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Part A: Some Reactions of Norbornene Oxide: Part B: Arylnorbornene Oxides

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To the Graduate Council:

I am submitting herewith a dissertation written by Thomas J. Gerteisen entitled "Part A: Some Reactions of Norbornene Oxide: Part B: Arylnorbornene Oxides." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Chemistry.

Donald C. Kleinfelter, Major Professor

We have read this dissertation and recommend its acceptance:

Alexander Van Hood, John B. Vercellotti

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

September 4, 1970

To the Graduate Council:

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Donald C. Kleinfelter
Major Professor

We have read this dissertation
and recommend its acceptance:

Alexander Van Hook

Robert J Doverma

John R. Vercellotti

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

PART A: SOME REACTIONS OF NORBORNENE OXIDE:
PART B: ARYLNORBORNENE OXIDES

A Dissertation
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
acob
Thomas J. Gerteisen

December 1970

TO

MY MOTHER

AND

FATHER

ACKNOWLEDGEMENT

The author finds it difficult to express his deep felt appreciation in terms other than time-worn cliches, but nonetheless, it is especially due the following.

Dr. Donald C. Kleinfelter, who was always there when needed. He has expertly led many through the tangled, despairing labyrinth that is known as research, with a cheerful countenance and a reliant confidence that never fails to bolster one's own selfconfidence.

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ABSTRACT

PART A

In this thesis research on the action of Grignard reagents with norbornene oxide has been initiated and found to be of possible synthetic utility.

The products of the reaction of three aryl Grignard reagents, (phenyl, *o*- and *p*-tolylmagnesium bromide), and a typical alkyl Grignard reagent, (methylmagnesium iodide), have been separated, identified, and characterized. The reaction of the aryl organometallic compounds with norbornene oxide yielded mixtures of 7-*syn*-norbornenol, and the corresponding 2-*exo*-aryl-7-*syn*-norbornanols. The unsaturated norbornanol was the predominant product in each case, its percentage yield being slightly higher in the case of the somewhat more sterically encumbered *o*-tolyl reagent. Methylmagnesium iodide and norbornene oxide reacted to give a mixture of four norbornanols, 7-*syn*-norbornenol, 2-*exo*-methyl-7-*syn*- and *anti*-norbornanols, and 2-*exo*-iodo-7-*syn*-norbornanol. A mechanistic justification of both types of reactions has been proposed.

The nuclear magnetic resonance (nmr) and infrared (ir) spectral data of the above products have been obtained and listed.

The mass spectra of six 7-norbornanols have been recorded, and tentative, partial fragmentation patterns forwarded. The compounds studied were 7-*syn*-norbornenol, 7-norbornanol, 2-*exo*-phenyl-7-*syn*-norbornanol, 2-*exo*-cyclohexyl-7-*syn*-norbornanol, 2-*exo*-methyl-7-*syn*-norbornanol, and 2-*exo*-methyl-7-*anti*-norbornanol.

PART B

The structure of the product of the acid catalyzed dehydration of 2-p-anisylnorbornane-2,3-cis-exo-diol in hydrochloric acid-tetrahydrofuran has been reassigned. It was discovered, on the basis of further data, that the structure of the high melting solid was that of the dimer of the epoxide, a p-dioxane, rather than the epoxide itself. This change was proposed for many reasons. A near total nmr analysis of the compound was completed, including double irradiation experiments, an iterative computer program comparison between the theoretically generated and experimental spectra, and high temperature nmr studies. The o,o,o',o'-tetradeuterio derivative was synthesized and by means of elevated temperature nmr the free energy barrier to rotation about the aryl-norbornane bond was computed to be 19.6 kcal mole^{-1}.

Two 2-arylnorbornene-2,3-exo-oxides (phenyl and 4-chlorophenyl) have been synthesized and their nmr and ir spectral data reported. Some chemical reactions of the phenyl-norbornene oxide have been accomplished. The reaction of the oxide with phenylmagnesium bromide gave but one product, 3,3-diphenyl-2-exo-norbornanol, in marked contrast to the behavior of norbornene oxide. Hydride reduction gave exclusively 3-endo-phenyl-2-exo-norbornanol, contrary to norbornene oxide which yielded a mixture of 2-exo-norbornanol, and 7-norbornanol. The oxirane ring of the arylnorbornene oxides is evidently quite strained as acetic acid and absolute methanol add across the carbon-oxygen bond easily to yield 3-exo-acetoxy-2-endo-phenyl-2-exo-norbornanol and 3-exo-methoxy-3-endo-phenyl-2-exo-norbornanol, respectively.

The ultraviolet spectra of the two arylnorbornene oxides have been scanned and compared with those of the analogous styrene oxides and their olefinic predecessors.

