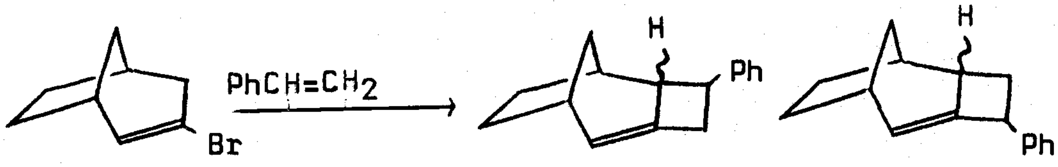


However, running the reaction in dimethylsulfoxide-d$_6$ yields 76 in which the olefinic proton is ca. 85% replaced by deuterium. Since incorporation of deuterium into enol ether products by exchange is not observed, we are forced to the conclusion that the reaction pathway involves an alkyne intermediate at least 85% of the time; however, the addition of tert-butyl alcohol is for some reason regiospecific.



76 102

Our results are in conflict with those very recently reported by Devaprabhakara and co-workers (64). They report that reaction of 75 with potassium tert-butoxide in dimethylsulfoxide affords a 62% yield of pure 76. The authors thus suggest an allenic intermediate and attempt to trap it. Treatment of 75 with potassium tert-butoxide in dimethylsulfoxide, in the presence of styrene, afforded, after distillation, a 50% yield of a mixture of 1:1 styrene:C_8H_{10} adducts, 75A and 75B.



75 75A 75B

The incorporation of olefinic deuterium when the reaction is run in deuteriated solvent, and the presence of 7% of 102 indicate that an allenic intermediate is far from being the exclusive intermediate, as suggested by Devaprabhakara and co-workers. In order to demonstrate the correctness of the trapping experiment, it would be necessary to show that a cyclobutene derivative formed from an acetylenic intermediate would be stable under both the reaction conditions and upon distillation.

EXPERIMENTAL SECTION

Preparation of *exo*-Tricyclo[3.2.1.0^{2,4}]oct-6-ene, **65**. This compound was prepared by the addition of methylene to norbornadiene by the Simmons-Smith procedure (59). To a 1 l three-necked flask equipped with mechanical stirrer, pressure equalizing dropping funnel, reflux condenser and nitrogen inlet tube, was added 65 g (1 mol) of zinc-copper couple (73), 400 ml of anhydrous ether and 92 g (1 mol) of freshly distilled norbornadiene. A few ml of methylene iodide and 1 g of iodine were added and the solution was heated to reflux. Methylene iodide (268 g, 1 mol) was then added dropwise over 0.5 hr and the solution was refluxed under nitrogen for 6 hr. Upon cooling, the mixture was filtered, washed with equal portions of saturated ammonium chloride, water and brine, then dried over anhydrous magnesium sulfate. Ether was then removed under reduced pressure. Pot to pot distillation yielded a clear liquid which is a mixture of norbornadiene and the desired hydrocarbon. Removal of the norbornadiene by distillation through a vigreaux column yielded 15 g (14%) of tricyclic alkene.

Addition of Dibromocarbene to *exo*-Tricyclo[3.2.1.0^{2,4}]-oct-6-ene. The procedure of Moore and co-workers (65) was followed with minor experimental modifications. To a slurry of 50 ml of pentane, 9.3 g (0.08 mol) of potassium *tert*-

butoxide and 9.5 g (0.09 mol) of alkene was added at -15° with stirring, 28 g (0.11 mol) of bromoform in 30 ml of pentane, dropwise over one hour. The solution then was allowed to warm to room temperature and was stirred for 2 hr. An equal volume of water was then added; the organic layer was separated, washed with water and brine, and dried with anhydrous magnesium sulfate. The volatile components were removed under reduced pressure, and distillation (78-80°, 0.1 torr) yielded 5.0 g (0.018 mol) of 7,8-dibromo-exo-tricyclo[3.3.1.0^{2,4}]non-6-ene, 66, which was a 42% yield based on recovered hydrocarbon. Infrared and nmr spectra were identical with those reported (60).

Preparation of 7-Bromo-exo-tricyclo[3.3.1.0^{2,4}]non-6-ene, 67. A 500 ml flask was charged with 250 ml of anhydrous ether and 1.5 g (0.04 mol) of lithium aluminum hydride. To this was added 4.8 g (0.016 mol) of 7,8-dibromo-exo-tricyclo[3.3.1.0^{2,4}]non-6-ene in 50 ml of ether. The solution was stirred 18 hr at room temperature. A saturated ammonium chloride solution was added dropwise to destroy the excess lithium aluminum hydride, and the ether layer was decanted off, washed with brine, and dried over magnesium sulfate. After removal of the solvent under reduced pressure, the vinyl bromide was then distilled, bp 43-45° at 0.33 torr yielding 1.6 g (50%) which was 80% pure by vpc analysis (col 6, 140°, 60 ml/min). Vpc purified bromide yielded ir (0.1 mm, CCl_4): 3090 cm^{-1} (shoulder, cyclopropyl or vinyl C-H stretch), 3030 cm^{-1} (s, cyclopropyl or vinyl C-H stretch), 1626 (s, C=C stretch), 1021 (s, cyclopropyl deformation), 698 (m, vinyl C-H out of plane bending); nmr (100 MHz, CCl_4): δ 6.34 (doublet, J=6.5 Hz, 1H, vinyl proton), 2.90 to 2.20 (multiplet, 4H, bridgehead protons at C-1 and C-5 along with methylene protons at C-8), 1.55 (doublet of triplets J_d=3.5 Hz, J_t= 7 Hz, 1H, cyclopropyl methine at C-4), 1.34 (triplet, J 3 Hz, 2H, methylene protons at C-9), 1.07 (doublet of triplets J_d 3.5 Hz, J_t 7 Hz, 1H, cyclopropyl methine hydrogen at C-2), 0.32 (multiplet, 2H, cyclopropyl methylene hydrogens at C-3).

Anal. Calcd for $C_9H_{11}Br$: C, 54.30; H, 5,57. Found: C, 54.22; H, 5.58.

Debromination of 7-Bromo-*exo*-tricyclo[$3.3.1.0^{2,4}$]non-6-ene with Sodium. Following the general method of Gassman and Pape (74), a 15 ml flask equipped with a magnetic stirrer, reflux condenser and nitrogen inlet tube was charged with 0.9 g (4.5 mmol) of vinyl bromide, one ml of *tert*-butyl alcohol (10 mmol) and 5 ml of tetrahydrofuran. Under nitrogen 0.5 g (20 mmol) of sodium was added and the mixture was treated at reflux for 20 hr. Upon cooling, the sodium chunks were manually removed and 3 ml of methanol was added with cooling. The solution was then poured over 50 ml of ice and extracted three times with 5 ml of pentane. The pentane extracts were then combined, washed with equal volumes of water and brine, dried over anhydrous sodium sulfate, and most of the solvent was removed by distillation through a vigreaux column. Subjection to vpc analysis (col 1, 90°, 60 ml/min) indicated an 83% yield (internal cymene standard) of tricyclo[3.3.1.0^{2,4}]oct-6-ene, 61. Infrared and nmr are identical with those of an authentic sample (17b).

Preparation of Norbornadiene Dimer. The general method of Mrowca and Katz (75) was used. Norbornadiene (118g, freshly distilled from calcium hydride) and 4 g of rhodium on carbon were placed in a 250 ml flask equipped with a reflux condenser, magnetic stirrer and nitrogen inlet tube. After refluxing for 24 hr, an equal volume of hexane was added and the solution was suction filtered through celite. After removal of solvent under reduced pressure, distillation (bp 70-72°, 0.3 torr) yielded 60 g (51%).

Preparation of Tetracyclo[4.3.0.0^{2,4}0^{3,7}]non-8-ene (Deltacyclene) 68. The method of Coates and Kirkpatrick (8b) was used with minor experimental modifications. Norbornadiene dimer (52 g, 0.27 mol) was dropped onto pyrex helices heated to 200° at a rate of one drop every three seconds. With a nitrogen flow of 60 ml/min (ie. nitrogen was bled into the system at such a rate that an oil pump pulled a vacuum of 10-15 torr), dimer vapors were then drawn through a quartz column packed with broken pieces of quartz heated to 485-490°. The clear product was collected by a series of three traps cooled to -78°. After all the dimer had passed through the system, the traps were rinsed with pentane, which was removed under reduced pressure. Distillation bp 74-76° (75 torr), yielded 25 g (75%) of deltacyclene, which was shown to be >95% pure by vpc analysis (col 1, 100°, 60 ml/min).

The Reaction of Dibromocarbene with Deltacyclene. To a mixture of 10 g (0.84 mol) of deltacyclene and 22 g (0.085 mol) of bromoform at -15° was added 6.2 g (0.055 mol) of potassium *tert*-butoxide over a period of 20 min. The mixture was then allowed to warm to room temperature and stir for 2 hr. Ether (100 ml) and water (100 ml) were added; the organic layer was separated and washed with saturated ammonium chloride, water, and brine, and dried over anhydrous magnesium sulfate. After removing the solvent under reduced pressure, distillation, bp 99-101° (0.15 torr), yielded 5.0 g of (58% based on recovered deltacyclene), ir (0.1 mm, CCl_4): 3050 cm^{-1} (m), 3010 (w)(both attributable to either cyclopropyl or vinyl C-H stretch), 1620 (m, C=C stretch), 1144, 979, 813 (all strong, skeletal vibrations), 1013 (m, cyclopropyl deformation), and 690 and 680 (s, vinyl C-H out of plane bending); nmr (60 MHz, CCl_4): δ 6.23 (doublet, J=6 Hz, 1H, vinyl proton), 4.69 (unresolved doublet, J=2 Hz, 1H, proton α to bromine on C-10), 2.52 (broadened singlet, 1H, bridgehead proton at C-1), 2.23 (singlet, 1H, bridgehead proton C-6), 2.19 (doublet, J=6 Hz, 1H, bridgehead proton C-7), 1.8-0.9 (complex absorptions, 5H).

Lithium Aluminum Hydride Reduction of 9,10-Dibromotetracyclo$[4.4.0.0^{2,4}0^{3,7}]$dec-8-ene, 69. Three grams (0.010 mol) of the title dibromide in 5 ml of anhydrous ether was added dropwise to a stirred suspension of 0.8 g (0.02 mol) of lithium aluminum hydride in 30 ml of anhydrous ether. After stirring overnight at room temperature, excess hydride was destroyed by adding saturated ammonium chloride solution. The ether layer was decanted off, washed with water and brine, and dried over anhydrous magnesium sulfate. Solvent was removed under reduced pressure, and distillation, bp 73-75° (0.24 torr), yielded 1.0 g (47%) of 9-bromotetracyclo$[4.4.0.0^{2,4}0.^{3,7}]$dec-8-ene, ir (0.1 mm, CCl_4): 3077 cm^{-1} (m, cyclopropyl or vinyl C-H stretch), 3000 (w, cyclopropyl or vinyl C-H stretch), 1642 (m, C=C stretching), 965 (m), 955 (m), and 800 (s); nmr (100 MHz, CCl_4): δ 6.06 (doublet, J=6.5 Hz, 1H, vinyl proton on C-8), 2.60 (multiplet, 2H, methylene protons on C-10), 2.04 (doublet, J=6.5 Hz, 1H, bridgehead C-7), 2.00 (singlet, 1H, bridgehead C-1), 1.75 (singlet, 1H, bridgehead at C-6), 1.52 (doublet of triplets, J_d=1 Hz, J_t =5 Hz, 1H, cyclopropyl methine at C-3), 1.43 (singlet, 2H, C-5 methylene protons), 1.07 (multiplet, 2H, cyclopropyl methine protons at C-2 and C-4).

Anal. Calcd for $C_{10}H_{11}Br$: C, 56.90; H 5.25.

Found: C, 56.79; H, 5.07.

Reduction of 9-Bromotetracyclo$[4.4.0.0^{2,4}0^{3,7}]$dec-8-ene, 70, with Sodium. A 25 ml three necked flask equipped with a magnetic stirrer, nitrogen inlet tube and reflux condenser was charged with 1.0 g (4.8 mmol) of the title bromide, 1 ml (10 mmol) of *tert*-butyl alcohol and 5 ml of tetrahydrofuran under a nitrogen atmosphere. Sodium (0.6 g, 25 mmol) was added and the solution was heated at 60° for 10 hr. The excess sodium was then removed manually and methanol (5 ml) was added with cooling. The solution was then poured into a separatory funnel containing ice and pentane. The organic layer was separated and the aqueous layer was extracted twice with pentane. The organic layers were combined, washed with water and brine, dried with anhydrous magnesium sulfate, and most of the solvent was removed by distillation through a vigreaux column. Vpc analysis (col. 1, 100°, 60 ml/min) revealed a 76% yield (internal cymene standard) of tetracyclo$[4.4.0.0^{2,4}0^{3,7}]$dec-8-ene, 62, which gave ir and nmr identical to that of an authentic sample (76).

Reaction of 9,10-Dibromotetracyclo$[4.4.0.0^{2,4}.0^{3,7}]$-dec-8-ene, 69, with Sodium and tert-Butyl Alcohol in Tetrahydrofuran. The reaction was run in an identical manner as the reduction of 9-bromotetracyclo$[4.4.0.0^{2,4}.0^{3,7}]$dec-8-ene (see above), using 1.0 g (3.5 mmol) of the title dibromide. Vpc analysis (col 1, 110°, 60 ml/min) showed two products present in equal amounts in a total yield of ca. 75%. The shorter retention time product was identified as tetracyclo[$4.4.0.0^{2,4}.0^{3,7}$]dec-8-ene by comparison of its infrared and nmr spectra with that of an authentic sample (76). The longer retention time product was identified as 10-tert-butoxytetracyclo[$4.4.0.0^{2,4}.0^{3,7}$]dec-8-ene from its spectral data; mass spectral analysis: parent peak m/e=204; ir (0.1 mm, CCl_4) 3045 cm^{-1} (m), 3022 (m)(both attirbutable to either cyclopropyl or vinyl C-H stretch), 1640 (w, C C stretch), 1385 and 1360 (both s, tert-butyl C-H bending), 1195 (s, tert-butoxy skeletal deformation), 700 (m, vinyl C-H out of plane bending); nmr (60 MHz, CCl_4): δ 5.80 (doublet of doublets, J=6.5, 9.5 Hz, 1H, olefinic proton at C-8), 5.25 (broadened doublet, J=9.5 Hz, 1H, olefinic C-9 proton), 3.80 (broadened singlet, 1H, α to oxygen), 2.15-1.60 (multiplet, 4H, protons on C-1, 3, 6 and 7), 1.40 (singlet, 2H, C-5 methylenes), 1.33-0.50 (complex signals including a 9 proton singlet at 1.19, 11H).

High resolution mass spectrum. Calcd for $C_{14}H_{20}O$: 204.151; Found: 204.152.

Reactions of Vinyl Bromides 67, 70 and 75 with potassium tert-Butoxide in Dimethylsulfoxide. To a dry 10 ml flask was added 4 ml of dimethylsulfoxide (freshly distilled from calcium hydride) and 0.25 g of potassium tert-butoxide (Ventron). The vinyl bromide (ca. 0.7 mmol) was then added with a syringe through a rubber septum and the solution was stirred at room temperature under nitrogen for 48 hr. After quenching and dilution with 200 ml of water, 50 ml of brine was added and the solution extracted three times with 20 ml of pentane. The organic layers were combined, washed three times with 250 ml of water and once with 50 ml of brine. After drying over anhydrous sodium sulfate, most of the solvent was removed either by rotary evaporation under reduced pressure or by distillation through a vigreaux column. Vpc analysis on column 1 revealed two peaks in variable ratios. Reinjection of the shorter retention time peak resulted in appearance of both peaks, while reinjection of the longer retention time component yielded only itself. At shorter reaction times a third peak was present due to unreacted starting material. Analysis on column 5 revealed a small component (3-7%) with a retention time slightly longer than the thermal rearrangement product. In order to observe the shorter retention time product uncontaminated by its thermolysis product, the reaction was run on about one fourth the scale described above, and after quenching with water, the solution was extracted several times with a total of one ml of carbon tetrachloride. The carbon tetrachloride was then washed 3 times with 10 ml of water, and once with 5 ml of brine. After drying over anhydrous sodium sulfate, the carbon tetrachloride was subjected to nmr analysis. In each case, there was a doublet at low field due to one olefinic proton, and a singlet at δ 1.3 which integrated to about nine times that of the olefinic doublet. The rest of the spectrum, in each case, was very similar to the corresponding vinyl bromide used as starting material. What must have been non-volatile impurities were present to an extent of 30-40% which caused the integration of the upfield portion of the spectrum to be high. Yields of enol ether products were calculated by adding a known amount of benzene to the nmr sample and comparing the benzene integration with those of the olefinic doublet and the *tert*-butyl singlet.

Reaction of 7-Bromo-exo-tricyclo[3.3.1.0^{2,4}]non-6-ene, 67, with Potassium tert-Butoxide in Dimethylsulfoxide. The title bromide was treated as described above. Vpc collection of the longer retention time peak, identified as *exo*-tircyclo[3.3.1.0^{2,4}]octan-7-one, 71, yielded a mass spectral parent peak of m/e=136; ir (0.1 mm, CCl_4): 3096 cm^{-1} (w, cyclopropyl C-H stretch), 3030 (m, cyclopropyl C-H stretch), 1707 (s, C=O stretch), 1350 and 1193 (m, skeletal vibrations), and 1028 (cyclopropyl deformation); nmr (CCl_4, 100 MHz): δ 2.29 (broad singlet, $W_{\frac{1}{2}}$=5 Hz, 6H, protons on C-1, C-5, C-6 and C-8), 1.40 (singlet, 2H, C-9 protons), 1.13 (doublet of doublets, J=3.5, 7.5 Hz, 2H, cyclopropyl methyne protons at C-2 and C-4), 0.35 (complex multiplet, 2H, cyclopropyl methylene protons on C-3).

Anal. Calcd for $C_9H_{12}O$: C, 79.39; H, 8.88 Found:

C, 79.24; H, 8.81.

The shorter retention time peak, identified as 7-tert-butoxy-exo-tricyclo[3.3.1.$0^{2,4}$]non-6-ene, 72, could not usually be vpc collected without some contamination from 71, however, an infrared of the mixture indicated the following absorptions due to 72 (0.1 mm CCl_4): 3086 and 3021 cm^{-1} (shoulders, assignable to either olefinic or cyclopropyl C-H stretching), 1637 (s, C=C stretch), 1387 and 1362 (m and s, t-butyl C-H deformations), 1175 and 1152 (s, doublet, C-O stretch), and 1026 (m, cyclopropyl deformation); nmr (CCl_4, 100 MHz): δ 5.20 (doublet, J=6.5 Hz, 1H, vinyl proton at C-6), δ 1.27 (singlet, 9H, 6-butyl protons), (integrations of the remainder of the upfield region of the spectrum were high due to impurities, but the patterns are very similar to those of the vinyl bromide starting material 67), δ 2.5 to 1.8 (multiplet due to bridgeheads at C-1 and C-5, and methylene protons at C-8), 1.6 to 0.8 (multiplets due to protons on C-2, C-4, C-9 and the singlet due to tert-butyl), and 0.2 (cyclopropyl methylenes at C-3).

Analysis of the ketone collected on column 1 on col 5 indicated a small peak (ca. 3%) with a slightly longer retention time than 71.

Reaction of 9-Bromotetracyclo[4.4.0.$0^{2,4}$.$0^{3,7}$]dec-8-ene, 70, with Potassium tert-Butoxide in Dimethylsulfoxide. The title bromide was treated as described above. Vpc collection of the longer retention time peak identified as tetracyclo[$4.4.0.0^{2,4}.0^{3,7}$]decan-8-one, <u>73</u>, yielded a mass spectral parent ion of m/e=148; ir (0.1 mm, CCl_4): 3082 cm^{-1} (m, cyclopropyl C-H stretch), 1717 (s, C=O stretch), 1030 (m, possibly cyclopropyl deformation), 1357, 1202, 970 and 854 (m skeletal vibrations); nmr (60 MHz, CCl_4): δ 4.60 (doublet, J=3 Hz, 4H, methylene protons at C-8 and C-10), 3.95 (broad multiplet, 4H, protons on C-1, 4, 6 and 7), 2.85 (slightly broadened singlet, 2H, cyclopropyl protons on C-2 and C-3), and 2.23 (singlet, 2H, C-5 methylene protons.

High resolution mass spectrum. Calcd for $C_{10}H_{12}O$: 148.089; Found: 148.091.

The shorter retention time component, identified as 9-tert-butoxytetracyclo[$4.4.0.0^{2,4}.0^{3,7}$]dec-8-ene, <u>74</u>, which easily underwent retro-ene reaction under vpc conditions, yielded ir (0.1 mm, CCl_4): 3077 cm^{-1} (m, cyclopropyl or olefinic C-H stretch), 1644 (s, C=C stretch), 1385 (w) and 1364 (s, both due to <u>tert</u>-butyl C-H deformations), and 1162 (s, C-O stretch); nmr (CCl_4, 100 MHz): δ 4.85 (doublet, J=6.5 Hz, 1H, olefinic proton at C-8), δ 1.27 (singlet, 9H, t-butyl protons), (integrations of the remainder of the high field spectrum were high due to impurities, but the patterns were very similar to those of the vinyl bromide starting material, <u>70</u>), δ 2.5-0.7 (complex signals). Analysis of the ketone collected on column 1 on column 5 indicated a small peak (ca. 5%) with a slightly longer retention time than 73, and an m/e=148.

Reaction of 3-Bromobicyclo[3.2.1]oct-2-ene with Potassium *tert*-Butoxide in Dimethylsulfoxide. The title bromide was treated as described above. Vpc analysis (col 1, 100°) at moderate ($<150°$) injection port and detector temperatures yielded one peak identified as 3-tert-butoxybicyclo-[3.2.1]oct-2-ene, 76 (64) by its spectral properties: ir (0.1 mm, CCl_4): 1645 cm^{-1} (m, C=C stretch), 1391 (m) and 1368 (s, both due to *tert*-butyl C-H deformations), 1170 (s, C-O stretch): nmr (CCl_4 100 MHz), δ 5.04 (doublet, J=6.5 Hz, vinyl C-2 proton), 2.5-2.1 (multiplet, 2H, bridgehead C-1 and C-5), 2.0-1.2 (complex signals including a 9 proton singlet at δ 1.14, 17H).

Vpc analysis (column 1) with high ($>225°$) injection port temperatures revealed another peak with longer retention time which was identified as bicyclo[3.2.1]octan-3-one, 77, by comparison of its spectral properties with those reported (65). Vpc analysis on col 5 yielded a peak with slightly longer retention time than 77, identified as bicyclo[3.2.1]octan-2-one, 103, as described below.

The component identified as 103 yielded a mass spectral parent ion m/e=124. Vpc collection of 103 on col 5 yielded a mixture of 77 and 103 in the ratio of 70:30. A total of ca. 10 mg of the mixture was placed in 150 mg of methanol-O-d (99% d_1) along with 2 mg of sodium methoxide, and allowed to stand 12 hr.

Mass spectral analysis at 65 eV yielded the following relative peak heights:

m/e	Deuteriated 77	Deuteriated 103
123	<2%	<2%
124	<2	2
125	3	19
126	6	100
127	42	11
128	100	<2
129	15	<2
130	<2	<2

Reaction of 7-Bromo-*exo*-tricyclo[3.3.1.$0^{2,4}$]non-6-ene, 67, with Potassium *tert*-Butoxide in Dimethylsulfoxide-d_6. The reaction was carried out as described above. Carbon tetrachloride workup as described above yielded ether 72d with an nmr spectrum in which the integration of the olefinic proton and the t-butyl have decreased from 1:9 to ca. 0.15:9, indicating that the olefinic proton has been largely replaced by deuterium. Vpc collection yielded ketone 71d in which the absorption at δ 2.29 due to the protons α to the ketone and at the bridgehead carbons C-1 and C-5 integrated to 5.1±0.2 protons.

Reaction of 3-Bromotricyclo[3.2.1]oct-2-ene, 75, with Potassium *tert*-Butoxide in Dimethylsulfoxide-d_6. The reaction was carried out as described above. Vpc collection yielded ether 77d which was subjected to nmr analysis.

Integration of the olefinic doublet at δ 5.04 indicated that this proton had been ca. 85% replaced by deuterium.

Kinetic Studies of Cyclohexene, 36, 61, and 62 with Potassium *tert*-Butoxide in Perdeuteriodimethylsulfoxide. The exchange solution was made up by adding 193 mg of a 1:1 adduct of potassium *tert*-butoxide and *tert*-butyl alcohol to 2.0 ml of dimethylsulfoxide-d_6 under nitrogen (0.55 M). The hydrocarbons to be studied were purified by vpc and 10 μl of hydrocarbon was placed in a small tube and cooled in a dry ice bath under nitrogen, 150 μl of 0.55 M KOtBu in DMSO-d_6 was added, and the tube was sealed. Five tubes were made up in the above manner for each of the hydrocarbons studied, and all were held at -78° until the start of the kinetic run. All 20 tubes were then placed in a 61.0° constant temperature bath and, at the times indicated (Table VI), were withdrawn, quenched with 100 μl of water, extracted twice with 20 ml of pentane. The pentane solutions were washed with water, dried with anhydrous sodium sulfate, and the resulting deuteriated hydrocarbon was collected by preparative vpc. Mass spectral analysis at 14 eV, after correcting for the statistical distribution of C-13, yielded the relative amounts of d_0, d_1, d_2, and d_3. The % of d_0 is presented in Table VI.

Table VI. Allylic Hydrogen Exchange in 0.55 N Potassium *tert*-Butoxide in Perdeuteriodimethylsulfoxide (61°).

Run	Cmpd	Time(Sec)	Amount of d_0
1	<u>36</u>	90	0.87
2	<u>36</u>	120	0.75
3	<u>36</u>	300	0.60
4	<u>36</u>	420	0.52
5	<u>36</u>	780	0.27
6	C_6H_{12}	42,000	0.994
7	C_6H_{12}	151,000	0.988
8	C_6H_{12}	565,000	0.956
9	C_6H_{12}	687,000	0.936
10	C_6H_{12}	730,000	0.920
11	<u>61</u>	12,600	1.00
12	<u>61</u>	144,000	0.990
13	<u>61</u>	243.000	0.992
14	<u>61</u>	407,000	0.982
15	<u>61</u>	1,140,000	0.945
16	<u>62</u>	12,600	1.00
17	<u>62</u>	144,000	0.992
18	<u>62</u>	243,000	0.990
19	<u>62</u>	407,000	0.965
20	<u>62</u>	1,140,000	0.947

Product Analysis of the Reaction of Tricyclo[3.3.1.0^{2,4}]non-6-ene with Potassium tert-Butoxide in Dimethylsulfoxide. To a 0.5 ml solution of 0.55 M potassium tert-butoxide in dimethyl sulfoxide was added 40 mg of 61. The mixture was placed in a sealed tube and heated at 155° for 15 hr. The solution was then quenched with water and extracted with pentane. The pentane was washed with water, dried over anhydrous sodium sulfate and analyzed by vpc on columns 1 and 3. The sole peak had vpc retention time and infrared identical to the starting alkene, 61.

Product Analysis of the Reaction of Tetracyclo [4.4.0.0^{2,4}.0^{3,7}]dec-8-ene with Potassium tert-Butoxide in Dimethylsulfoxide. Treatment of 62 in a manner identical to that described above was followed by vpc and infrared analysis, which showed 62 to be the only product of neutralization of the exchange mixture.

Test for Deuterium Exchange by 7-tert-Butoxytricyclo-[3.3.1.0^{2,4}]non-6-ene. After treatment of 60 mg of 67 with potassium tert-butoxide in dimethylsulfoxide as described above, the solution was diluted with water and extracted with ether. The ether extracts were washed with water and brine, and dried over anhydrous sodium sulfate. Removal of the ether by rotary evaporation yielded an oil. To this was added 0.1 g of potassium tert-butoxide and ca. 1 ml of perdeuteriodimethylsulfoxide. After stirring for 48 hr, the solution was worked up as described above and

and the ketone 71 (resulting from retro-ene reaction in the vpc) was subjected to mass spectral analysis at 16 eV. No deuterium incorporation was observed (<2%).

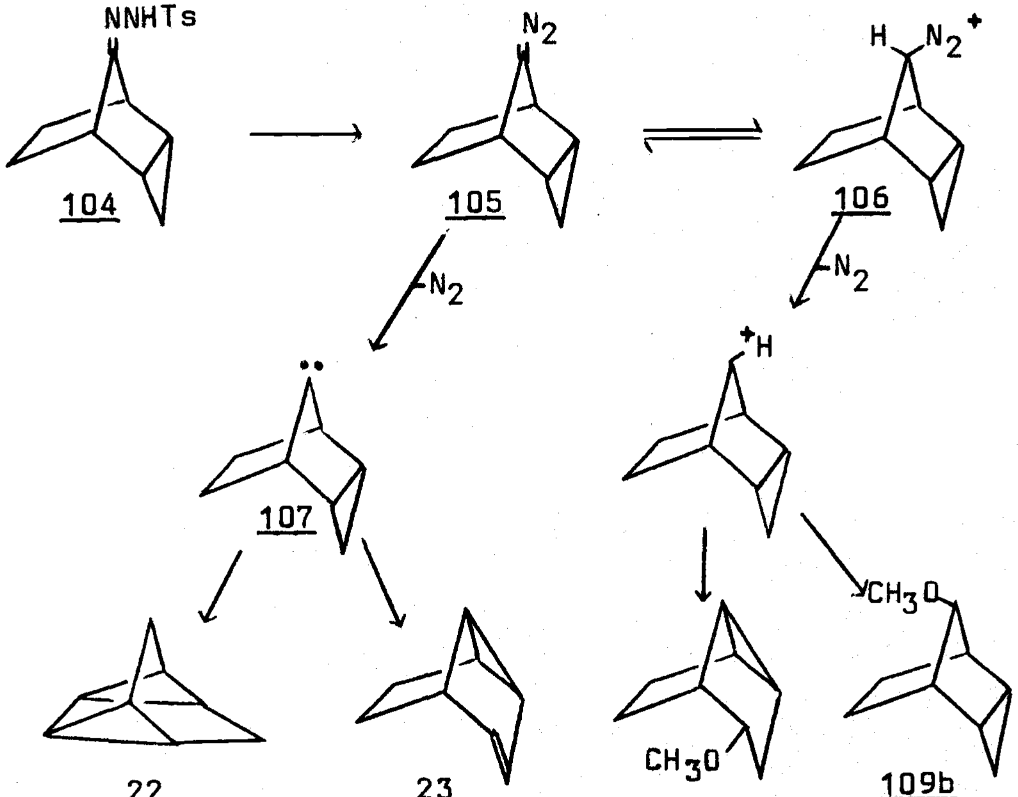
Test for Rearrangement of 10-*tert*-Butoxytetracyclo-$[4.4.0.0^{2,4}.0^{3,7}]$dec-8-ene. Potassium *tert*-butoxide (0.15 g, 1.3 mmol) and 0.8 ml of dimethylsulfoxide were stirred at room temperature for 70 hr with 10 mg (0.05 mmol) of the title ether. The solution was then quenched with 10 ml of water and extracted three times with one ml of ether. The ether extracts were washed with water and brine and analyzed by vpc (col 1, 140°, 60 ml/min). No rearrangement to a vinyl ether was detected (<0.1%).

PART III

STUDIES IN THE 8-CARBENA-*endo*-TRICYCLO[3.2.1.$0^{2,4}$]OCTANE SYSTEM

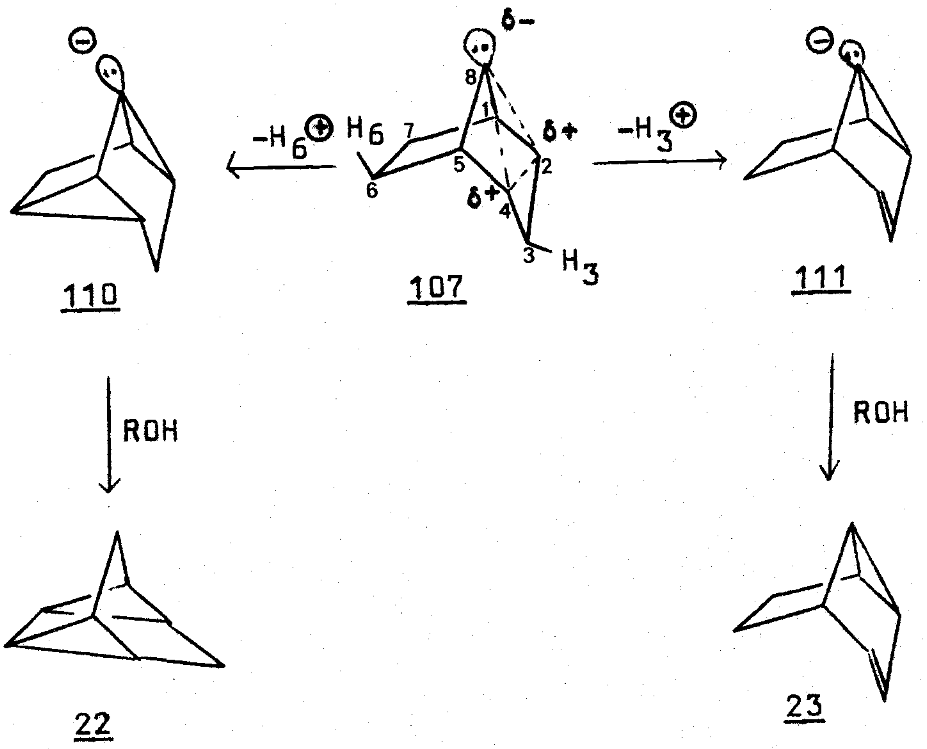
RESULTS AND DISCUSSION

Freeman and Raghavan, as discussed in the introduction, have recently studied the methoxide ion induced thermal decomposition of *endo*-tricyclo[3.2.1.$0^{2,4}$]octan-8-one tosylhydrazone, 104, in diglyme (25). Treatment of 104

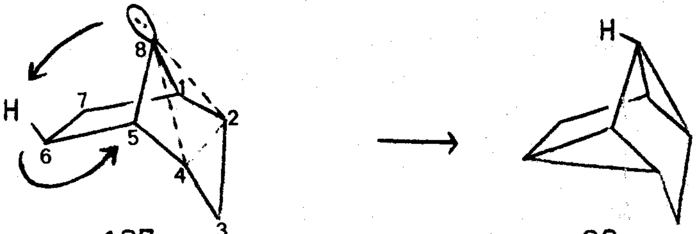


with greater than 5 equivalents of sodium methoxide at 140-160° yielded four products as shown above. The ether products were shown to arise from carbonium ion formation, leaving formation of hydrocarbon products to carbene intermediacy.

The hydrocarbon products, 22 and 23, were shown to be derived from a different intermediate than the ether products, and it was thought that these products could be best explained by the intermediacy of a non-classical carbene. Formation of 22 could be explained by intermolecular abstraction of the proton at C-6; 22 could also result from a concerted intramolecular pathway involving breakage



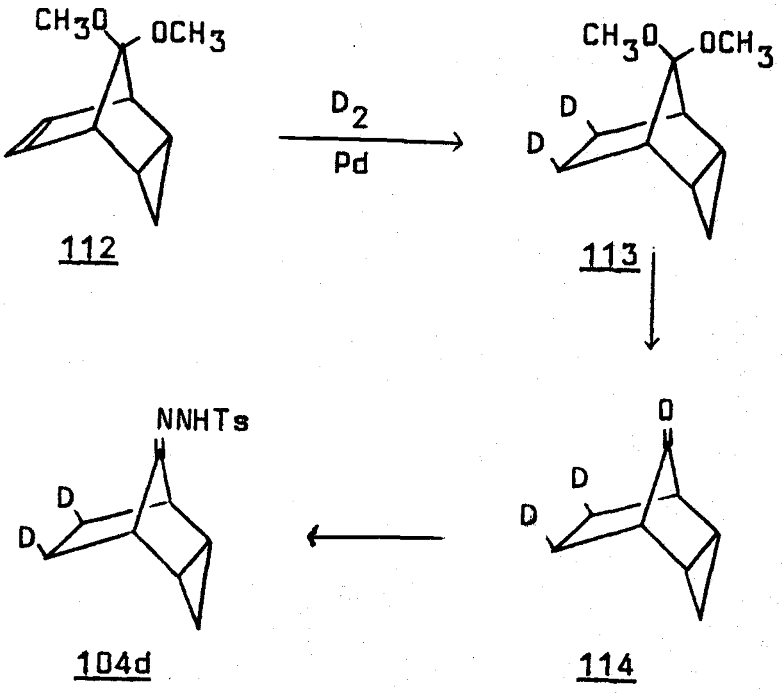
of the C-2-C-4 bond, C-2-C-8 bond formation, hydrogen migration from C-6 to C-8 and bond formation between C-6 and C-4. An important difference between these two pathways is that the intermolecular pathway proceeds via a carbanion 110, which would be protonated by the most likely source of protons, the methanol formed from neutralization of the tosylhydrazone, while the intramolecular reaction pathway necessarily will not involve proton incorporation from the solvent.



107 22

In order to test this hypothesis and determine which pathway was operative, Raghaven synthesized tosylhydrazone 104 and, using sodium methoxide, D_2O and Aliquat 336, replaced >97% of the hydrogen on nitrogen by deuterium. Since it had been observed that neutralization of carbanions exhibits a deuterium isotope effect near unity for deuterium incorporation (77), it would be expected that if the intermolecular pathway were operative, neutralization of the anion 110 by methanol-O-d would lead to >97% deuterium incorporation into 22, while 22 formed by an intramolecular pathway would be expected to contain no deuterium. Raghaven reported that mass spectral analysis of 22, formed from decomposition of tosylhydrazone-N-d, indicated that 22 contained 23±3% d_1. It thus seemed that the intramolecular pathway was the major pathway, while intermolecular formation of 22 was a minor route.

In order to confirm the dichotomy of mechanistic pathways, the obvious next step would be to replace the hydrogen on C-6 with deuterium, and observe whether deuterium is lost from the molecule (abstraction by base) or remains in 22 (intramolecular pathway). To this end, tosylhydrazone 104d was synthesized. Addition of deuterium gas to 112 afforded deuteriated ketal 113. Hydrolysis in glacial



acetic acid yielded 114, and subsequent treatment of 114 with tosylhydrazine afforded 104d. $Eu(fod)_3$ chemical shift studies (Figure 1) coupled with spin decoupling in the nmr of ketone 114 indicated that the deuterium addition to ketal 112 had been *exo*. Two batches of tosylhydrazone 104d were prepared. Batch *A* was shown to contain 80% deuterium in the *exo*-C-6 and C-7 positions, and *B* was shown to contain 43% deuterium at *exo*-C-6 and C-7 (see Table VII).

Tosylhydrazone 104d was treated with sodium methoxide (6.5 eq) in diglyme at 150-160°. Vpc analysis indicated the same four products, except for deuteriation, as found by Raghaven (25b) for the reaction of undeuteriated tosylhydrazone 104 in ratios of 33±1:4±1:29±1: 6 ±1 (22d : 23d: 109a:109b)(25c). It might have been expected that when the hydrogen on C-6 (C-7) was replaced by a deuterium, a change in the ratio of 22:23 would be observed, due to a possible isotope effect to abstraction of the C-6 hydrogen. If there was a change in the product ratios due to an isotope effect, the change, and therefore the isotope effect, was small. Table VII gives the data from mass spectral analysis of 22 and 23, along with the deuterium content of the starting tosylhydrazone. As noted in Table VII, even at low ionizing potentials, it was not possible to eliminate all the p-1 peak in the mass spectra of some of the compounds. This was corrected for after assuming no isotope effect for the loss of hydrogen. The deuterium content of

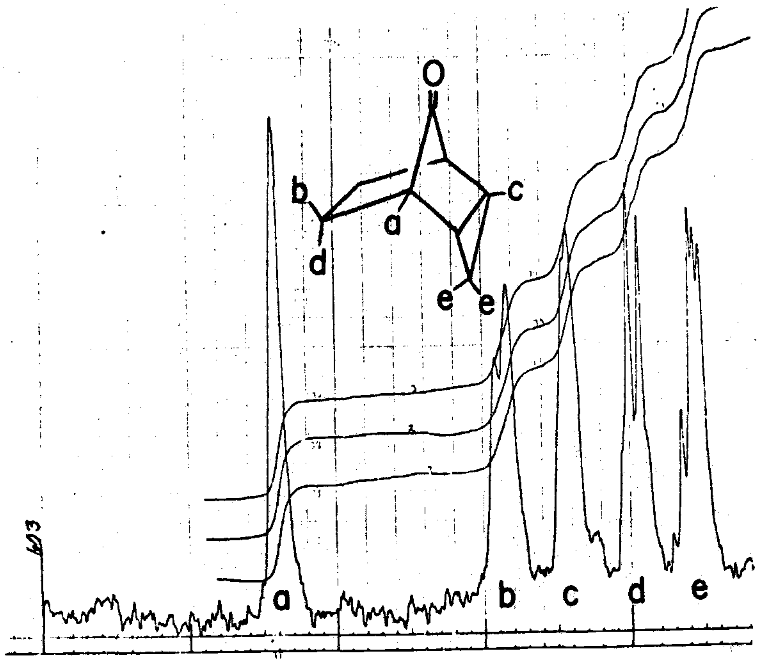


Figure 1a. 100 MHz Spectrum of _endo_-Tricyclo[3.2.1.0^{2,4}]-octan-8-one with Eu(fod)$_3$ added (sw 1,000 Hz, CCl$_4$).

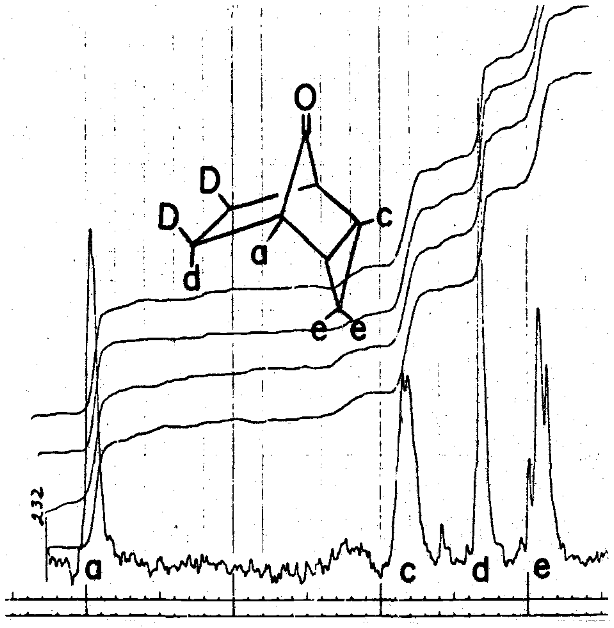


Figure 1b. 100 MHz Spectrum of _exo_-_exo_-6,7-Dideuterio-_endo_-tricyclo[3.2.1.0^{2,4}]octan-8-one, 114 (2 × 0.8 D), with Eu(fod)$_3$ added (sw 1,000 Hz, CCl$_4$).

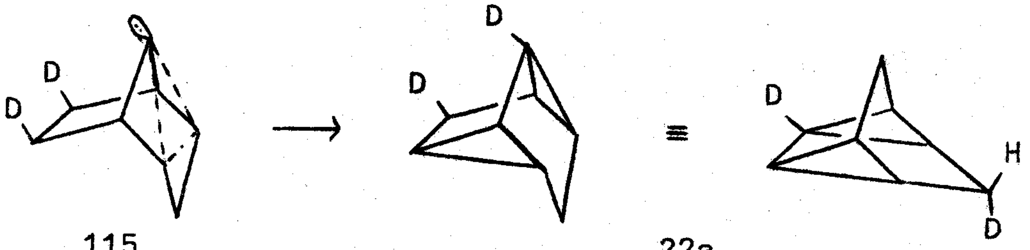
104d of batch B was determined by measuring the deuterium content of endo-tricyclo[3.2.1.0^{2,4}]octane, 114r, which was formed from 104d by sodium borohydride reduction. The percent d_0, d_1 and d_2 was calculated after correcting for the residual p-1 peak as described above, and allowing for the statistical distribution of C-13 (62) (22d and 23d are the deuteriated hydrocarbons formed in the decomposition of 104d.