The mass spectra have been obtained for norbornene oxide, 5-*endo*-acetoxynorbornene oxide, 2-phenylnorbornene-2,3-*exo*-oxide, 2-(4-chlorophenyl)-norbornene-2,3-*exo*-oxide, 2-phenylnorbornene, and 2-(4-chlorophenyl)-norbornene. Limited degradation pathways have been proposed.

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PART A

SOME REACTIONS OF NORBORNENE OXIDE

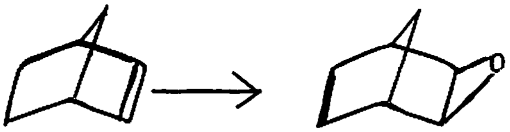
CHAPTER I

INTRODUCTION

A. History

1. Syntheses of Norbornene Oxides

The synthesis of norbornene-2,3-exo-oxide, or simply norbornene oxide, (I), was first described simultaneously by Kwart and Vosburgh[1] and Walborsky and Loncrini,[2] in 1954. Kwart and Vosburgh utilized the reaction of monoperphthalic acid upon norbornene, (II), for a yield of 25%, while Walborsky and Loncrini reacted (II) in the cold with sodium acetate buffered 40% peracetic acid for a yield of 70%. In 1960 Soloway and Cristol[3] reported a yield of 80% by the action of perbenzoic acid on (II).

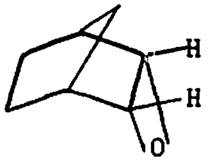


(1)

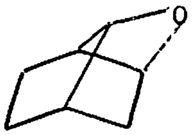
(II) (I)

The three teams of researchers reported pure (I) as being formed, but in 1962 Watanobi, Pillai, and Pines[4] utilized the method of Walborsky and Loncrini and reported a ternary mixture as being formed, the ratio of products being 25:18:7, as determined by preparative gas-liquid chromatography, (glc). They suggested the corresponding structures to be (I), the endo isomer of (I), structure (III), and the 2,7 four membered oxirane structure (IV). In 1963, Kwart and Takeshita[5] described the product of peracetic acid oxidation of norbornene as being a mixture of 94% (I) and 6% (III).

Crandall,[6] in 1964 resolved the anomaly presented by Watanobi, et al.,[4] by

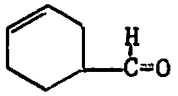


(III)



(IV)

describing the rearrangement of (I) during exposure to the column packing during gas chromatographic analysis (Chromosorb P on Carbowax 20 M at 120°C). He isolated and identified the three products as 3-cyclohexenealdehyde, (V), norcamphor, (VI), and 2-nortricyclenol (VII). H. C. Brown and co-



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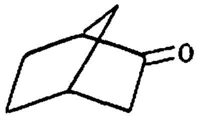

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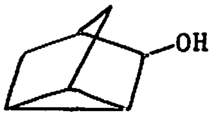
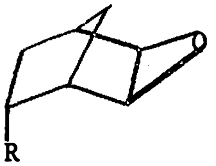


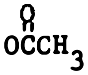
(VII)

workers,[7] in 1967, described the product of epoxidation of (II) as being 99.5% (I), and 0.5% (III), although the method of epoxidation was not mentioned.

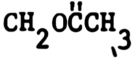
Since 1957 a variety of substituted norbornene oxides have been reported. Among them are those with 5-<u>endo</u> substituents such as (VIII), (IX), (X), and (XI), reported by Henbest and Nicholls,[8] and (XII), synthesized by Shahak, Manor, and Bergman.[9]



VIII R = OH

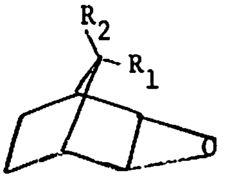
IX R =  $\mathrm{O}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{CH_3}$

X R = CH_2OCH_3

XI R =  $\mathrm{CH_2O}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{CH_3}$

XII R = CH_3

Norbornene oxides with moieties in the 7-*syn* and 7-*anti* positions are known, such as (XIII), by Tori,[10] and (XIV), (XV), and (XVI), reported



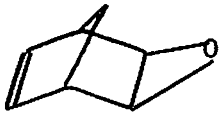
XIII $R_1 = O\overset{O}{\overset{\|}{C}}CH_3,\ R_2 = H$

XIV $R_1,R_2 = OCH_3$

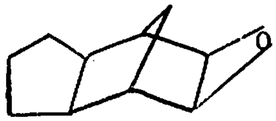
XV $R_1 = H,\ R_2 = OH$

XVI $R_1,R_2 = \,>\, = O$

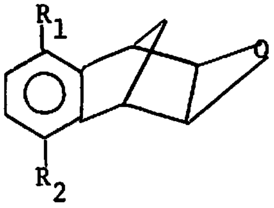
by Gassman.[11] The synthesis of the mono *exo* epoxide of norbornadiene, (XVII), has been reported by Tori,[10] and Soloway[12] has described the epoxidation of dihydrocyclopentadiene dimer, in which the oxirane ring is within the norbornyl framework, (XVIII). Bartlett[13] has described the synthesis and properties of the *exo* epoxide of the benzonorbornadiene, (XIX), and Meinwald[14] the *o*,*o*'-diacetate of (XIX), (XX). Christol, Caste, and Plēnat[15] have synthesized a variety of 5 substituted, and 5,6 disubstituted norbornene oxides, (XXI)-(XXVIII).