Table VII. Mass Spectral Results of the Methoxide Ion Induced Thermal Decomposition of 104d

Cmpd	% p-1 of p	eV	% d_0	% d_1	% d_2
104d[a]	1.5	8.0	7.6±0.5[d]	26.2±0.5	66.2±0.9
23d	1.3	11.0	8.5±0.6	25.0±0.7	66.5±1.0
22d	2.2	11.0	11.9±0.5	24.4±0.5	63.7±0.6
114r[b]	4.5	11.0	35.3±0.5	33.0±0.5	31.7±0.7
23d	<0.5	11.0	33.9±0.7	35.8±0.7	30.2±0.5
22d	2.7	8.0[c]	37.2±0.5	34.0±0.5	28.8±0.6

a) Batch A; b) from $NaBH_4$ reduction of 104d, batch B; c) spectrum for this run only run on a Finnigan 1015 S/L mass spectrometer; d) one standard deviation

The results show rather conclusively that only a few percent, if any, deuterium is lost from the molecule in formation of both 22d and 23d, and these results rule out intermolecular abstraction of the C-6 hydrogen. In order to eliminate the possibility of hydrogen-deuterium exchange by <u>22</u>, cyclohexanone tosylhydrazone, in which the α positions and the nitrogen were 85-90% deuteriated, was decomposed in the presence of 6 equivalents of sodium methoxide, 0.5 equivalents of methanol-O-d, and 0.3 equivalents of <u>22</u>, at 160° in diglyme. Mass spectral analysis at 10.2 eV ($p-1 < 0.4\%$) indicated that the p+1 peak for <u>22</u> before treatment to the exchange conditions was 8.51±0.12% of p, while after treatment with deuteriated cyclohexanone tosylhydrazone, as described above, the p+1 peak for recovered <u>22</u> was 8.39±0.09% of p. With a 95% confidence level (1.96 standard deviations) there was < 0.3% deuterium incorporation into <u>22</u>. With base abstraction of the C-6 proton clearly ruled out, remaining was the intramolecular pathway.



<u>115</u>

<u>22a</u>

It was hoped that observation of the nmr spectrum of the deuteriated product would further pin down the mechanistic process. The nmr spectrum (CCl_4, 100 MHz) of <u>22</u> is

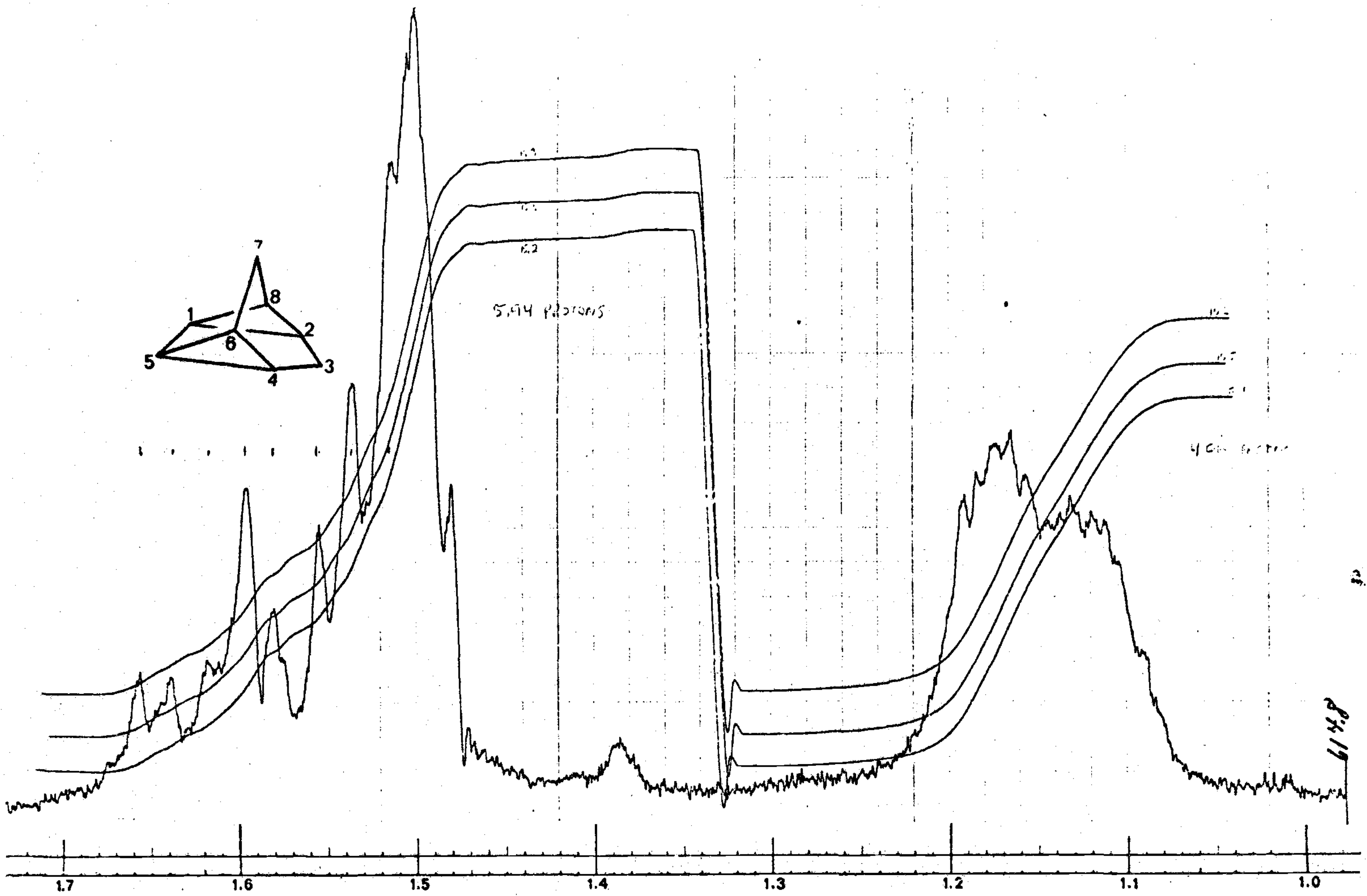
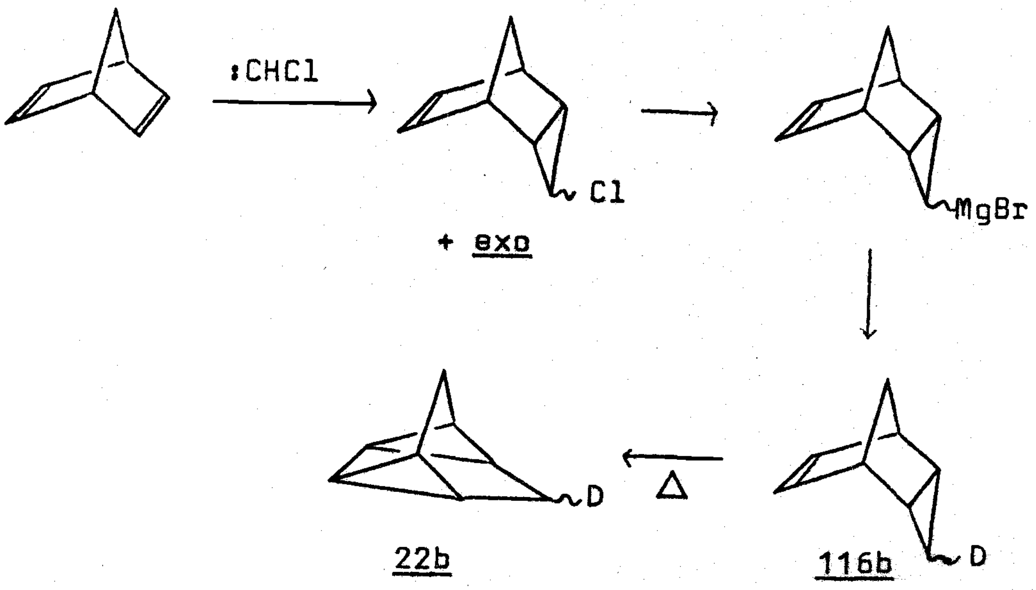


Figure 2. 100 MHz Proton NMR Spectrum of Tetracyclo[3.3.0.$0^{2,4}$.$0^{4,6}$]octane, <u>22</u> (sw 100 Hz, CCl_4).

given in Figure 2. There are two areas of absorption, at ca. δ 1.55 and 1.13, which integrate to 6 and 4 protons respectively. In order to assign the spectrum unambiguously, several deuteriated derivatives of *22* were also subjected to nmr analysis. Preparation of a mixture of *syn* and *anti*-3-deuteriotricyclo[3.2.1.0^{2,4}]oct-6-ene, *116b*, as shown below (78), was followed by pyrolysis at 240° yielding *22b* (79). Nmr analysis of *22b* (Figure 3) reveals that the absorption at δ 1.55 now integrates to 5.1 protons while the signal at δ 1.13 integrates to 4.0 protons.



Since *116b* was a 20:80 mixture of *syn* and *anti*-3-deuterio-epimers, it would seem that the methylene protons at C-3 (of *22*), and therefore the methylene protons at C-7, ab-

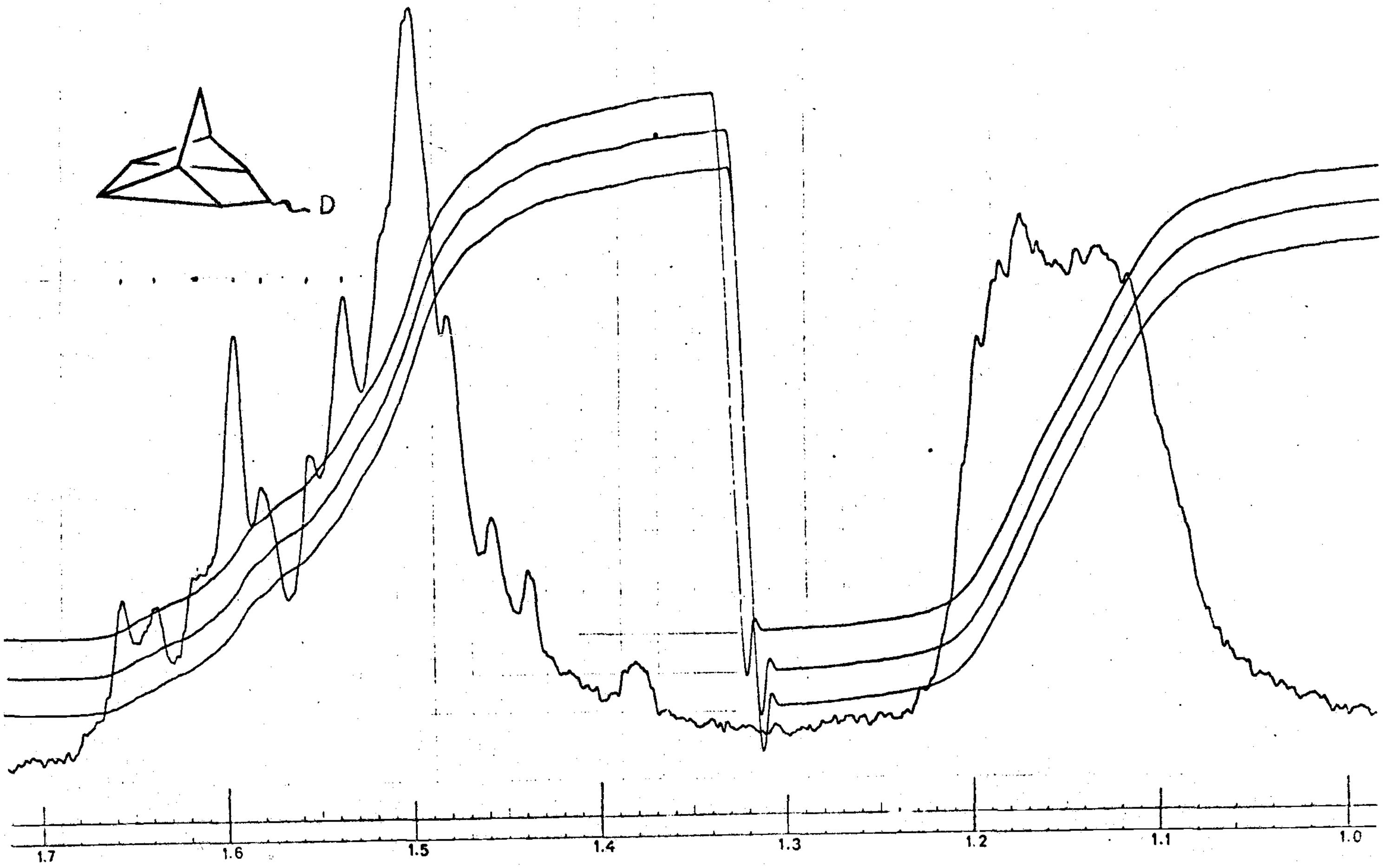
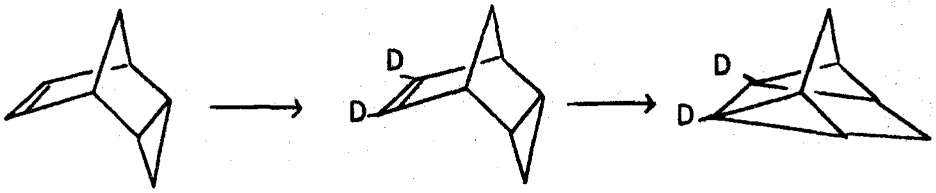


Figure 3. 100 MHz Proton NMR Spectrum of 3-Deuteriotetracyclo[3.3.0.$0^{2,8}$.$0^{4,6}$]octane, <u>22b</u> (0.9 D) (sw 100 Hz, CCl_4).

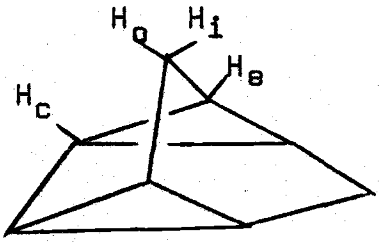
sorb at ca. δ 1.55.

To complete the unambiguous assignment of the nmr of 22, 116 was treated with cyclohexylamide-d_2 and lithium cyclohexylamide-d_1 by the method of Zimmerman and co-workers (80) yielding 116c. Mass spectral and nmr analysis



116 116c 22c

indicated > 80% olefinic deuterium incorporation. Pyrolysis at 240° yielded 22c. The proton nmr spectrum of 22c (Figure 4) shows a dramatic reduction of a signal centered at δ 1.58. The absorptions at ca. δ 1.55 and 1.13 now integrate to 4.2 and 4.0 protons respectively. Also, the signal at δ 1.13 has sharpened up appreciably, indicating strong coupling between the corresponding protons.



22

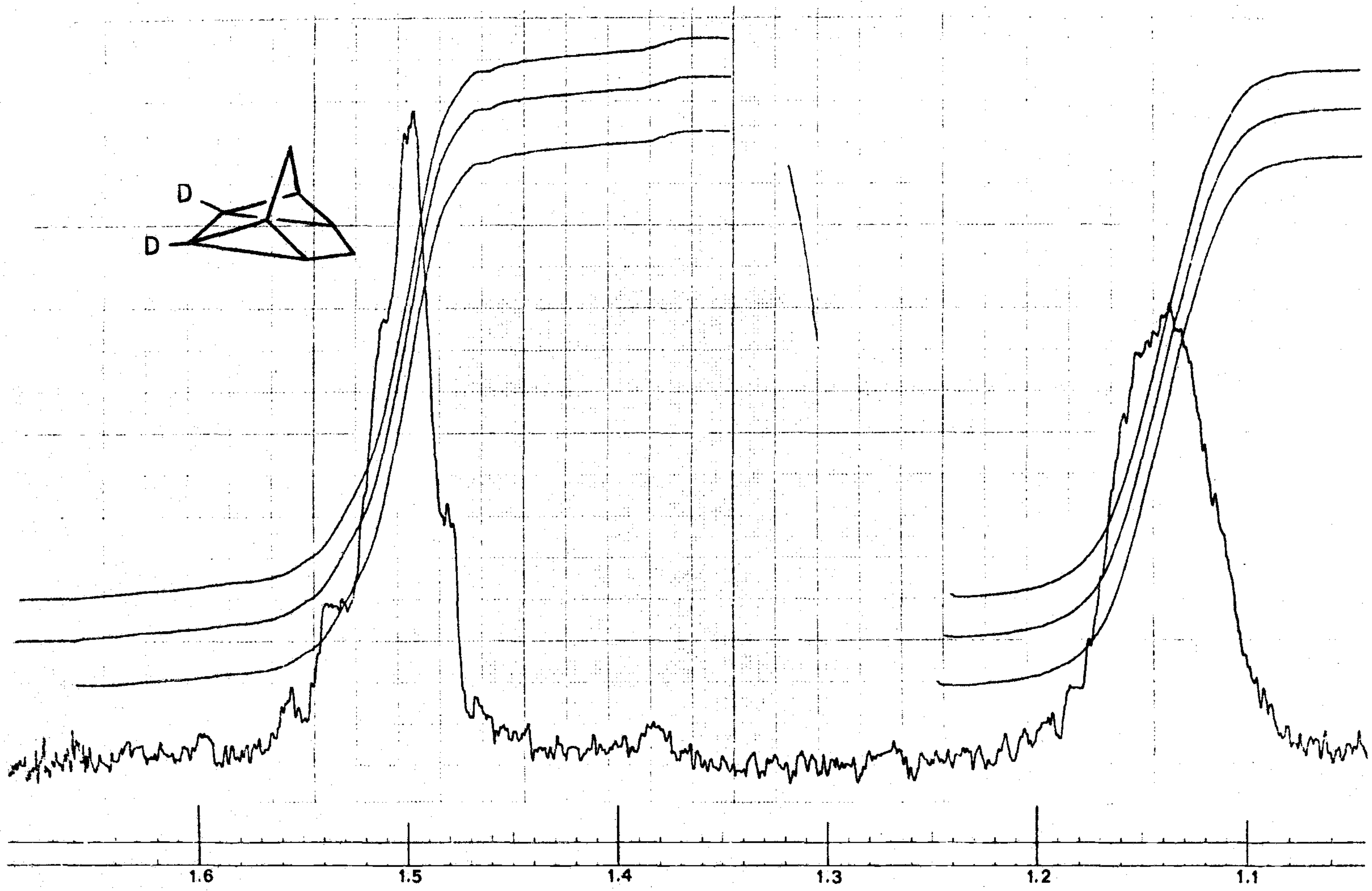


Figure 4. 100 MHz Proton NMR Spectrum of 1,5-Dideuteriotetracyclo $[3.3.0.0^{2,8}.0^{4,6}]$octane, 22c (2 x 0.8 D) (sw 100 Hz, CCl_4).

The nmr spectrum of 22 can now be completely assigned. The 4 equivalent protons, H_e, form a very broadened doublet with J≅6 Hz at δ 1.13. The methylene protons H_o and H_i give rise to a fairly sharp signal at δ 1.50, and the two equivalent H_c protons give rise to a highly split signal centered at δ 1.58, which overlaps with the H_o and H_i absorptions.

Since the product of an intramolecular hydrogen shift, 22a, would be expected to have partial deuterium substitution for H_o and H_c, it would be expected that the 6-proton signal at ca. δ 1.55 would integrate to 4.4 protons, while the signal at δ 1.13 would not change in intensity. Figure 5 shows the nmr spectrum of 22d actually formed from the decomposition of 104d (batch A). The absorption at δ1.55 now integrates to 5.2 protons, and the signal at δ 1.13 integrates to 3.2 protons. Also, there seems to be little change in the highly split signal arising from the H_c protons. Thus the nmr of 22d arising from 104d seems to be inconsistent with both the intramolecular and intermolecular pathways suggested by Raghaven and Freeman (25).

In order to confirm these results and get a "handle" on the process of carbene generation and subsequent product formation in the *endo*-tricyclo[3.2.1.0^{2,4}]octane system, 2-methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one tosylhydrazone, 121, was synthesized in a manner analogous to that used for synthesis of the unmethylated tosylhydrazone 104 (25b).