(XVII)

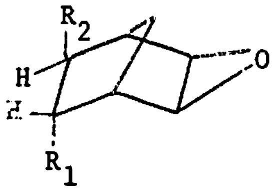


(XVIII)



XIX $R_1,R_2 = H$

XX $R_1,R_2 = O\overset{O}{\overset{\|}{C}}CH_3$



XXI $R_1 = CO_2CH_3$, $R_2 = H$

XXII $R_1 = H$, $R_2 = CO_2CH_3$

XXIII $R_1 = CH_2OH$, $R_2 = CH_2Cl$

XXIV $R_1 = CO_2CH_3$, R_2CH_2Cl

XXV $R_1 = CH_2Cl$, $R_2 = CO_2CH_3$

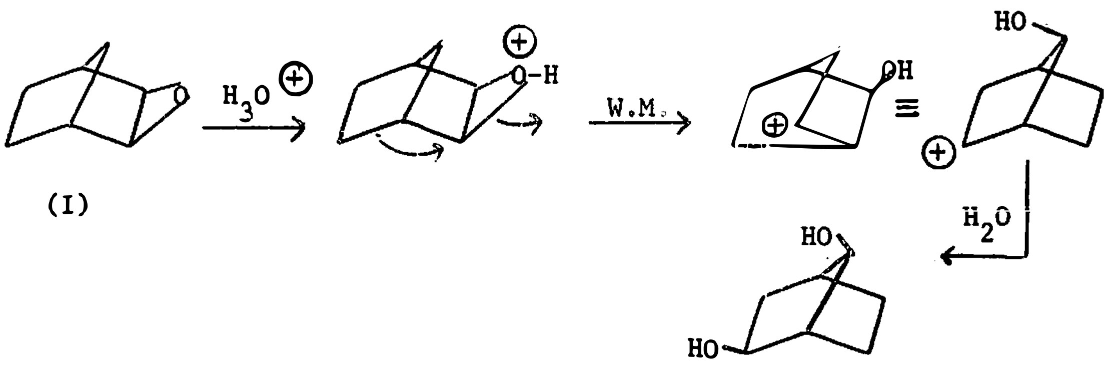
XXVI $R_1 = CH_2I$, $R_2 = CO_2CH_3$

XXVII $R_1 = CH_2O\overset{O}{\overset{\parallel}{C}}CH_3$, $R_2 = CO_2CH_2$

XXVIII $R_1 = CH_2OH$, $R_2 = CO_2H$

2. Reactions of Norbornene Oxides

As might be expected, the oxirane ring is highly reactive toward acidic reagents. Kwart and Vosburgh,[1] and Walborsky and Loncrini,[2] reported that acidic hydrolysis, (dilute sulfuric acid or formic acid), of norbornene oxide, (I), yielded the 2-exo-7-syn-norbornane diol, (XXIX) obviously the result of a Wagner-Meerwein rearrangement as depicted in equation (2).

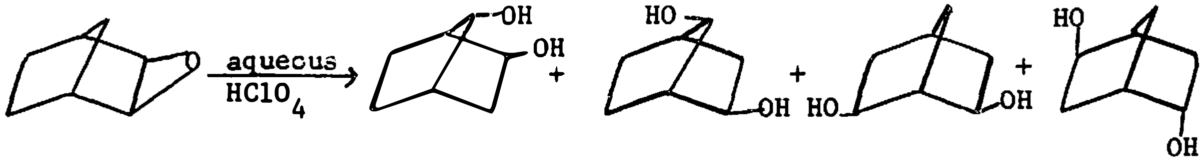


(I)

(XXIX)

(2)

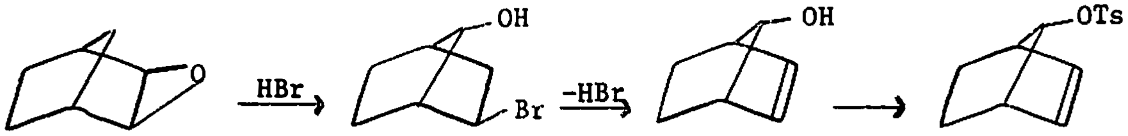
Crandall,[6] however, has shown this hydrolysis product to be a mixture of four isomeric norbornane diols. He reacted norbornene oxide with aqueous perchloric acid and determined the product distribution to be 74% (XXIX), 22% of the anti isomer of (XXIX), (XXX), and 4% of a mixture of 2,6 and 2,5 diols, (XXXI) and XXXII).