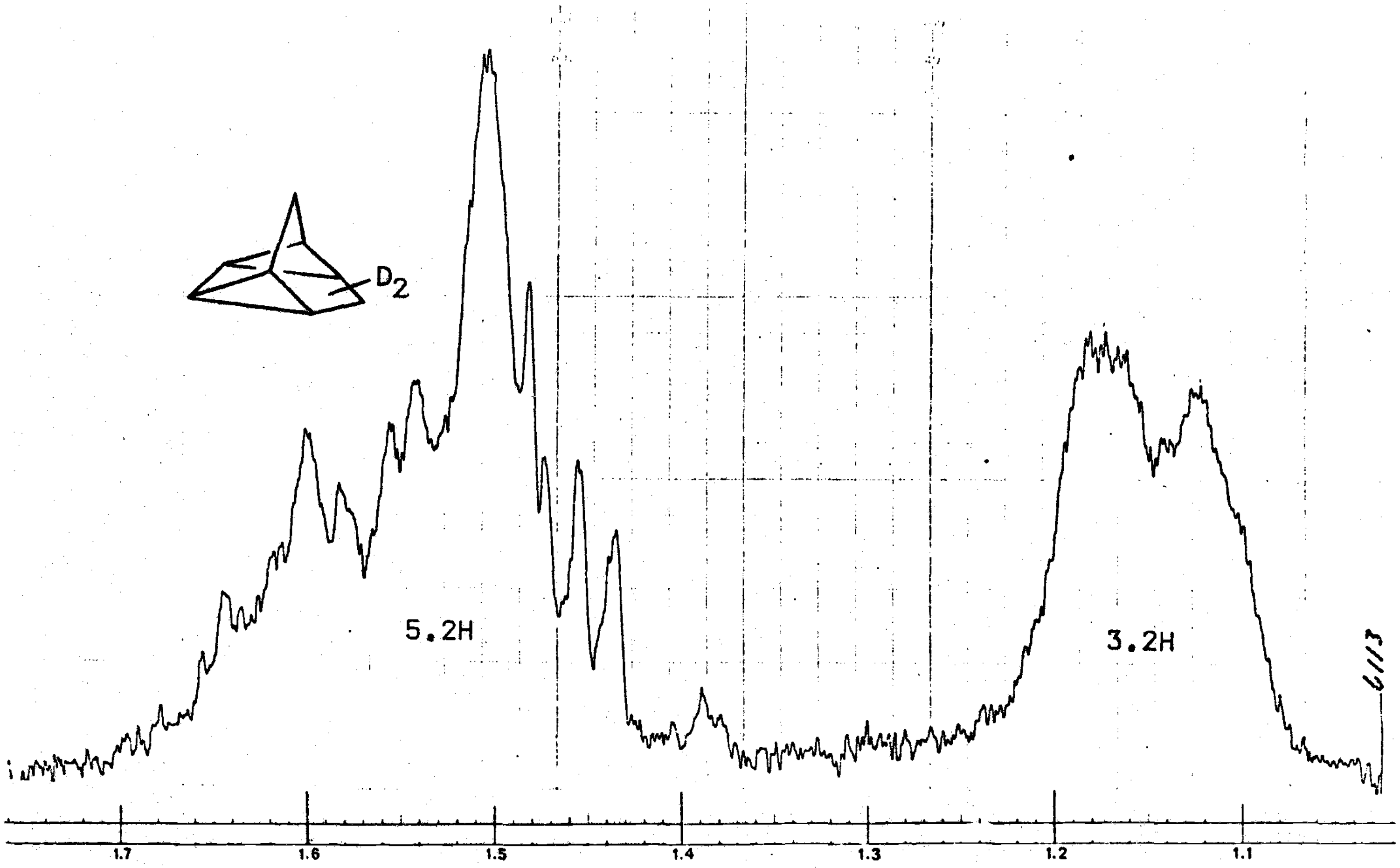
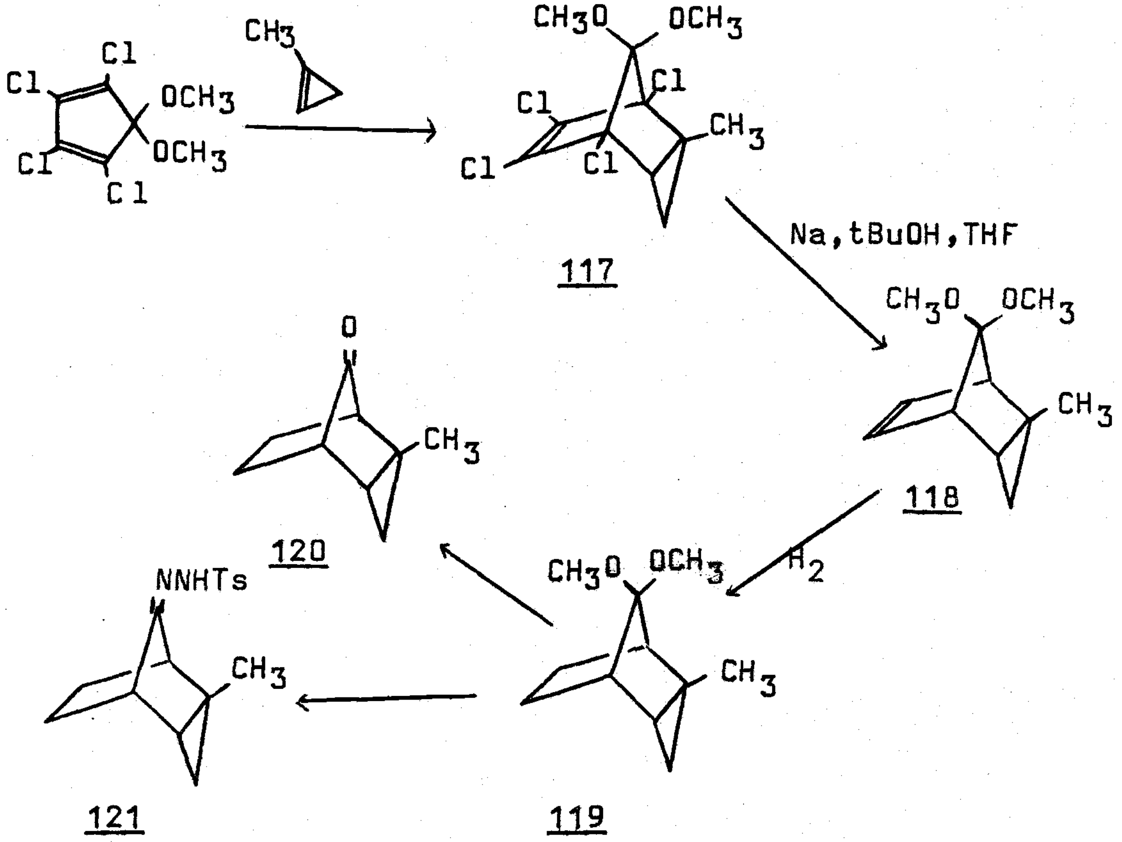


Figure 5. 100 MHz Proton NMR Spectrum of Dideuteriated Tetracyclo-[3.3.0.$0^{2,8}$.$0^{4,6}$]octane, 22d, from Decomposition of Tosylhydrazone 104d (sw 100 Hz, CCl_4).

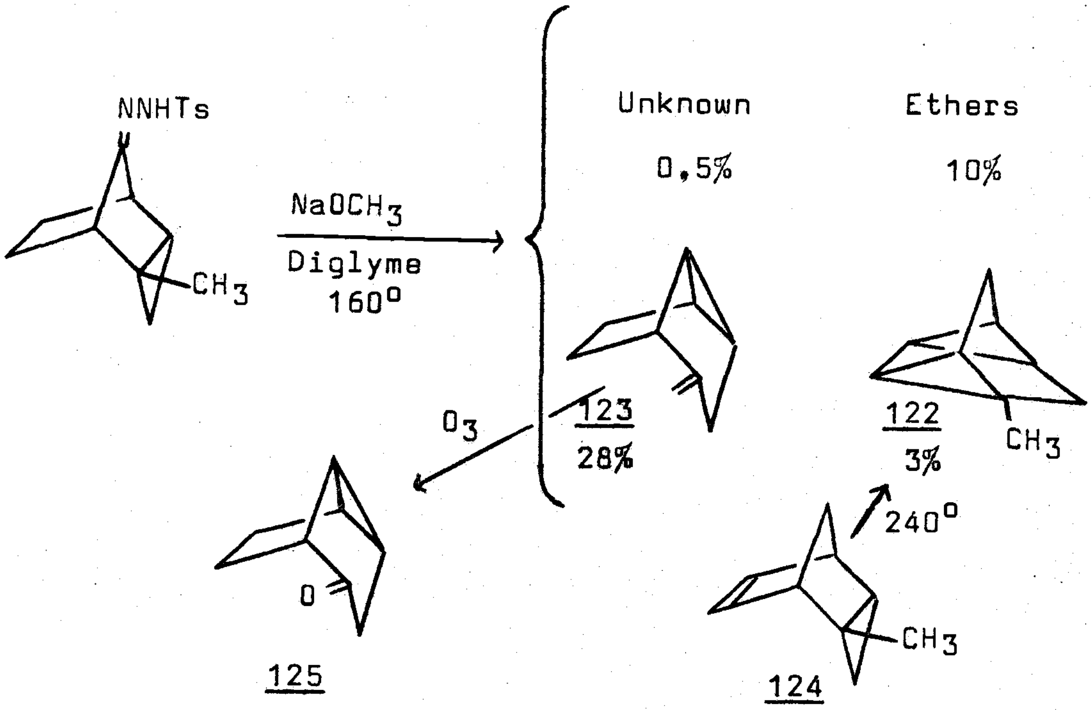
Treatment of 5,5-dimethoxy-1,2,3,4-tetrachlorocyclopentadiene (25b) with methylcyclopropene (81) produced 117 in nearly quantitative yield. Reduction of 117 with sodium and *tert*-butyl alcohol in tetrahydrofuran yielded alkene ketal 118 in 56% yield. After hydrogenation to yield 119, difficulties were encountered in isolating 120, so tosylhydrazone 121 was prepared directly from the ketal by heating tosylhydrazine and 119 with *p*-toluenesulfonic acid catalyst in 90% aqueous methanol.



Tosylhydrazone 121 was then subjected to methoxide ion induced decomposition at 150-160° in diglyme, with 6.5 equivalents of sodium methoxide. Vpc analysis showed 3 peaks in the hydrocarbon region of the chromatogram, and 3 peaks with longer retention time. An internal vpc standard showed the yields of the hydrocarbon products to be 0.5%, 3% and 28%, with the total yield of the longer retention time products being ca. 10%. The three longer retention time peaks were found to all have mass spectral parent ions of m/e=152, corresponding to methyl ethers. Since it has been shown that methyl ethers arise from a carbonium ion component (25b, 57), these products were not investigated further. The 0.5% product could not be isolated in sufficient quantity or purity for identification.

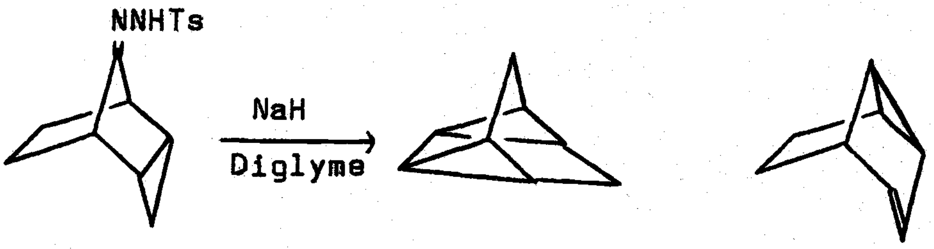
The 3% component yields a mass spectral parent ion of m/e=120 corresponding to C_9H_{12} and has an infrared absorption (0.1 mm, CCl_4) at 3020 cm^{-1} and no C=C absorption. The nmr spectrum exhibits no olefinic protons (all the absorption is between δ 1.8 and 1.0). The structure was tentatively assigned as 2-methyltetracyclo[$3.3.0.0^{2,8}0^{4,6}$]octane, <u>122</u>, and this was confirmed when pyrolysis of 2-methyltricyclo[$3.2.1.0^{2,4}$]oct-6-ene, <u>124</u> (81), yielded a compound identical in all respects with <u>122</u> (79).

The 28% component gives a mass spectral parent ion of m/e=120; infrared absorptions at 1647 cm^{-1} and at 877 cm^{-1} indicate the presence of a terminal double bond, and the nmr spectrum reveals a 2 proton singlet at δ 4.54. This product was tentatively identified as 2-methylenetricyclo[$3.3.0.0^{4,6}$]octane, <u>123</u>, and this was subsequently shown



to be correct when ozonolysis yielded the known ketone tricyclo[$3.3.0.0^{4,6}$]octan-2-one, 125 (7). Generation of 8-carbena-2-methyltricyclo[$3.2.1.0^{2,4}$]octane, 126, is thus analogous to carbene generation in the unmethylated system, 107, with a tetracyclic hydrocarbon and an alkene formed, presumably, from the carbene, and ethers from a carbonium ion component.

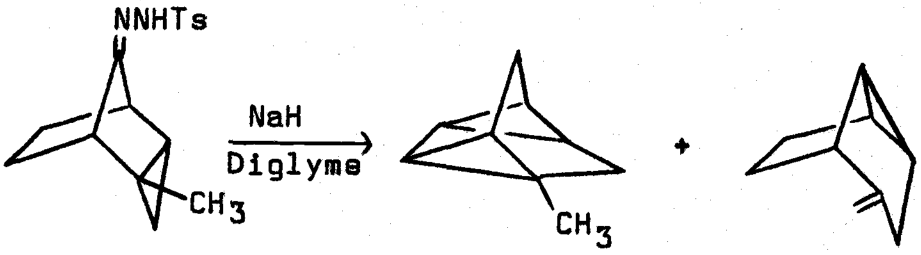
Since Raghaven's work indicated that there is a carbonium ion component in the methoxide induced decomposition of 104, it was thought that perhaps use of sodium hydride as base could eliminate the carbonium ion component, since there would be no alcohol of neutralization present. Treatment of tosylhydrazone 104 with excess (2-3 equivalents) sodium hydride in diglyme at 160° yielded 22 and 23 in the same ratio as observed for methoxide ion induced decomposition, while no ether products were observed.



104 22 23

8 : 1

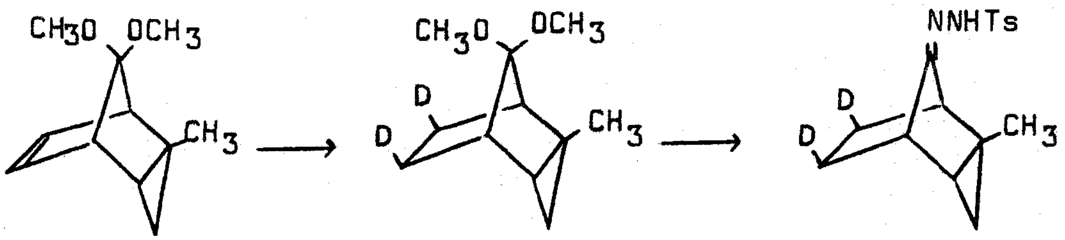
Tosylhydrazone 121 was then treated with excess (2-3 equivalents) of sodium hydride in diglyme at 160°. No ethers were formed, but the ratios of the hydrocarbons changed. In fact, while the yield of hydrocarbons increased to 50-60%, the ratio of 123 to 122 dropped from 9:1 (observed in methoxide ion induced decomposition) to as low as 1.5:1, indicating that 123 is formed at least



121 122 123

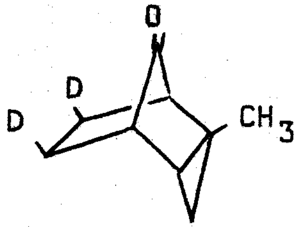
to some degree by a carbonium ion mechanism. Actually, the ratio of 123 to 122 was not constant but varied from 3:1 to 1.5:1 in different runs.

In order to determine whether the mechanism of formation of 122 was analogous to that for formation of 22, deuteriated tosylhydrazone 121d was synthesized by adding deuterium to ketal alkene 118, followed by hydrolysis of 119d and *in situ* formation of 121d. A small amount of deuteriated ketal was hydrolyzed to the corresponding ketone, 120d,



118 119d 121d

which was subjected to spectral analysis. Eu(fod)$_3$ chemical shift studies of the nmr of 120d (Figure 6) showed that the *exo*-C-6 and C-7 positions contained 85% deuterium.



120d

Decomposition of deuteriated tosylhydrazone 121d with excess (1-3 equivalents) sodium hydride in diglyme at 160° yielded deuteriated hydrocarbons 122d and 123d. Mass spectral analyses of 122d and 123d are presented in Table VIII (pg 141), and indicate that, as in the formation of 22d

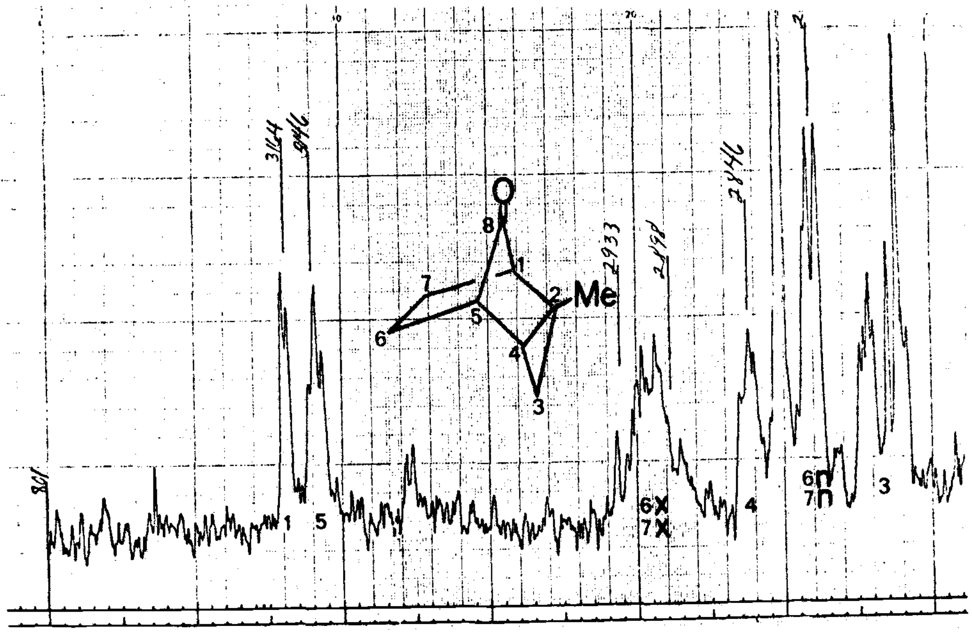


Figure 6a. 100 MHz Spectrum of 2-Methyl-endo-tricyclo-[3.2.1.$0^{2,4}$]octan-8-one, 120, with $Eu(fod)_3$ added (sw 1,000 Hz, CCl_4).

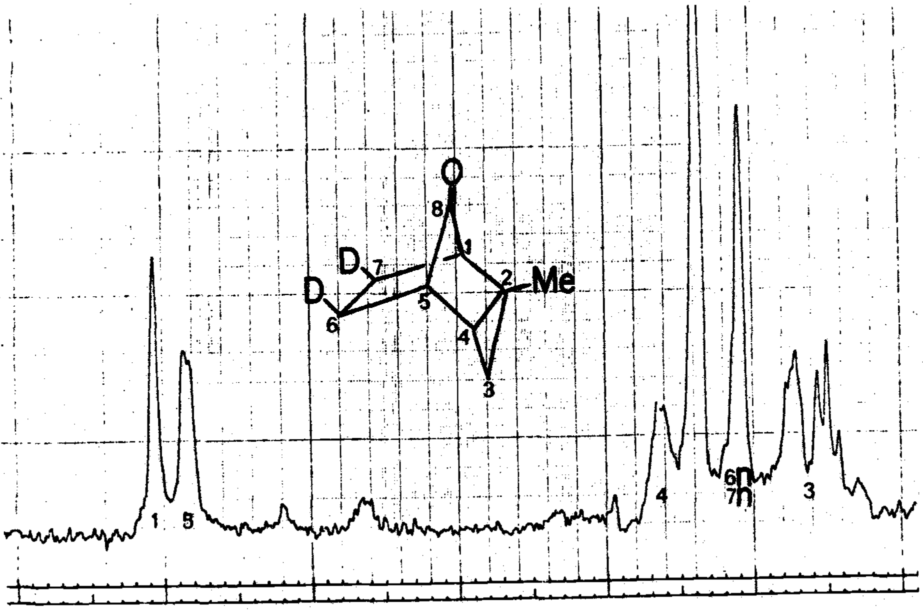
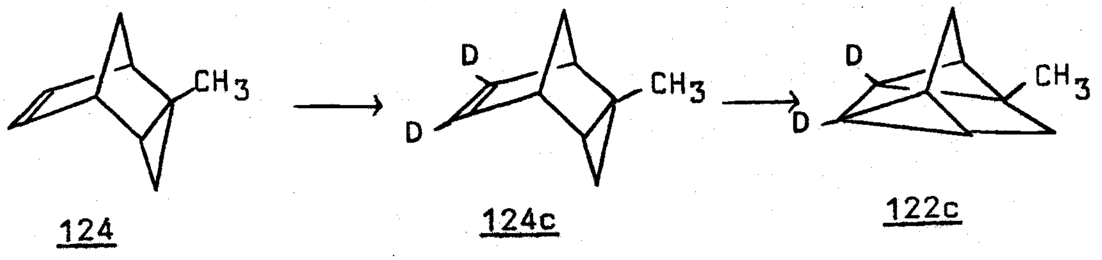


Figure 6b. 100 MHz Spectrum of 6,7-Dideuterio-2-Methyl-endo-tricyclo[3.2.1.$0^{2,4}$]octan-8-one, 120d, (2 x 0.8 D) with $Eu(fod)_3$ added (sw 1,000 Hz, CCl_4).

and 23d from 104d, there is little deuterium loss to the solvent.

The nmr spectrum of 122 is quite complex, and consists (C_6H_6, 100 MHz) of a series of signals between δ 1.75 and 0.99 (Figure 7). There are five bands of absorptions, labled W, X, Y, Z and M: δ 1.75-1.66 (band W, 3H), 1.66-1.57 (band X, 2H), 1.55-1.40 (band Y, doublet of doublets, J=4 Hz, 6 Hz, 1H), 1.33-1.09 (band Z, 3H) and 1.00 (band M, 3H, methyl group).

In order to assign these signals, several deuteriated derivatives of 122 were synthesized. Treatment of 124 (81) with N,N-dideuteriocyclohexylamine and lithium N-deuteriocyclohexylamide (80) yielded 124c, which was shown by mass spectral and nmr analysis to contain 80% deuterium in the olefinic positions. Pyrolysis of 124c at 160° yielded 122c.



The nmr spectrum (C_6H_6, 100 MHz) of 122c (Figure 8) shows that absorption band W (δ 1.75-1.66) now integrates to ca. 2.2 protons, and the doublet of doublets at δ 1.55-1.40 has nearly completely dissappeared, integrating to ca. 0.2

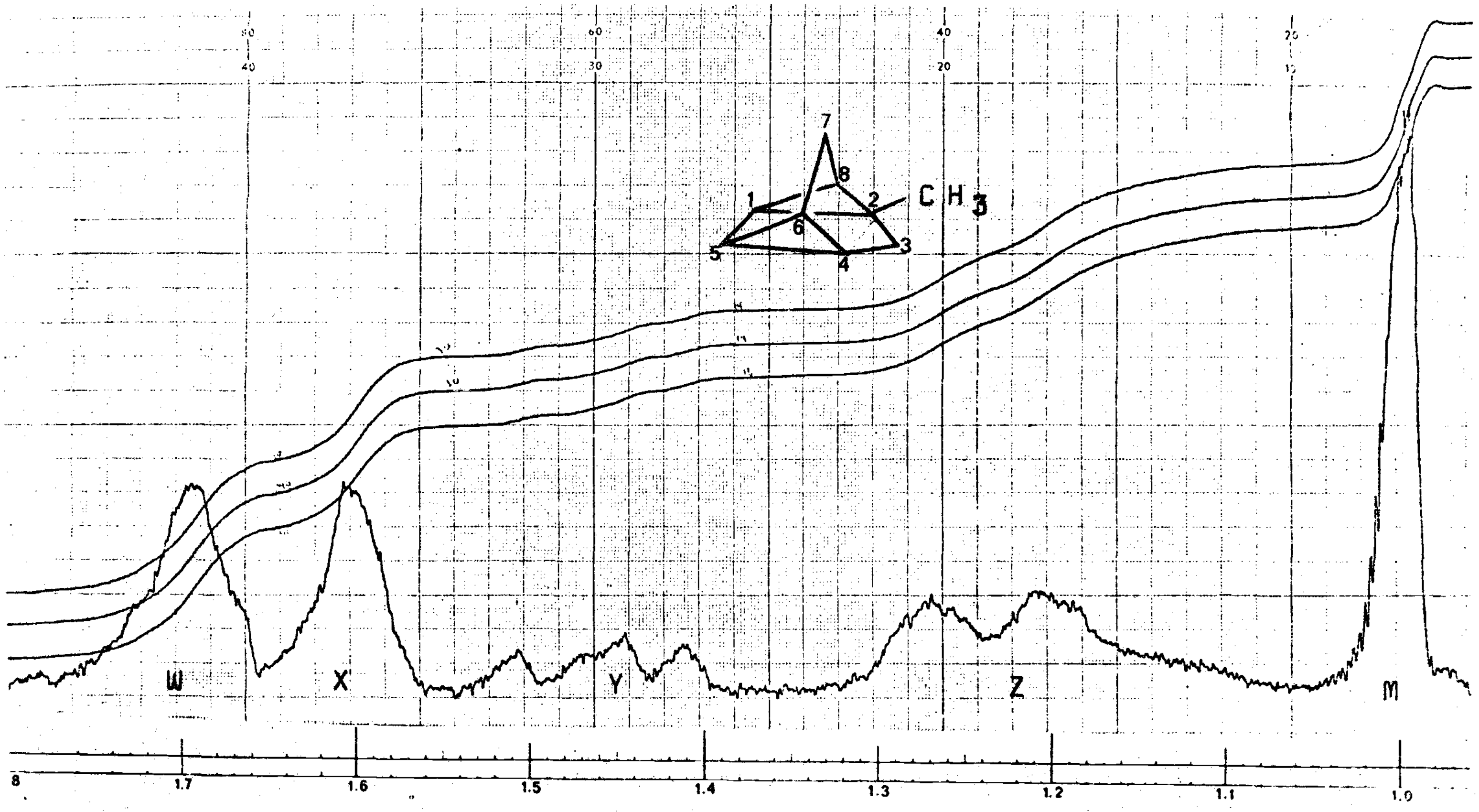


Figure 7. 100 MHz Proton NMR Spectrum of 2-Methyltetracyclo[3.3.0.$0^{2,8}$.$0^{4,6}$]-octane, <u>122</u> (sw 100 Hz, C_6H_6).

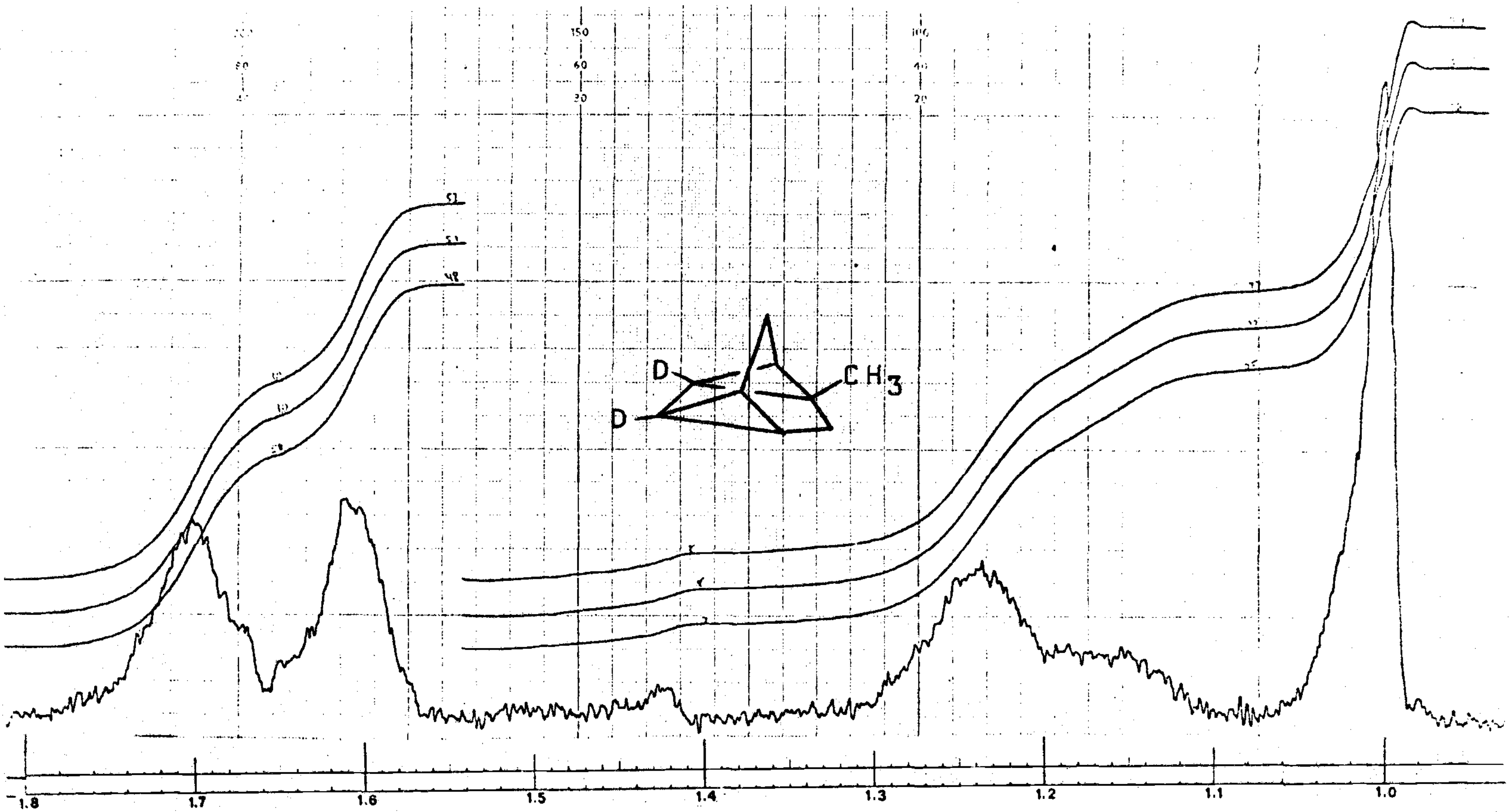
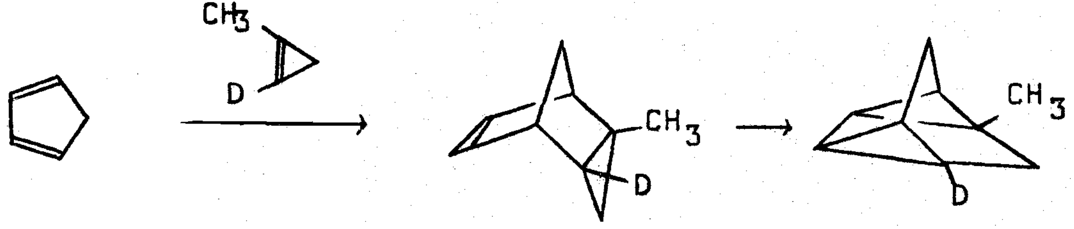


Figure 8. 100 MHz Proton NMR Spectrum of 1,5-Dideuterio-2-methyltetracyclo-[3.3.0.0^{2,8}.0^{4,6}]octane, <u>122c</u> (2 x 0.8 D) (sw 100 Hz, C_6H_6)

protons. The low field deuterium was assigned to C-5, while the doublet of doublets was assigned to C-1. This is consistant with the upfield shift expected for a bridgehead hydrogen vicinal to a syn periplanar methyl group (82). The deuterium nmr of 122c is also quite helpful (Figure 9). at δ 1.67 is an absorption which seems to be a skewed triplet or doublet of doublets, with J 1≈Hz. This coupling is between a hydrogen and a deuterium and is about one-sixth that which would be observed for the corresponding hydrogen-hydrogen coupling. This signal corresponds to a deuterium on C-5. With less splitting (a skewed doublet, J≈1 Hz) is a signal at δ 1.45, which must correspond to a deuterium at C-1. The deuterium at C-5 would be expected to be split by hydrogens on C-4 and C-6 (coupling by cis protons on a cyclopropyl ring is usually on the order of 6≈Hz) (83b), while the deuterium on C-1 would be expected to be split only by the proton at C-8 (vicinal deuterium-deuterium splitting would be negligible).

In order to clarify further the nmr spectrum, C-4 deuteriated 122e was synthesized by pyrolysis of 124e. Preparation of 124e was accomplished by treating cyclopenta-



124e

122e

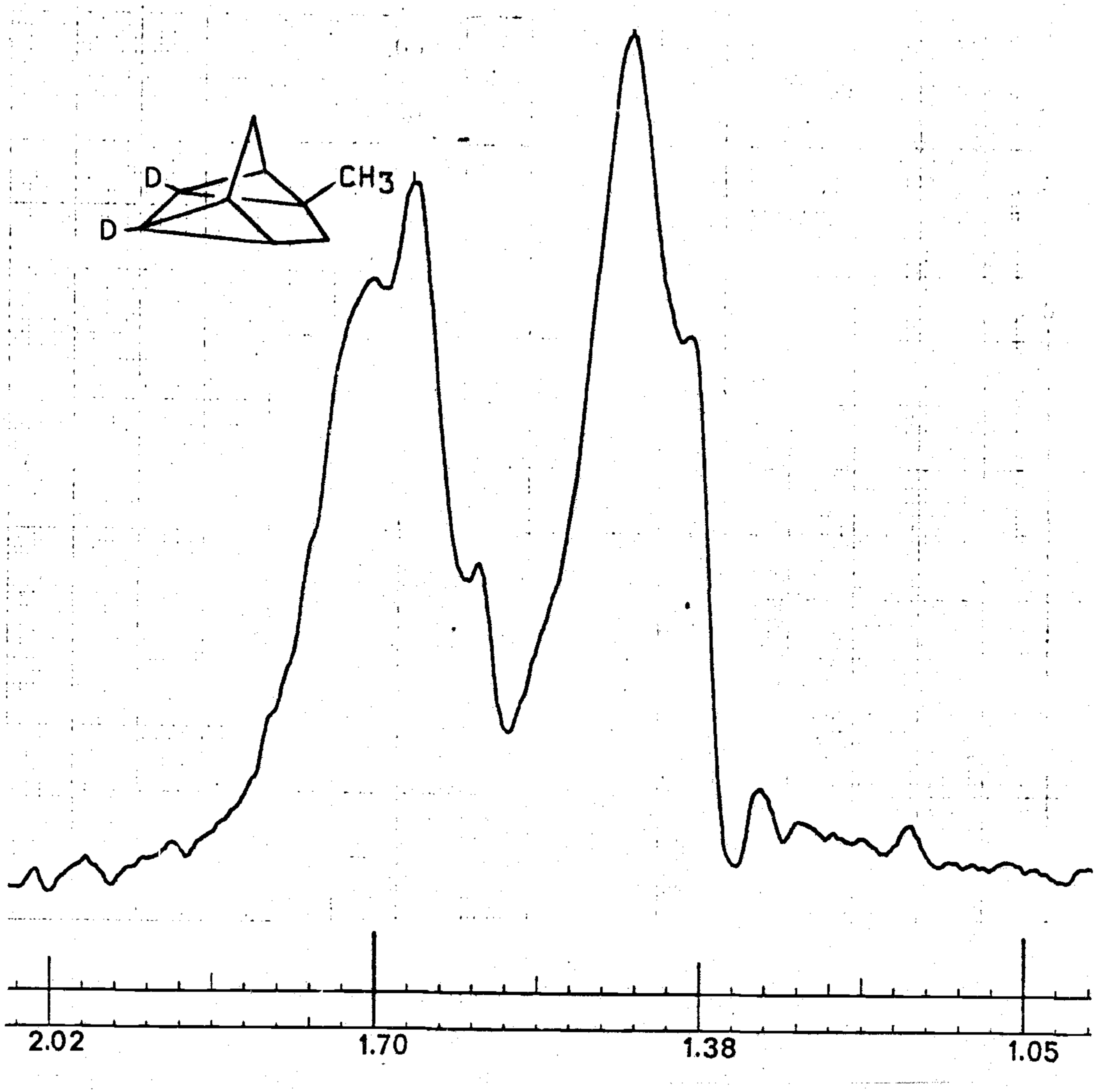


Figure 9. 15.4 MHz Deuterium NMR of 1,5-Dideuterio-2-methyltetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane, <u>122c</u> (2 x 0.8 D) (sw 50 Hz, C_6H_6).

diene with 2-deuterio-1-methylcyclopropene (81). Mass spectral and nmr analysis showed 124e to consist of 98% d_1 at C-4. The proton nmr spectrum (Figure 10) of 122e (which mass spectral analysis indicated also contained 98% d_1) is noticeably changed. Absorption band W has now become quite resolved, indicating that protons in W are coupled to the proton at C-4. Band X has also sharpened up appreciably, indicating some small coupling with C-4, and the doublet of doublets at δ 1.45, assigned to the proton at C-1, has not changed. The broad band from δ 1.33-1.09 has become less pronounced, and now integrates to only 2 protons.

The deuterium nmr of 122e (Figure 11) confirms the proton nmr assignment, that band Z includes the proton (deuterium) on C-4, with a broad signal at δ 1.14.

It is important to realize, in the proton nmr of 122 (Figure 7), the significance of the doublet of doublets at δ 1.45. It is due to the proton at C-1, and is split by 6 Hz and 4 Hz. The deuterium nmr spectrum of 122c (Figure 9) shows this δ 1.45 signal to be a (skewed) doublet with J=1.0 Hz. This corresponds to a proton-proton coupling of ca. 6 Hz. Thus the proton (Figure 6) at δ 1.45 is split by 4 Hz by the proton at C-5 (this coupling disappears in the deuterium nmr of 122c) and by 6 Hz due to the proton at C-8. These assignments are further confirmed by the various intensities of the lines of the doublet of doublets.

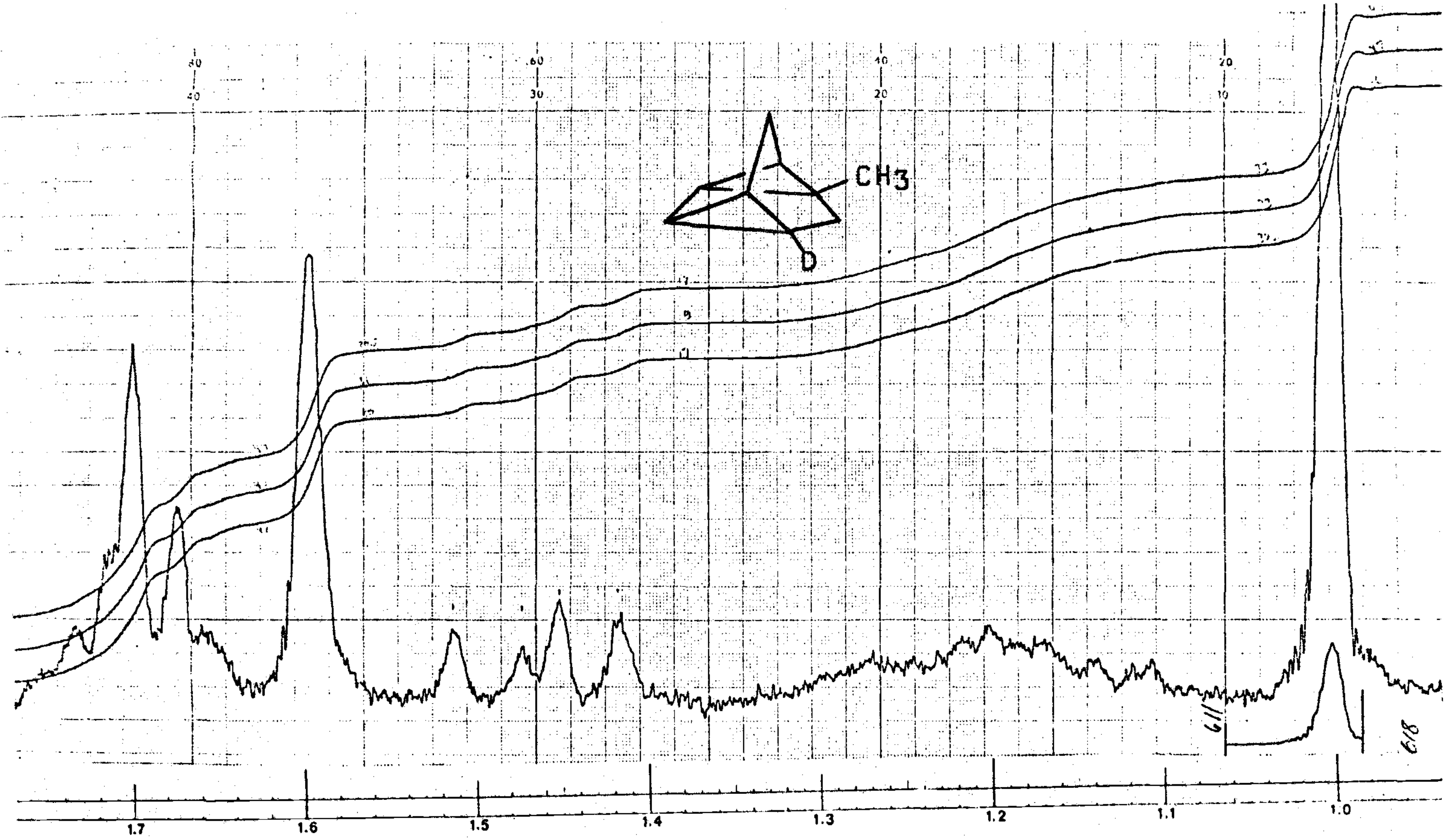


Figure 10. 100 MHz Proton NMR of 4-Deuterio-2-methyltetracyclo-[3.3.0.0^{2,8}.0^{4,6}]octane, 122e (1.0 D) (sw 100 Hz, C_6H_6).

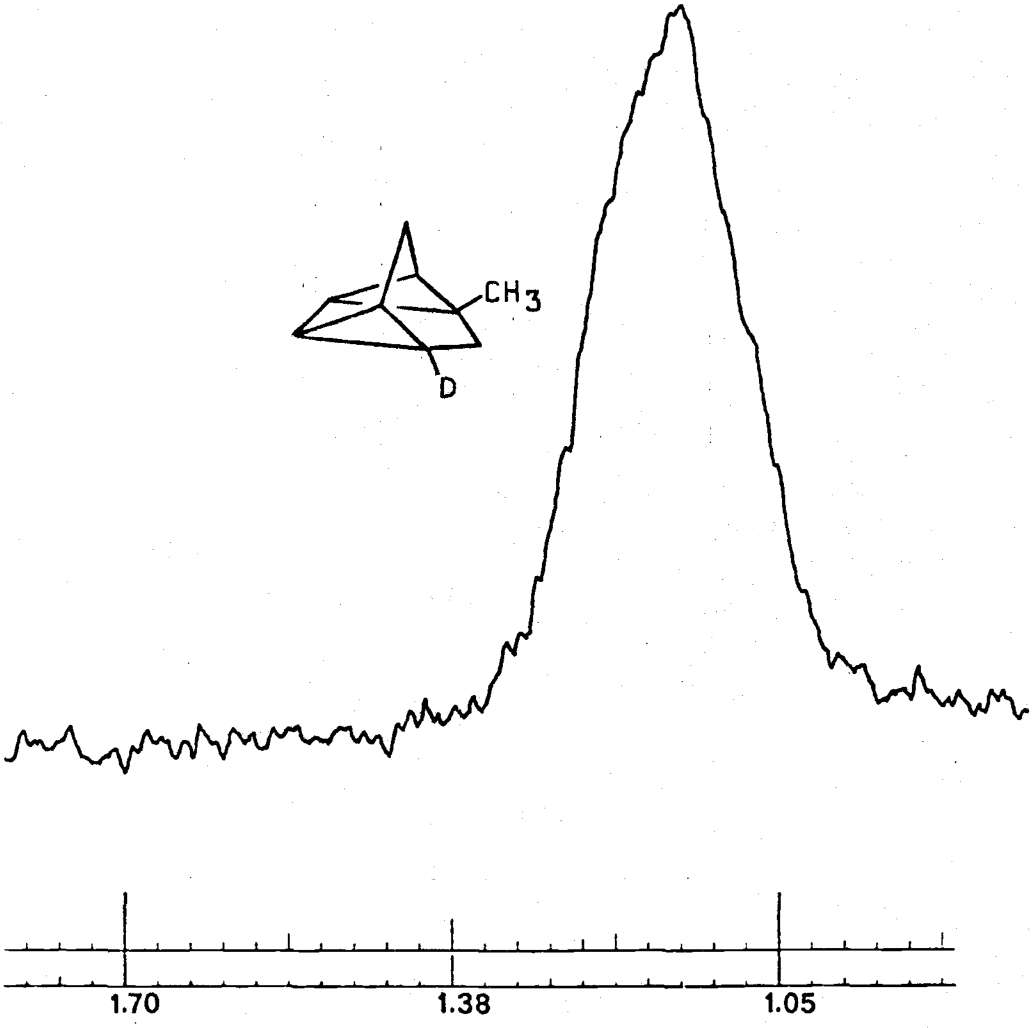
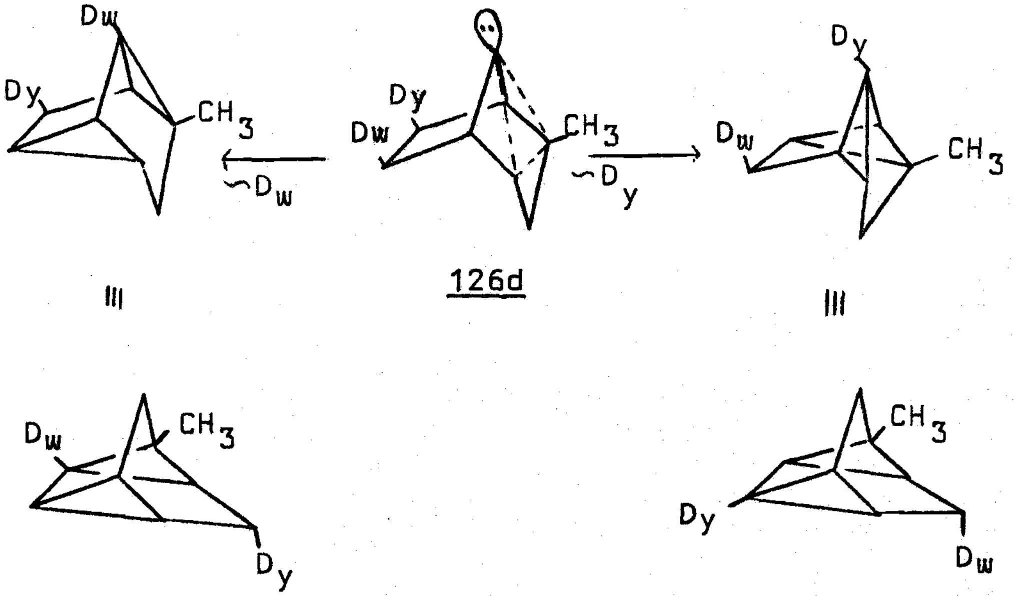


Figure 11. 15.4 MHz Deuterium NMR Spectrum of 4-Deuterio-2-methyltetracyclo[3.3.0.$0^{2,8}$.$0^{4,6}$]octane, <u>122e</u> (1.0 D) (sw 50 Hz, C_6H_6).

It can be seen (Figure 10 is a good example) that the 4 Hz splitting is more intense on the left side, that is, it "points" to the proton (in this case the signal due to the proton on C-5 at δ 1.67) with which it is coupled (83a). The 6 Hz splitting is more intense on the upfield side, since it points to the proton on C-8, and the C-8 proton would be expected to be shifted upfield from even the δ 1.14 signal of the C-4 proton, due to the shielding effect of the methyl (82). Thus by observing, in the proton nmr of a deuteriated 122, the lone proton at δ 1.45, along with its splitting, we would have direct evidence for deuterium incorporation at C-1, C-5 or C-8.

Returning to the decomposition of deuteriated tosylhydrazone 104d, mass spectral analysis of the product 122d indicated that little, if any, deuterium is lost in product formation (Table VIII, pg 141), ruling out an intermolecular abstraction of protons from C-6 or C-7 of 126. Intramolecular migration of hydrogen from C-6 or C-7 to C-8, along with simultaneous bond making and breakage, analogous to that suggested for formation of 22 via 107, would account for the retention of deuterium in 122d. There would be two possible products, depending upon which deuterium migrated. In both cases, a deuterium would end up on a methylene at C-7; however, migration of D_w would place a deuterium at C-1, 128, while migration of D_y would place a deuterium at C-5, 129. Each situation would be observable by the analysis of the signal at δ 1.45 discussed above.



128 129

The most obvious aspect of the proton nmr of 122d (Figure 12) is that the signal at δ 1.45 has changed neither in intensity nor splitting. Thus the deuteriums in 122d are not at C-1, C-5 or C-8. This is quite significant since it completely rules out an intramolecular pathway as described above. Where are the deuteriums? The proton nmr of 122d shows a decrease of the W band to ca. 2 protons and a decrease of band Z to 1.1 protons. Here the deuterium nmr of 122d (Figure 13) is very helpful. Centered at δ 1.72 is a signal that is definitely a doublet (J=1.75 Hz) with a secondary splitting that looks like a (skewed) doublet (J=1 Hz). The 1.75 Hz splitting corresponds to a proton-proton splitting of 11 Hz, which is reasonable for a geminal splitting (83b, 84). The second splitting, which would correspond to a proton-proton coup-

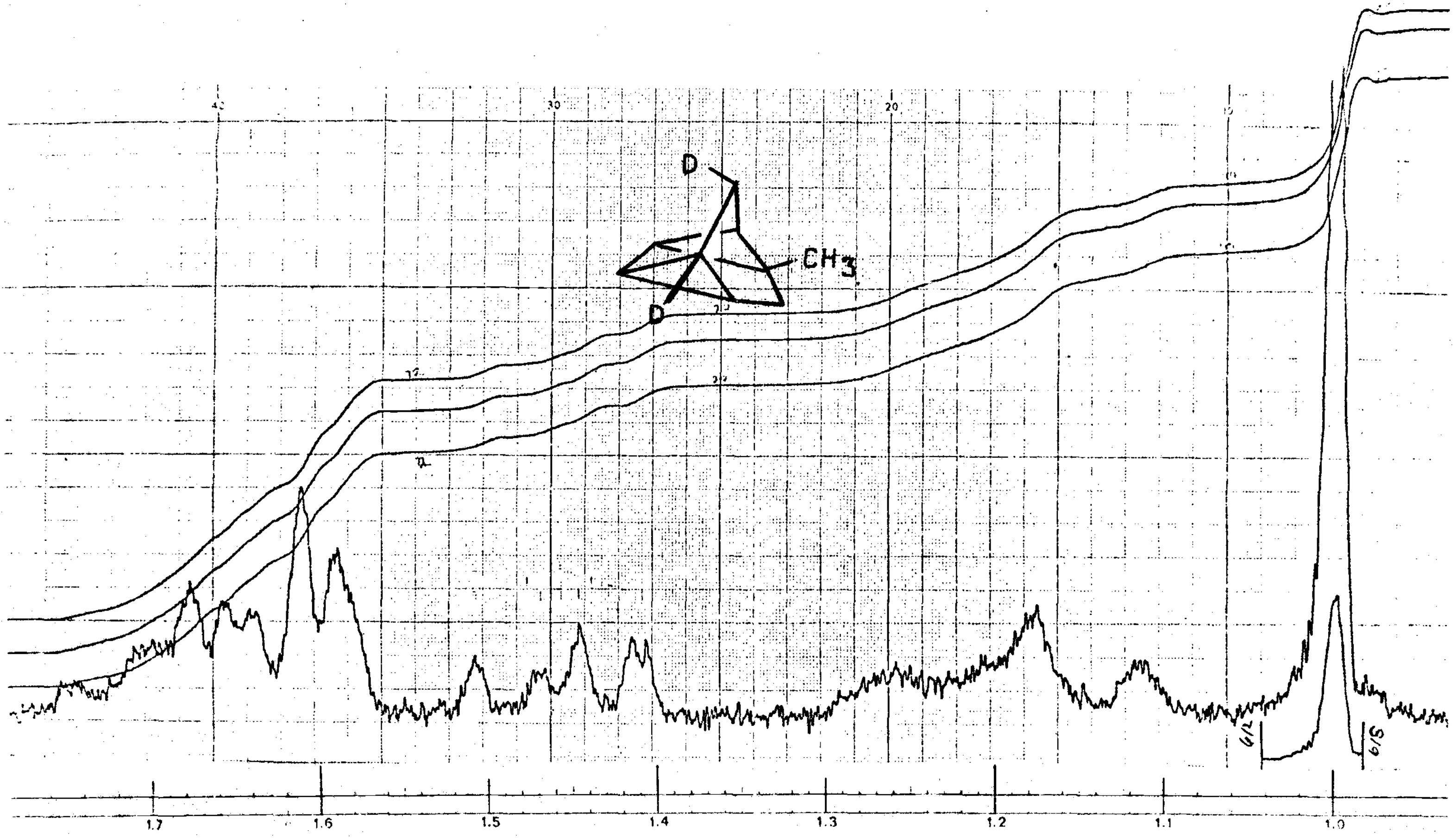


Figure 12. 100 MHz Proton NMR Spectrum of Dideuteriated 2-Methyltetracyclo-$[3.3.0.0^{2,8}.0^{4,6}]$octane, 122d (2 x 0.8 D), from the Decomposition of Tosylhydrazone 121d (sw 100 Hz, C_6H_6).

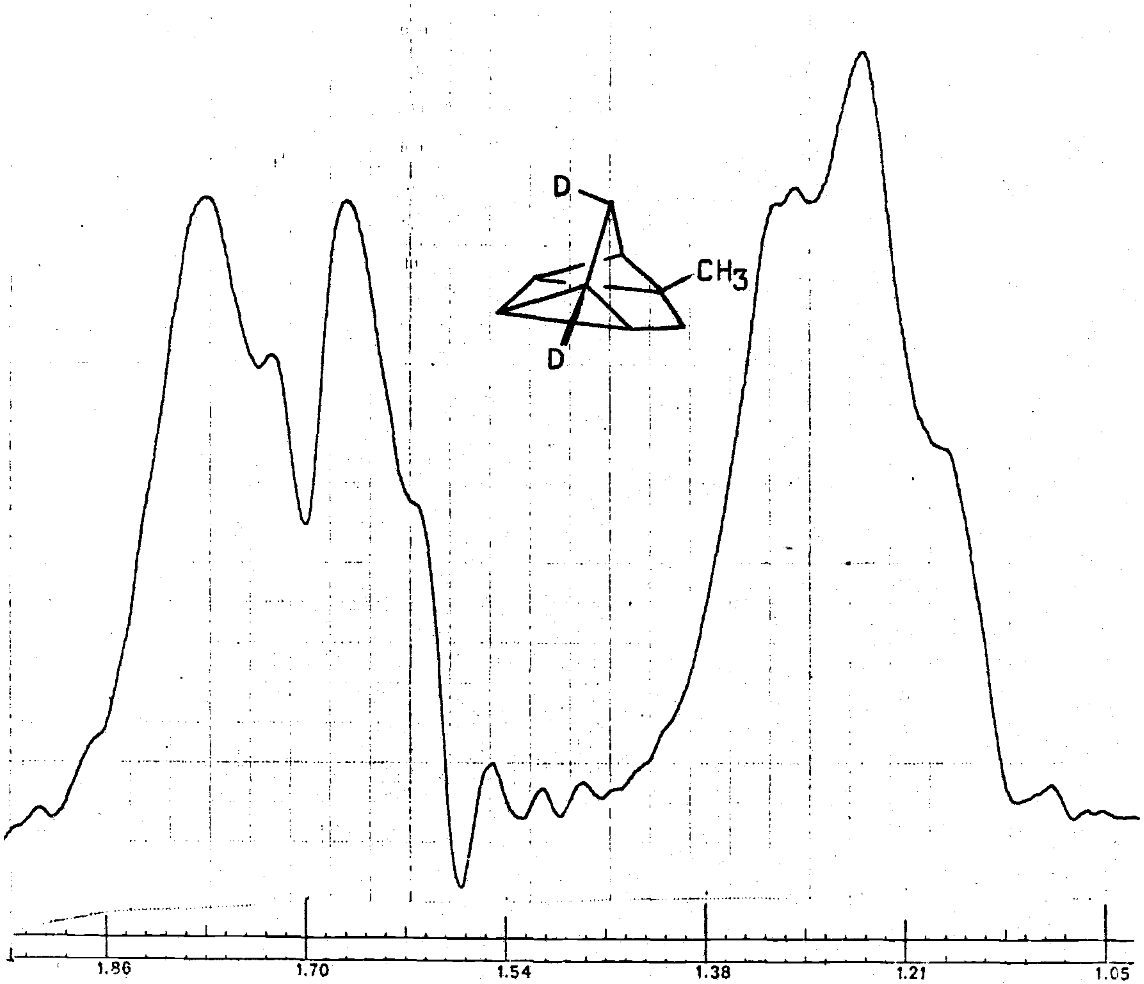
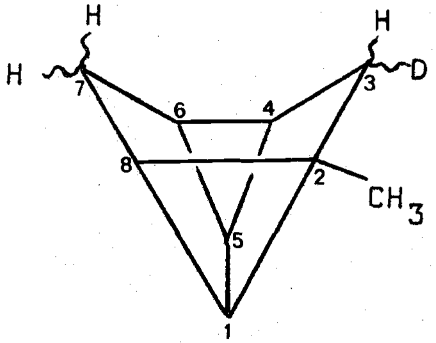


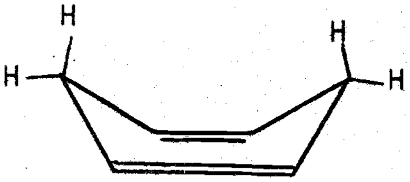
Figure 13. 15.4 MHz Deuterium NMR Spectrum of Dideuteriated 2-Methyltetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane, <u>122d</u> (2 x 0.8 D), from the Decomposition of Tosylhydrazone <u>121d</u> (sw 25 Hz, C_6H_6).

ling of ca. 6 Hz, is more difficult to explain. Coupling of the methylenes of C-3 add C-7 with the bridgehead protons at C-2, C-4, C-6 add C-8 would be expected to be much smaller than 6 Hz (83c).



Models indicate that carbons 2,3,4,6,7 and 8 of <u>122</u> make up a boat form of cyclohexane. Since the large geminal splitting indicates that the δ 1.72 deuterium is on C-3 or C-7, one possible explanation for the 1 Hz (H-D) splitting would be a long range coupling between the hydrogens on C-3 and C-7.

Spin-spin coupling between the protons of C-3 and C-6 of 1,4-cyclohexadiene derivatives has been shown to range from 7-11 Hz (84). Possibly the large amount of p character in the cyclopropyl bonds of <u>122</u> allows a significant

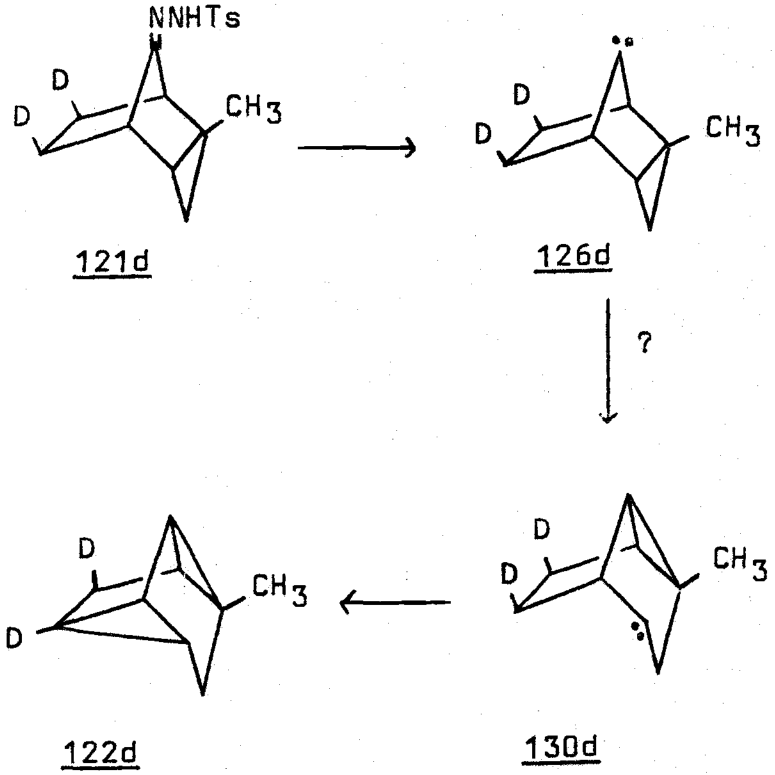


$J_{1,4}$=7-11 Hz

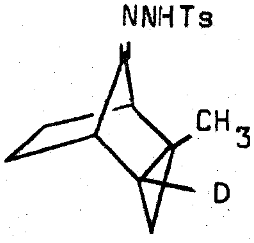
amount of spin-spin coupling between protons at C-3 and C-7 of 122.

The other signal observed in the deuterium nmr spectrum of 122d is a skewed triplet (or doublet of doublets) with J=1 Hz (corresponding to H-H coupling of ca. 6 Hz) at δ 1.26. The lack of a large geminal splitting indicates that this deuterium is not at C-3 or C-7. The lack of any change in the δ 1.45 absorption in the proton nmr indicates that the deuterium is not at C-1, C-5 or C-8. Since it was established that the C-4 proton absorbs at δ 1.14, the only remaining position is at C-6. A proton at C-6 would be expected to be coupled by approximately 6 Hz with the hydrogens at C-4 and C-5, and slightly (possibly 0.5-2 Hz) with the methylene protons at C-7 (83b).

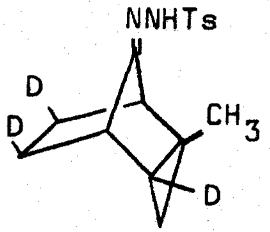
The question still remains, what is the mechanism of formation of 122 (and of 22)? The discovery of a deuterium atom at C-6 of 122d (from the decomposition of 121d) gives a hint to the mechanism of formation of 122. The two deuteriums in 121d are adjacent to each other, and if there has been no deuterium migration (we know there has been no deuterium migration to C-8 of the carbene formed from 121d), then the two deuteriums are still adjacent, and C-6 and C-7 of 122 correspond to C-6 and C-7 of 121d. Bond formation must have taken place between C-2 and C-8, and C-4 and C-6, with bond breakage of the C-2-C-4 bond of 127. Tetracyclooctane 122d would be at least one of the expected products of carbene 130d, which could arise by a formal carbene-carbene rearrangement from 126d. In order for such a formal rearrangement to take place, a proton must be lost



from C-4 of 126d, and C-8 must pick up a proton. In order to test this hypothesis, tosylhydrazones 121f and 121g were

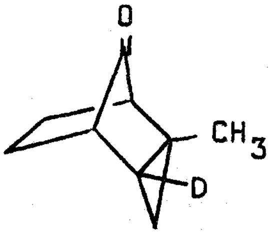


121f

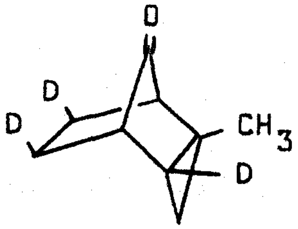


121g

synthesized as described above, using 2-deuterio-1-methylcyclopropene (81). Table VIII indicates the deuterium content of <u>121f</u> and <u>121g</u>, which was determined by mass spectral analysis of the parent-28 (C=O) peak of the corresponding ketone precursers, <u>120f</u> and <u>120g</u>.



<u>120f</u>



<u>120g</u>

When tosylhydrazones <u>121f</u> and <u>121g</u> were decomposed in diglyme at 160° in excess (2-3 equivalents) sodium hydride, deuteriated methyltetracyclooctanes <u>122f</u> and <u>122g</u>, and tricyclic olefins <u>123f</u> and <u>123g</u> were formed, as usual, with the ratio of <u>123</u> to <u>122</u> in the range of 3:1 to 1.5:1. Results of mass spectral analyses of the deuteriated products are given in Table VIII. The data indicate clearly that deuteriated <u>122</u> formed in the reaction has lost most (80-90%) of the deuterium at C-4, as would be expected if a carbene were formed at C-4. Observation of the deuterium nmr of <u>122</u>f was hampered by the low amount of deuterium in the molecule, but Figure 14 shows the result. The single absorption occurs at δ 1.45, which means that there is <u>no</u> residual deuterium at C-4, but 10-20% of a deuterium has been incorporated at C-1. Methine C-1, of <u>122</u> is C-8 of

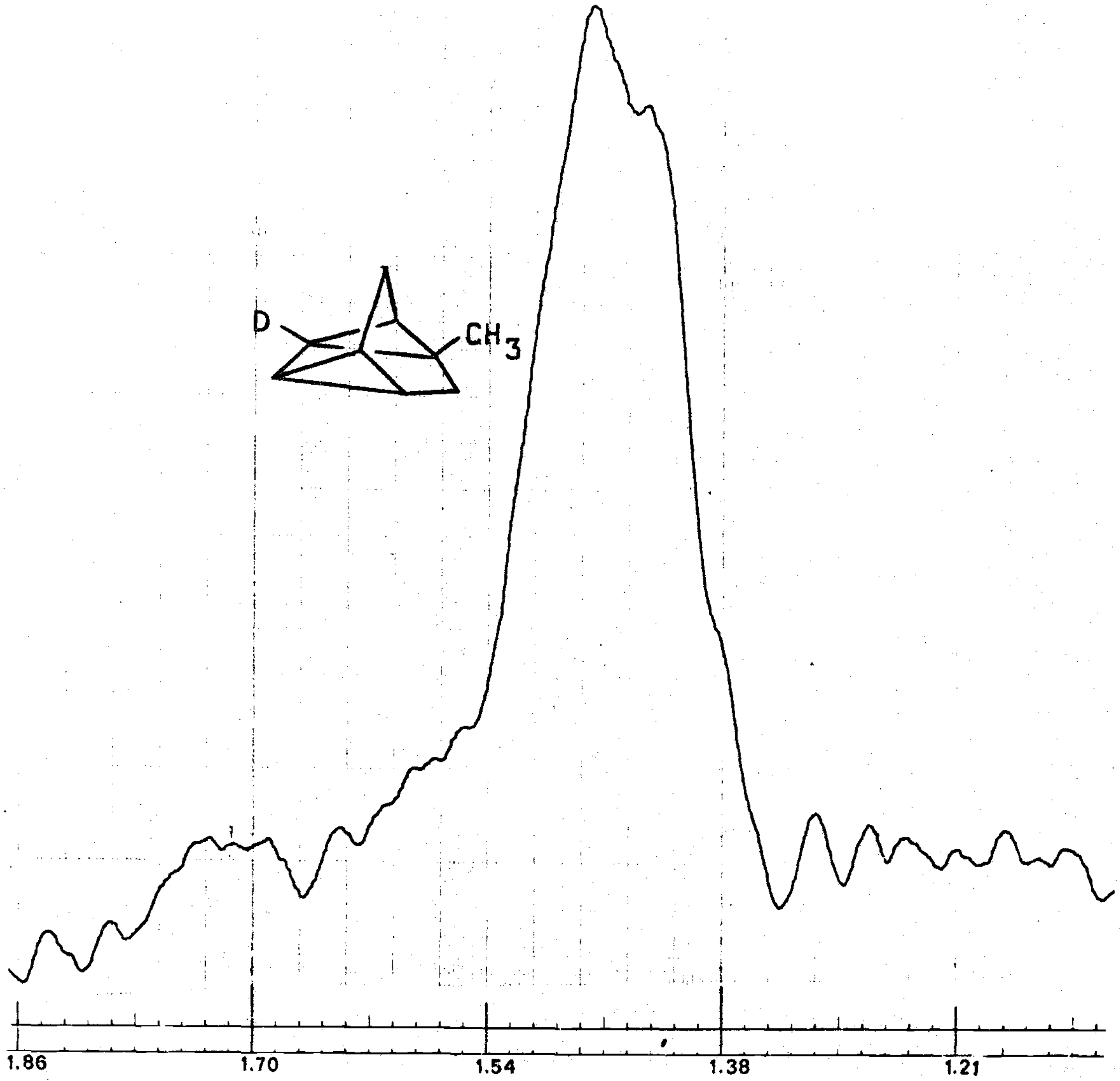


Figure 14. 15.4 MHz Deuterium NMR Spectrum of 1-Deuterio-2-methyltetracyclo[$3.3.0.0^{2,8}.0^{4,6}$]octane, <u>122f</u> (ca. 0.15 D), from the Decomposition of Tosylhydrazone <u>121f</u> (sw 25 Hz, C_6H_6).

the originally formed carbene, <u>126</u>, which must pick up a hydrogen (or deuterium) in order to undergo a formal carbene-carbene rearrangement. To confirm that loss of the deuterium from C-4 is a part of the mechanism to form <u>122</u>, <u>122e</u> was treated with 3 equivalents of sodium hydride in diglyme at 160°. Before treatment, <u>122e</u> contained 97.8± 1.0% d_1; after the attempted exchange, the recovered <u>122e</u> was shown by mass spectral analysis to contain 99.1±1.0% d_1. Since deuterium is not lost from the C-4 position after formation of <u>122f</u>, the deuterium must be lost either in the product forming step or before. Since <u>123f</u> has not lost any deuterium, but has actually picked up appoximately 10% or so more deuterium, the tosylhydrazone must not be exchanging. Deuterium is lost in the product forming step leading to <u>122f</u>, but not in the step leading to <u>123f</u>. Both <u>123f</u> and <u>123g</u> pick up some deuterium during the reaction.

In order to determine whether these results were due to the sodium hydride, tosylhydrazone <u>121f</u> was treated with 5.6 equivalents of sodium methoxide in diglyme at 160°. The usual hydrocarbon products, <u>123h</u> and <u>122h</u>, were formed in a ratio of 9:1. Mass spectral analyses of the resulting hydrocarbons are given in Table VIII. Tetracyclic <u>122h</u> has lost most of its deuterium. Thus the proposed carbene-carbene rearrangement is not dependent on the strongly basic sodium hydride, but takes place with sodium methoxide.

As discussed in Part I, the Bamford-Stevens decompo-

Table VIII. Mass Spectral Results of the Thermal Decomposition of the Sodium Salts of <u>121d</u>, <u>121f</u> and <u>121g</u>.

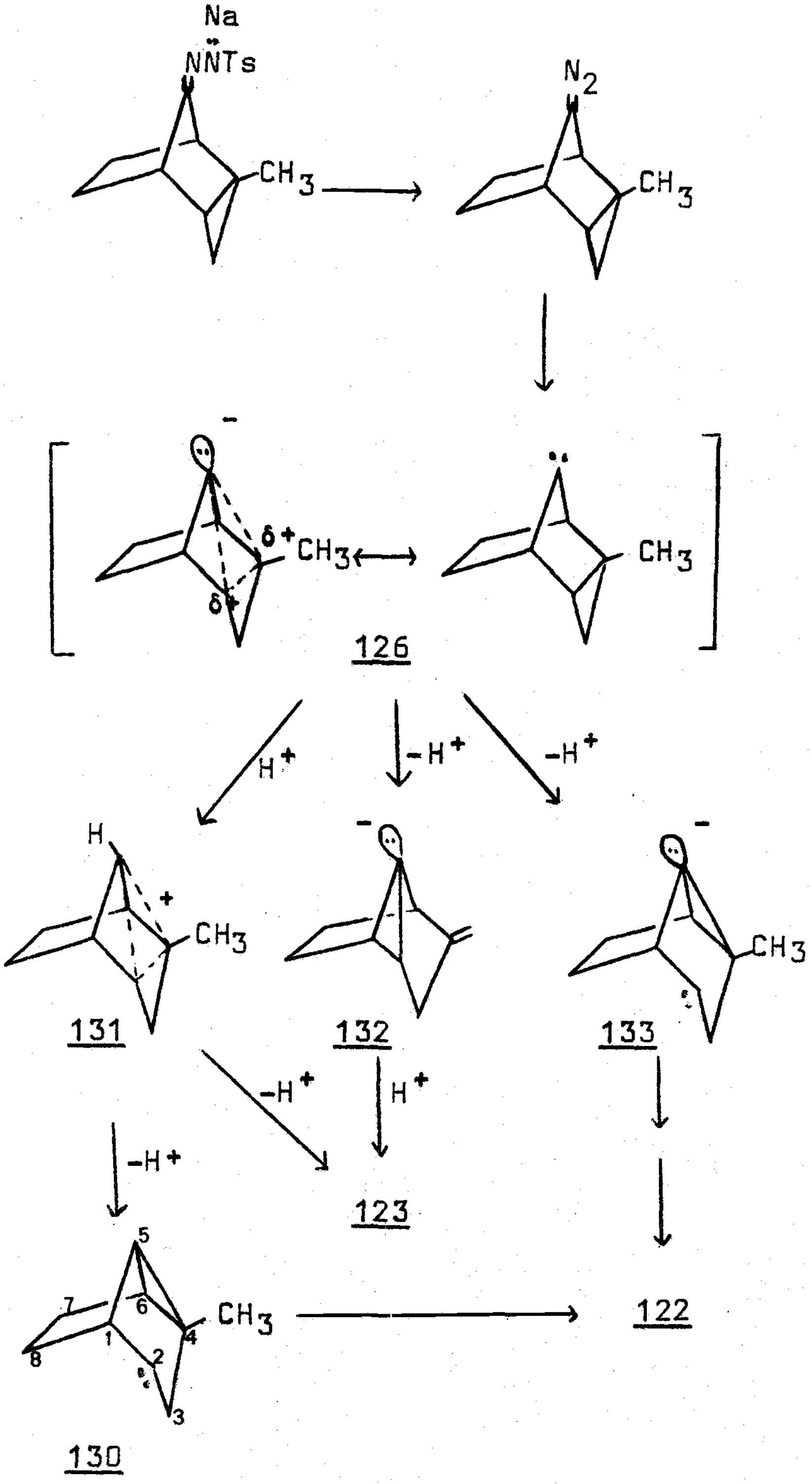
Cmpd	%d_0	%d_1	%d_2	%d_3	%d_4
<u>121d</u>[a]	6.1±0.7[d]	19.4±0.7	74.5±0.9	-	-
<u>122d</u>	5.3±0.5	23.0±0.5	71.7±0.5	-	-
<u>123d</u>	4.1±0.5	23.0±0.6	71.5±0.6	1.1±0.6	-
<u>121f</u>	4.3±0.5	93.0±0.4	2.7±0.7	-	-
<u>122f</u>	84.0±0.5	16.1±0.5	-	-	-
<u>123f</u>	5.5±0.6	79.5±0.6	14.9±0.7	-	-
<u>121g</u>[b]	0.5±0.4	3.9±0.4	19.5±0.5	74.5±0.5	1.8±0.7
<u>122g</u>	2.5±0.5	14.9±0.5	71.9±0.5	10.7±0.5	-
<u>123g</u>	0.8±0.6	2.9±0.6	17.0±0.5	71.5±0.6	7.5±0.7
<u>121f</u>[b]	4.3±0.4	93.0±0.4	2.7±0.7	-	-
<u>122h</u>[c]	93.2±1.2	6.8±0.9	-	-	-
<u>123h</u>[c]	9.8±0.9	86.0±1.1	4.2±0.8	-	-

a) Determined by mass spectral analysis of 2-methyl-<u>endo</u>-tricyclo[3.2.1.0^{2,4}]octane obtained by reduction of <u>121d</u>. b) Determined by mass spectral analysis of the ketone precurser. c) From sodium methoxide induced decomposition of <u>121f</u>. d) One standard deviation.

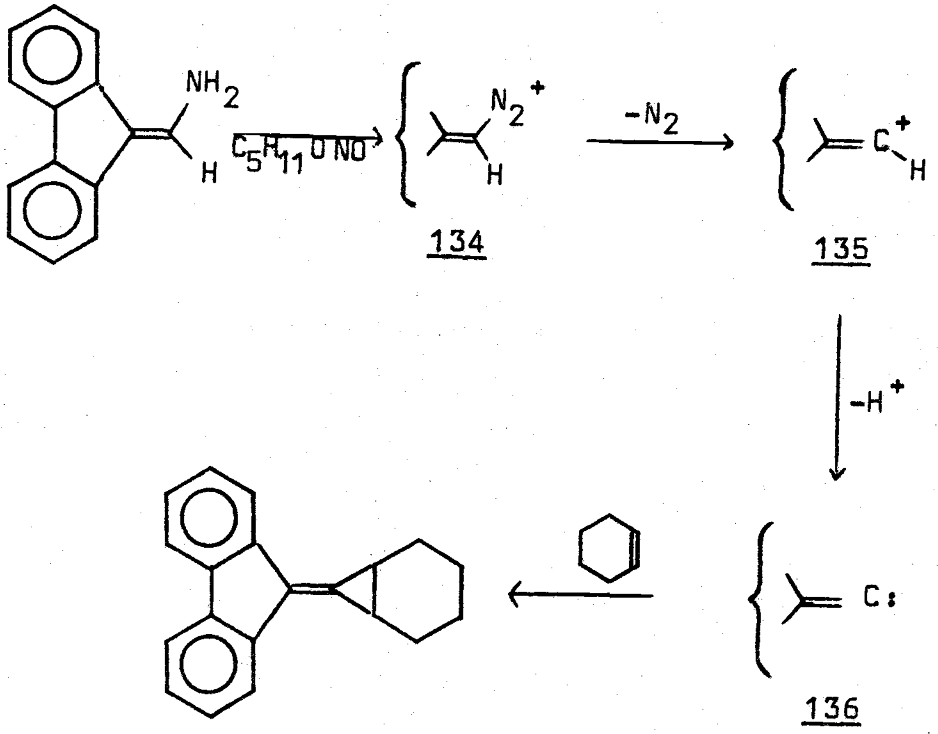
sition of a tosylhydrazone with excess base in an aprotic sovlent proceeds via loss of p-toluenesulfinate from the tosylhydrazone anion to the diazo compound. In some systems, use of excess of a strong base such as methyllithium or sodium hydride leads to an olefin via elimination (48). This cannot happen in this endo -tricyclo[3.2.1.0^{2,4}]octane system because olefin formation would be in violation of Bredt's rule.

Once the diazo compound loses nitrogen and a carbene is formed, there are a number of possible pathways leading from 126 to 122 and 123 (Scheme 6). Carbene 126 might be expected to be nucleophilic because of delocalization of the electrons of the cyclopropyl ring, much as diphenylcyclopropenylidine and cycloheptatrienylidine are nucleophilic (will only add to electrophilic olefins, for example) (85). Abstraction of a proton (presumably from the solvent) would lead to the very stable trishomocyclopropenyl cation 131. Loss of a proton from the methyl group would yield 123, while loss of a proton from C-4 would lead to carbene 130. Models indicate that the C-4-C-5 zero carbon bridge in 130 holds the bicyclo[3.2.1]octane skeleton rigid, with the empty p orbital oriented very similarly to the empty p orbital of 2-carbenanorbornane, so insertion into the C_8-H bond to yield 122 would be the expected major product. Loss of a proton from a carbonium ion, to yield a carbene, is not common but has been observed in some

Scheme 6


Na
NNTs
CH_3
N_2
CH_3
δ^+
CH_3
δ^+
CH_3
126
H^+
$-H^+$
$-H^+$
H
+
CH_3
CH_3
131
132
133
$-H^+$
H^+
$-H^+$
123
5
7
6
CH_3
8
1
2
4
3
130
122

systems. For instance, generation of 134 in cyclohexene leads to cation 135. Loss of a proton yields carbene 135, which was trapped with cyclohexene (86).



Most of the examples of carbenes generated from carbonium ions by loss of a proton occur with the reaction of base with a "stable" carbonium ion (usually carbonium ions stabilized by a hetero atom) (38c). In one such example,

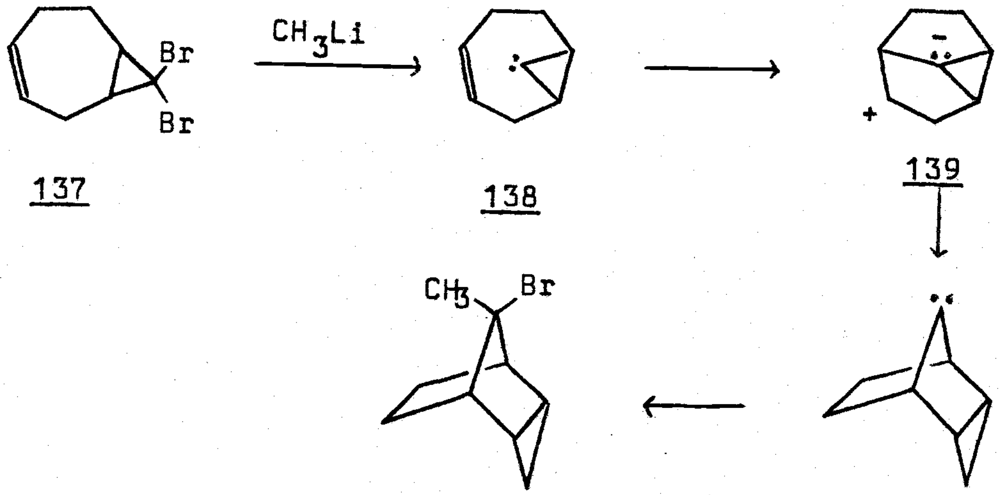
$$(CH_3O)_2\overset{\oplus}{C}H \quad BF_4^{\ominus} \xrightarrow{B:^{\ominus}} (CH_3O)_2C{=}C(OCH_3)_2 \longrightarrow \text{esters}$$

the fluoborate salt is deprotonated by base to yield esters, which come from the carbene dimerization product (87).

Loss of a proton from the methyl group of 126 would lead to 132, which upon abstraction of a proton (again, presumably from the solvent), would yield 123. Loss of a proton from C-4 of 126 would lead to carbene-anion 133, which, after carbon-hydrogen insertion and abstraction of a proton, would yield 122.

Confirmation that the hydrocarbon products were not coming directly from carbene 126 was found when the dry lithium salts of tosylhydrazones 104 and 121 were pyrolyzed at 170° (0.2 torr). In both cases the yield of volatile products was found to be under one percent. In these cases, the carbene was generated in the absence of solvent, and the nucleophilic intermediate formed reacted intermolecularly to yield non-volatile products.

Baird and Reese have recently proposed 107 as an intermediate in the reaction of 137 with methyllithium in ether (88). Formation of carbene (carbenoid) 138 leads



137 138 139

140 107

eventually to stereospecific formation of <u>140</u>, and the authors suggest that <u>139</u> rearranges to <u>107</u>. If <u>107</u> is in fact formed, it is reacting intermolecularly rather than intramolecularly, as we have observed for <u>107</u> and <u>126</u> generated from tosylhydrazone decomposition.

EXPERIMENTAL SECTION

Dechlorination of 1,5,6,7-Tetrachloro-8,8-dimethoxy-*endo*-tricyclo[3.2.1.0^{2,4}]oct-6-ene with Sodium (7). A 500 ml flask equipped with a magnetic stirrer, dropping funnel and reflux condenser was charged with 150 ml of reagent grade tetrahydrofuran, 40 ml (0.42 mol) of *tert*-butyl alcohol, and 15 g (0.66 mol) of 10 mm sodium cubes. The solution was heated to reflux and 15 g (0.050 mol) of the title chlorinated ketal (25b) was added with 50 ml of tetrahydrofuran over 0.5 hr. The solution was heated at reflux under nitrogen for 26 hr. After removal of the excess sodium, 75 ml of methyl alcohol was added with cooling. The solution was then poured over 500 ml of ice and 100 ml of ether. The organic layer was separated and the aqueous phase was extracted with 2 x 100 ml of ether; the ether layers were combined and washed with brine until the washings remained clear. The ether was removed at reduced pressure and the unsaturated ketal 112 was distilled, bp 86-87° (15 torr), lit. (7) bp 103-105° (33.5 torr), yielding 5.0 g (0.033 mol, 66%). Ir (neat, NaCl plates): 3077 cm^{-1} (m, cyclopropyl or vinyl C-H stretch), 3008 (s, cyclopropyl or vinyl C-H stretch), 1111 (s, C-O stretch), 1070 (s, C-O stretch), 1022 (m, cyclopropyl deformation), and 714 (s, C-H vinyl out of plane bending). Nmr is identical to that reported (7).

Deuteration of 8,8-Dimethoxy-*endo*-tricyclo[$3.2.1.0^{2,4}$]-oct-6-ene, 112. To 1.0 g (6.6 mmol) of unsaturated ketal in 6 ml of methanol was added 30 mg of 5% paladium on charcoal. The suspension was stirred under 1 atmosphere of 98% deuterium. When deuterium uptake ceased, the methanol, after filtration, was removed by distillation, yielding 0.9 g of 6,7-dideuterio-8,8-dimethoxy-*endo*-tricyclo[$3.2.1.0^{2,4}$]-octane, 113. The nmr spectrum is identical with that of 8,8-dimethoxy-*endo*-tricyclo[$3.2.1.0^{2,4}$]octane (7), except that the doublet at δ 1.60, due to the *exo*-C-6 and C-7 protons, has nearly disappeared, integrating to 0.4 protons, and the doublet at δ 0.94 (*endo* protons) has collapsed to a singlet.

Hydrolysis of 6,7-dideuterio-8,8-dimethoxy-*endo*-tricyclo[$3.2.1^{2,4}$]octane. The method of Pincock and Haywood-Farmer (7) was followed. A 10 ml flask was charged with 0.9 g (5.9 mmol) of deuteriated ketal and 8 ml of glacial acetic acid, and the solution was stirred at 80° for 20 hr. The solution was then diluted with 10 ml of pentane, and 6.4 g of sodium hydroxide in 15 ml of water was added slowly. About 15 ml of water was added and the aqueous phase was extracted with 3 x 10 ml of pentane. The pentane layers were combined, washed with brine, and dried over anhydrous magnesium sulfate. The solvent was removed by rotary evaporation at room temperature yielding 0.7 g of crude deuteriated ketone 114. The nmr spectrum was identical with that reported (7) except that the multiplet at δ 1.55 (exo-methylenes) now integrates out to 0.4 pro-ons tons, and the doublet at δ 1.19 has collapsed to a singlet. Figure 1 shows the deuteriated and undeuteriated ketone after treatment with $Eu(fod)_3$. The ketone was used without further purification.

Preparation of 6,7-Dideuterio-*endo*-tricyclo[3.2.1.^{2,4}]-octan-8-one Tosylhydrazone, **104d**. The general procedure of Bamford and Stevens (42, 25b) was used. To 0.8 g (6.5 mmol) of deuteriated *endo*-ketone, **114** in a 25 ml flask was added 15 ml of 95% ethanol, 1.2 g (6.5 mmol) of tosylhydrazine, and 1 drop of concentrated hydrochloric acid. The solution was heated at 80° for 2 hr. The flask was allowed to cool to room temperature, then was placed in a refrigerator overnight. The white crystals were collected and dried in a vacuum oven at 70°, yielding 1.0 g (3.4 mmol, 53%) of tosylhydrazone with mp 168-169° dec, lit. (undeuteriated) (89) 172-173° dec. Mass spectral analysis using a low ionizing potential (8.0 eV) yielded $d_0=7.6\pm0.5\%$, $d_1=26.2\pm0.5\%$, and $d_2=66.2\pm0.9\%$. (A second batch was synthesized which was determined to consist of $d_0=35.3\pm0.5$, $d_1=33.0\pm0.5$ and $d_2=31.7\pm0.7$, by mass spectral analysis of its sodium borohydride reduction product 6,7-dideuterio-*endo*-tricyclo-[3.2.1.0^{2,4}]octane at 11.0 eV).

Decomposition of 6,7-Dideuterio-*endo*-tricyclo[3.2.1.0^{2,4}]-octan-8-one Tosylhydrazone, **104d** with Excess Sodium Methoxide.

A 25 ml flask equipped with a magnetic stirrer and reflux condenser was charged with 292 mg (1 mmol) of deuteriated tosylhydrazone, 15 ml of dry diglyme, and 350 mg (6.5 mmol) of sodium methoxide. The resulting suspension was stirred at 160^o for 2 hr. After cooling, 15 ml of pentane was added and the solution was poured into 200 ml of water. Extraction by 3 x 20 ml of pentane of the water layer was followed by combining the pentane layers, washing with 2 x 100 ml of water and 50 ml of brine, drying over anhydrous sodium sulfate, and removal of most of the solvent by distillation through a vigreaux column. Vpc analysis (col 2, 100^o, 60 ml/min) showed identical products as the undeuteriated tosylhydrazone (25b), except for deuterium content, in ratios of 4±1:33±1:6±1:29±1 (23:22:109b:109a). The 4% component, tricyclo[3.3.0.0^{4,6}]oct-2-ene, <u>23</u>, and the 33% component, tetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane, <u>22</u>, were subjected to mass spectral analysis at low ionizing potentials, and the resulting deuterium content is given in Table VII.

<u>Test for Hydrogen-Deuterium Exchange by Tetracyclo[3.3.0.0^{2,8}.0^{4,6}]octane, 22</u>. To 5 ml of freshly distilled diglyme was added 110 mg (2.0 mmol) of sodium methoxide, 8 mg (0.24 mmol) of methanol-O-d (99% d_1) and 8 mg (0.07 mmol) of the title hydrocarbon. To this was added 0.5 mmol of cyclohexanone tosylhdrazone which had been prepared by the reaction of cyclohexanone with tosylhydrazine

in methanol-O-d. The solution was then stirred at 165° for two hr. After cooling to room temperature, 5 ml of pentane was added and the solution was poured into 100 ml of water. The aqueous phase was extracted with 3 x 10 ml of pentane; the pentane extracts were combined, washed with water and brine, and dried over anhydrous sodium sulfate. After removal of most of the solvent by distillation through a vigreaux column, vpc analysis (col 8, 110°, 60 ml/min) showed only tetracyclooctane and cyclohexene. Low voltage mass spectral analysis showed the cyclohexene (10.2 eV) to contain 61% d_4, 31% d_3, 7% d_2 and 1% d_1. The title hydrocarbon was found (10.2 eV) to contain 0.3% deuterium (95% confidence level).

Reaction of 5,5-Dimethoxy-1,2,3,4-tetrachlorocyclopentadiene with 1-Methylcyclopropene. The method of Magid and co-workers (81) was used to generate 1-methylcyclopropene. A 500 ml 3-necked flask equipped with a magnetic stirrer, dropping funnel and reflux condenser was charged with 100 ml of a 2.4 M solution of phenyllithium in 60:40 benzene-ether. Under nitrogen 9.0 g (0.115 mol) of 3-chloro-2-methylpropene in 30 ml of pentane was added dropwise over ½ hr. The solution turned milky white and was stirred at room temperature for one hr. The solution was then cooled to 0° in an ice bath and 23 g (0.5 mol) of absolute ethanol was added dropwise. The reaction mixture was then gently refluxed overnight, and the 1-methylcyclopropene was carried through a length of Tygon tubing by a nitrogen flow over the solution, and then bubbled through a solution of 13 g (0.053 mol) of 5,5-dimethoxy-1,2,3,4-tetrachlorocyclopentadiene (25b) and 20 ml of pentane at 0°. Removal of solvent by rotary evaporation yielded 16 g (100%) of 2-methyl-8,8-dimethoxy-1,5,6,7-tetrachloro-*endo*-tricyclo-$[3.2.1.0^{2,4}]$oct-6-ene, 117, (95% pure by vpc). Ir (0.1 mm, CCl_4): 3030 cm^{-1} (shoulder, cyclopropyl C-H stretching), 3012 (m, cyclopropyl C-H stretching), 1603 (s, C=C stretching), 1381 (3 methyl bending), 1193 (shoulder), 1178 (s) (all assignable to C-O stretching); nmr (100 MHz, CCl_4): δ 4.59 and 4.48 (singlets, 3H each, methoxy protons), 1.53 (doublet of doublet, J=3.5, 6.5 Hz, 1H, cyclopropyl methine at C-4), 1.41 (singlet, 3H, methyl group on C-2), and 0.61 (multiplet, 2H, cyclopropyl methylene protons).

Anal. Calcd for $C_{11}H_{12}O_2Cl_4$: C, 41.54; H, 3.80. Found: C, 41.40; H, 3.98.

Dechlorination of 2-Methyl-1,5,6,7-tetrachloro-8,8-dimethoxy-endo-tricyclo$[3.2.1.0^{2,4}]$oct-6-ene, 117, with Sodium. The procedure of Gassman and Pape (74) was followed with minor experimental modifications. To a 500 ml three-necked flask equipped with magnetic stirrer, dropping funnel and reflux condenser was added 175 ml of reagent grade tetrahydrofuran, 40 ml (0.42 mol) of *tert*-butyl alcohol and 20 g (0.9 mol) of 10 mm sodium cubes. The solution was heated to reflux and 16 g (0.053 mol) of the title ketal in 50 ml of tetrahydrofuran was added dropwise over one hr. After heating at reflux for 26 hr, the solution wa was decanted off the remaining sodium and 50 ml of methanol was added with cooling. The solution was then poured into a separatory funnel containing 1.5 l of ice and 500 ml of ether. The organic layer was separated, and the aqueous layer was extracted three times with 250 ml of ether. The ether layers were combined and washed with brine until the volume of the organic layer remained constant and the washings remained clear. The etheral solution was dried with anhydrous magnesium sulfate and most of the solvent was removed under reduced pressure. Distillation (89-91^{o}, 14 torr) yielded 5.0 g (0.028 mol, 56%), ir (0.1 mm, CCl_4): 3086 cm^{-1} (m, cyclopropyl C-H stretch), 3049 (shoulder, cyclopropyl or vinyl C-H stretching), 1565 (w, C=C stretching), 1374 (w, methyl bending), 1111 (s) 1092 (shoulder), and 1072 (s)(all assignable to C-O stretching), 1022 cm^{-1} (m, cyclopropyl deformation), and 707 (s, alkene C-H out of plane bending): Nmr (100 MHz, CCl_4): δ 5.67 (multiplet, 2H, vinyl protons), 3.00 and 2.92 (singlets, 3H each, methoxy protons), 2.82 (unresolved doublet, 1H, J=3 Hz, bridgehead C-5 proton), 2.46 (quintet, 1H, J =1.5 Hz bridgehead C-1 proton), 1.33 (singlet, 3H, methyl group on C-2), 0.93 (multiplet, 1H, cyclopropyl methine), 0.51 (doublet of doublets, J=5 Hz, 3.5 Hz, 1H, *syn*-cyclopropyl methylene), and δ 0.37 (doublet of doublets, J=5 Hz, 7 Hz, 1H, anti-cyclopropyl methylene protons.

Anal. Calcd for $C_{11}H_{16}O_2$: C, 73.30; H, 8.95. Found: C, 73.24; H, 9.06.

Preparation of 2-Methyl-8,8-dimethoxy-endo-tricyclo-[3.2.1.0^{2,4}]octane, 119. Unsaturated ketal 118 (2.0 g, 11.5 mmol) was dissolved in 15 ml of reagent grade methanol, and 50 mg of 5% paladium on charcoal was added. The solution was stirred under one atmosphere of hydrogen until hydrogen uptake ceased. The solution was then filtered and used without further purification. Vpc collection gives a sample with ir (0.1 mm, CCl_4): 3086 cm^{-1} (w, cyclopropyl C-H stretch, 3030 (shoulder, cyclopropyl C-H stretch), 1377 (w, methyl bending), 1093 (shoulder), 1087 (s), and 1064 (all assignable to C-O stretching), 1028 (m, cyclopropyl deformation); nmr (100 MHz, CCl_4): δ 3.25 and 3.13 (singlets, 3H each, methoxy protons), 2.10 (multiplet, 1H, bridgehead C-5 proton), 1.82 (multiplet, 1H, bridgehead C-1 proton), 1.54 (broadened doublet J=8 Hz, 2H, exo-methylene protons at C-6 and C-7), 1.21 (singlet, 3H, methyl protons), 0.96 (doublet J=8 Hz, 2H, endo-methylene protons at C-6 and C-7), 0.94 (multiplet, under part of 0.96 absorption, 2H, cyclopropyl methine and one cyclopropyl methylene), 0.44 (doublet of doublets, J=7, 8.5 Hz, 1H, one of the cyclopropyl methylenes on C-3).

Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.96. Found: C, 71.40; H, 10.24.

Hydrolysis of 2-Methyl-8,8-dimethoxy-endo-tricyclo-[3.2.1.0^{2,4}]octane. Saturated ketal 119 (one ml of hydrogenated mixture, containing 133 mg) was placed in a five ml flask with two ml of methanol and 0.1 ml of a solution of 5% sulfuric acid in water. The solution was stirred at 70^{o} for 4 hr, followed by dilution with 10 ml of water and one ml of a 10% Na_2Co_3 solution. The mixture was extracted three times with 5 ml of pentane; the pentane extracts were combined, washed twice with 10 ml of water and once with 10 ml of brine and dried over anhydrous sodium sulfate. Folowing removal of most of the penatne by distillation through a vigreaux column, the ketone 2-methyl-endo-tricyclo-[3.2.1.0^{2,4}]octan-8-one, 120, was collected by preparative vpc for ir and nmr analysis, ir (0.1 mm, CCl_4): 3096 cm^{-1} (s, cyclopropyl C-H stretching), 3040 (shoulder, cyclopropyl C-H stretching), 1761 (vs, C=O stretching), 1385 (w, methyl bending), 1042 (m, cyclopropyl deformation), 972 (m) and 877 (m); nmr (100 MHz, CCl_4): δ 2.17 (broadened singlet, $W_{\frac{1}{2}}$=9 Hz, 1H, bridgehead proton on C-5), 1.86 (broadened doublet, J=2 Hz, 1H, bridgehead proton on C-1), 1.70 (unresolved multiplet, 2H, exo-methylene protons on C-6 and C-7), 1.28 (singlet, 3H, methyl protons), 1.25 to 0.75 (unresolved multiplet, 5H).

Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 73.23; H, 9.51, analysis was low due to loss of carbon monoxide (7).

Preparation of 2-Methyl-*endo*-tricyclo[3.2.1.0^{2,4}]octan-8-one Tosylhydrazone. Into a 25 ml flask containing 2-methyl-8,8-dimethoxytricyclo[3.2.1.0^{2,4}]octane, 119 (1.9 g, 11 mmol) and 14 ml of methanol was placed one ml of water, 20 mg of p-toluenesulfonic acid and 1.86 g (11 mmol) of p-toluenesulfonylhydrazine. The solution was then heated at 65° for 2 hr, then placed on a steam bath, and water was added until the solution began to cloud. Upon cooling, crystals formed (2.2 g 65%, mp 119-121° dec.). Recrystallization from methanol-water yielded mp 125-126°, ir (0.1 mm $CHCl_3$): 3236 cm^{-1} (s, N-H stretching), 3090 (shoulder, aromatic or cyclopropyl C-H stretching), 3030 (shoulder, aromatic or cyclopropyl C-H stretching), 1681 (s, C=N stretching), 1597 (aromatic C=C stretching), 1335 (s, S-O stretching), 1163 (vs, S-O stretching), and 1019 (w, cyclopropyl deformation); nmr (100 MHz, $CHCl_3$): δ 2.98, 2.70, 2.47 and 2.14 (broadened singlets, ½H each, bridgehead protons at C-1 and C-5), 2.39 (singlet, 3H, aromatic methyl), 1.02 and 0.96 (both singlets, 1½H each, methyl group on C-2), 1.70 to 0.70 (complex multiplet, 7H). Half protons are due to *syn* and *anti* forms of the tosylhydrazone, which arise because of lack of rotation around the C=N bond.

High resolution mass spectra. Calcd for $C_{16}H_{20}SO_2N_2$: 304.125; Found: 304.126.

Decomposition of 2-Methyl-*endo*-tricyclo[3.2.1.0^{2,4}]-octan-8-one Tosylhydrazone, 121, with Excess Sodium Methoxide in Diglyme. Into a 10 ml flask equipped with a reflux condenser, drying tube and magnetic stirrer was placed 125 mg (0.41 mmol) of tosylhydrazone, and 200 mg (2.6 mmol) of sodium methoxide, along with 5 ml of dry diglyme. The flask was then placed in an oil bath maintained at 160° for 2 hr. After cooling to room temperature, the solution was diluted with 5 ml of pentane.and 100 ml of water, and extracted 4 times with 5 ml of pentane. The pentane extracts were combined, washed three times with 75 ml of water, once with 50 ml of brine and dried over anhydrous sodium sulfate. Most of the pentane was removed by distillation through a vigreaux column, and the residue was analyzed by vpd (col 8, 100°, 60 ml/min). Vpc analysis showed six peaks. Three were of fairly long retention time, had m/e 152, corresponding to methyl ethers, were present only to the extent of about 10% total yield, and were not characterized further. There were three peaks in the hydrocarbon region of the vpc. Their yields as determined by internal vpc standard, in order of increasing retention time, were 0.5%, 3% and 28%. The 0.5% component could not be isolated in sufficient amounts or purity to characterize.

The 3% component was identified as 2-methyltetracyclo-[3.3.0.0^{2,8}.0^{4,6}]octane, 122, on the basis of its spectral data; mass spectrum: parent peak at m/e 120; ir (0.1 mm mm CCl_4): 3050 cm^{-1} (shoulder, cyclopropyl C-H stretch), 3020 (m, cyclopropyl C-H stretch), 1378 (w, methyl bending), 1281, 1248, 858 and 827 (all w, skeletal vibrations); nmr (C_6H_6 100 MHz): δ 1.75 to 1.08 (complex series of multiplets, 9H), 1.00 (singlet, 3H, methyl). The structure assignment was confirmed by an independent synthesis of this compound (79).

High resolution mass spectra. Calcd for C_9H_{12}: 120.094; Found: 120.093.

The 28% component was identified as 2-methylenetricyclo[3.3.0.$0^{4,6}$]octane, <u>123</u>, on the basis of its spectral data; mass spectrum: parent peak at m/e=120; ir (0.1 mm, CCl_4) 3096 cm^{-1} (shoulder), 3077 (shoulder) and 3049 (m, all three attributable to either cyclopropyl or vinyl C-H stretch), 1647 (m, C=C stretch), and 877 (s, terminal vinyl group C-H out of plane bending); nmr (100 MHz, CCl_4): δ 4.54 (singlet, 2H, vinyl protons), 2.90 (doublet of triplets, J_d=1 Hz, J_t= 5 Hz, 1H, bridgehead proton at C-1), 2.75 to 1.2 (complex series of multiplets, 10H). The structure was confirmed by ozonolysis to the ketone (see below).

<u>Anal</u>. Calcd for C_9H_{12}: C, 89.93; H, 10.06. Found: C, 89.87; H, 10.07.

<u>Preparation of Tricyclo[3.3.0.$0^{4,6}$]octan-2-one, 125, by Ozonolysis of 2-Methylenetricyclo[3.3.0.$0^{4,6}$]octane, 123</u>. A solution of 20 mg of the unsaturated hydrocarbon

in 0.5 ml of CCl_4 and 1.5 ml of $HCCl_3$ was placed in a 5 ml pear shaped flask. Three percent ozone in oxygen from a Welsback Ozonator was passed through the solution at a rate of 80 ml/min at -5° and then into a solution of 2% potassium iodide in 2% sulfuric acid. After 15 min, iodine began to be liberated and the reaction was stopped. Half the solvent was removed under reduced pressure and 5 ml of ether was added. The organic layer was washed with 3 x 50 ml of water and 1 x 30 ml of brine. After drying with anhydrous sodium sulfate, the single product was collected by preparative vpc and identified as tricyclo[3.3.0.$0^{2,4}$]octan-2-one by comparison of vpc retention time, infrared and nmr with an authentic sample, which was prepared by oxidizing a sample of endo-tricyclo[3.3.0.$0^{4,6}$]octan-2-ol (supplied by Tanida) (5) with the procedure of Haywood-Farmer and Pincock (7).

Decomposition of 2-Methyl-*endo*-tricyclo[3.2.1.$0^{2,4}$]octan-8-one Tosylhydrazone, 121, with Sodium Hydride in Diglyme. Tosylhydrazone 121 (71.5 mg, 0.24 mmol) and 12 mg of sodium hydride (0.50 mmol) were placed in 4 ml of freshly distilled (from $LiAlH_4$) diglyme. After heating at 160° for 2 hr, the solution was cooled, diluted with 100 ml of water, *p*-cymene was added, and the solution was extracted with 4 x 10 ml of pentane. The pentane extracts were combined, washed with 3 x 50 ml of water and 1 x 50 ml of brine and dried over anhydrous sodium sulfate. After distilling most of the pentane through a vigreaux column, the solution was analyzed by vpc (column 2). Along with the p-cymene internal standard, there were 3 products in 50-60% overall yield in ratios of 1:6:8. The shortest retention time product could not be isolated in sufficient amounts or purity for identification. The second product was identified as 2-methyltetracyclo[3.3.0.$0^{2,8}$.$0^{4,6}$]octane, and the third product identified as 2-methylenetricyclo[3.3.0.$0^{4,6}$]octane, 123. The ratio of 122 to 123 was not constant, but varied from 1:1.5 to 1:3 in various runs.

Decomposition of endo-Tricyclo[3.2.1.$0^{2,4}$]octan-8-one Tosylhydrazone, 104, with Sodium Hydride. The title tosylhydrazone, 104 (50 mg, 0.16 mmol), was treated with 8 mg (0.3 mmol) of sodium hydride in 3 ml of dry diglyme. After stirring at 160° for 1 hr, the solution was cooled, cumene was added as an internal standard, and the reaction was worked up as described for the reaction of 121 with sodium hydride (above). Vpc analysis (columns 2 and 3) indicated two products along with the internal standard. The shorter retention time product, produced in 5% yield was identified as tricyclo[3.3.0.$0^{4,6}$]oct-2-ene, 23, and the longer retention time product, formed in 39% yield, was identified as tetracyclo[3.3.0.$0^{2,8}$.$0^{4,6}$]octane, 22.

Preparation of 2-Methyl-endo-tricyclo[3.2.1.$0^{2,4}$]-oct-6-ene, 124. 2-Methylcyclopropene (0.1 mol, see pg 151) was bubbled through a solution of 13.2 g (0.2 mol) of freshly cracked cyclopentadiene at 0°. After 6 hr, the unreacted cyclopentadiene was removed under reduced pressure, yielding, after distillation (bp 78-80°, 100 torr) 9.0 g (0.75 mol, 75%) of the title hydrocarbon (81).

Preparation of 4-Deuterio-2-methyl-endo-tricyclo-$[3.2.1.0^{2,4}]$oct-6-ene, 124e. 2-Methyl-2-deuteriocyclopropene (81) was bubbled through cyclopentadiene as described above. Mass spectral analysis showed 124e to contain 1.2-1.0% d_0 and 98.8-1.0% d_1, and in the nmr spectrum of 124e (CCl_4, 100 MHz), the pentet at δ 1.03 had completely disappeared.

Preparation of 6,7-dideuterio-2-methyl-endo-tricyclo-$[3.2.1.0^{2,4}]$oct-6-ene, 124c. The procedure of Zimmerman and co-workers was used with some modification (80). 2-Methyl-*endo*-tricyclo$[3.2.1.0^{2,4}]$oct-6-ene, *124*, (120 mg, 1 mmol) was added to a solution of 100 μl of 21.5% butyllithium (in hexane, Alpha) in 2 ml of cyclohexylamine-d_2 (ca. 95% N-D). The solution was stirred at 90° for 12 hr, quenched with D_2O and extracted with pentane. The pentane was washed with dilute hydrochloric acid, water, brine, and the title hydrocarbon was collected by preparative vpc. Mass spectral analysis at 12.6 eV indicated the alkene to consist of 3.4±0.9% d_0, 29.0±1.0% d_1, 66.6±1.0% d_2 and 1.0± 1.1% d_3. The nmr spectrum of *130b* showed olefinic proton absorption greatly diminished (ca. 10-20% H).

Preparation of 6,7-Dideuterio-endo-tricyclo[3.2.1.0^{2,4}]-oct-6-ene, 116c. The title alkene was deuteriated in the same manner as the methylated alkene 124c (above). Mass spectral analysis at 12.0 eV indicated 116c to consist of 3.0±0.8% d_0, 30.3±1.1% d_1, and 66.6±1.0% d_2. Nmr integration of the olefinic proton absorption showed ca. 15% olefinic hydrogen.

Preparation of exo-exo-6,7-Dideuterio-2-methyl-endo-tricyclo[3.2.1.0^{2,4}]octan-8-one Tosylhydrazone, 121d. Addition of 98% deuterium to 118 in methanol as described above for 113 yielded 119d, and treatment of 119d with tosylhydrazine, water, methanol and acid, as described for 121, yielded 121d. A small amount of 119d was hydrolyzed to ketone 120d, and Figure 6 gives the proton nmr spectra of 120 and 120d after treatment with Eu(fod)$_3$.

Preparation of 4-Deuterio-2-methyl-endo-tricyclo-[3.2.1.0^{2,4}]octan-8-one Tosylhydrazone, 121f. Addition of 2-deuterio-1-methylcyclopropene (81) to 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene (25b) yielded 4-deuterio-2-methyl-1,5,6,7-tetrachloro-8,8-dimethoxy-endo-tricyclo-[3.2.1.0^{2,4}]oct-6-ene. Subsequent treatment in a manner identical to that described for 121 yielded the title tosylhydrazone 121f.

Preparation of 4-exo-6-exo-7-trideuterio-2-methyl-endo-tricyclo[3.2.1.0^{2,4}]octan-8-one Tosylhydrazone, 121g. The title compound was prepared in a manner analogous to that used for 121d and 121f.

Decomposition of 4-Deuterio-2-methyl-endo-tricyclo-[3.2.1.0^{2,4}]octan-8-one Tosylhydrazone, 121f, with Excess Sodium Methoxide. Decomposition was effected in an identical manner to the decomposition of 121 with sodium methoxide. Mass spectral analyses of the products, 122h and 123h, along with the deuterium content of the tosylhydrazone precursor are given in Table VIII.

Decompositions of Deuteriated Tosylhydrazones 121d, 121f, and 121g with Sodium Hydride. Decomposition of 121d,, 121f and 121g were effected in an identical manner to the sodium hydride decomposition of 121. Mass spectral analysis of the products and tosylhydrazone precursors are presented in Table VIII.

Pyrolysis of endo-tricyclo[3.2.1.0^{2,4}]oct-6-ene derivatives, 116c, 124c and 124e. Following the procedure of R.B. Kinnel (79), vpc purified tricyclooctenes (ca. 25 mg per run) were pyrolyzed in a sealed pyrex tube at 240-260° for 20-30 hr. Vpc analysis on column 2 (100°, 60 ml/min) indicated >97% of the expected tetracyclooctane derivatives 22c, 122c and 122e.

Test for Exchange of 4-Deuterio-2-methyltetracyclo-[3.3.0.0^{2,8}.0^{4,6}]octane, 122e. The title hydrocarbon (2.2 ±1.0% d_0, 97.8±1.0% d_1, 20 mg) was placed in 5 ml of freshly distilled (from $LiAlH_4$) diglyme along with 80 mg of sodium hydride. The solution was heated at 160-170° for two hr, cooled, diluted with water, and extracted with pentane. The pentane was washed with water and brine, dried over anhydrous sodium sulfate, and the hydrocarbon was collected by preparative vpc. Mass spectral analysis indicated 0.8±1.0% d_0 and 99.2±1.0% d_1.

Pyrolysis of the Lithium Salt of endo-tricyclo[3.2.1.0^{2,4}]octan-8-one tosylhydrazone, 104. To a dry 5 ml flask was added 35 mg (0.13 mmol) of 104. Under nitrogen, 5 ml of anhydrous ether was added, followed by 65 μl of 1.1 M methyllithium (0.15 mmol). After swirling for 5 min, the ether was removed with a stream of nitrogen, and the dry salt was heated to 40° (0.2 torr) for one hr. The flask was then placed in a 170° oil bath and the volatile material trapped in a -78° cold bath. After 0.5 hr, the trapped material was rinsed into an nmr tube with CCl_4. The nmr signal of the crude product was very weak, and contained no olefinic absorptions.

Pyrolysis of the Lithium Salt of the Tosylhydrazone of 2-Methyl-endo-tricyclo[3.2.1.0^{2,4}]octan-8-one. The title tosylhydrazone, 121, (240 mg, 0.8 mmol) was placed in ca. 20 ml of anhydrous ether, and 400 μl of 2.2 M methyllithium in ether (0.88 mmol) was added dropwise. After swirling for ca. 5 min, the ether was evaporated with a stream of nitrogen. The dry salt was then warmed to 40° for 1 hr at 0.2 torr, then placed in a 170° oil bath for 0.5 hr. A small amount of yellow material was trapped in a -78° cold bath. Vpc analysis (col 2, 100°) showed no indication of any hydrocarbon products, though several unidentified products eluted with much longer retention times (190°).

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