(XXIX) (XXX) (XXXI) (XXXII)

(3)

The reaction of norbornene oxide with concentrated mineral acid gives different products. Reaction with 48% hydrobromic acid produced a bromohydrin, (XXXIII), 2-exo-bromo-7-syn-norbornanol, according to Walborsky and Loncrini,[16] and Winstein and Stafford.[17] The latter team utilized the dehydrohalogenation of this compound to obtain the then highly desirable 7-syn-norbornenyl tosylate, (XXXV). Bartlett and Giddings[13]

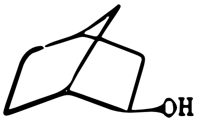


(4)

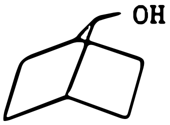
(I) (XXXIII) (XXXIV) (XXXV)

affected an analogous reaction with their benzonorbornene oxide, (XIX), and Shahak, Manor, and Bergmann[9] reported a fluorohydrin as being the product of the reaction of hydrofluoric acid with their 5-endo-methyl norbornene oxide, but no structural elucidation was attempted.

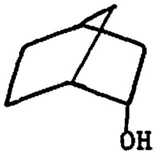
The reduction of norbornene oxides with metal hydrides, principally lithium aluminum hydride, $LiAlH_4$, has been often discussed. Ordinary hydride reduction in ether goes very slowly, if at all,[5] and more polar and higher boiling solvents are needed, such as tetrahydrofuran, (THF),[5,18] N-ethylmorpholine, (NEM),[1,5] or THF-diglyme.[18] In their pioneering paper, Walborsky and Loncrini[1] reported only *exo*-norbornanol, (XXXIV), as the product of $LiAlH_4$ reduction of norbornene oxide in NEM. However, Kwart and Takeshita[5] reported three isomeric norbornanols resulting from such a reduction in either THF, or NEM solution. The products were identified as 2-*exo*-norbornanol, (XXXIV), 7-norbornanol (XXXV), and 2-*endo*-norbornanol,



(XXXIV)



(XXXV)

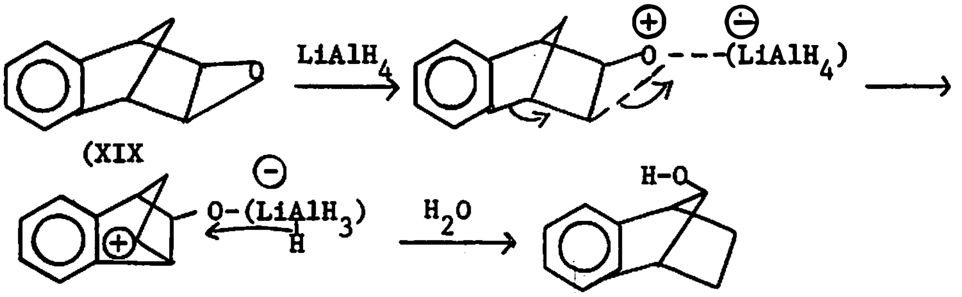


(XXXVI)

(XXXVI). Kwart and Takeshita[5] reportedly isolated pure *exo*-norbornene oxide and obtained *exo*- and 7-norbornanol alone from its reduction. Hence, the *endo*-norbornanol is a product of reduction of the *endo*-oxide, (III). Yoon and Brown,[18] on the other hand, observed 100% *exo*-norbornanol to be obtained by $LiAlH_4$ reduction with THF or THF-diglyme solvent.

Other reductions have been affected with norbornene oxide; among them are lithium diethylamide to yield nortricyclenol, (VIII),[6] and sodium-ethanol to give exclusively *exo*-norbornanol, (XXXIV).[5] Yoon and Brown[18] observed that, unlike other epoxides, reduction of norbornene oxide with aluminum hydride, AlH_3, gave a mixture of products, namely, *exo*-, *endo*- and 7-norbornanol, (XXXIV), (XXXVI), and (XXXV), respectively.

The reductions of substituted norbornene oxides have not been studied so closely. Soloway and Cristol[3] remarked that an *exo*-norbornanol was obtained from (XVIII), and Henbest and Nicholls reported the same for (VIII) and (X).[8] Gassman and Marshall[11] revealed that reduction of their epoxide, (XIV), with $LiAlH_4$ in THF with twelve days reflux gave 100% *exo* product. Bartlett and Giddings[13] on the other hand demonstrated the $LiAlH_4$ reduction of benzonorbornene oxide, (XIX), in ether gave exclusively the 7-norbornanol, the hydroxyl being oriented *syn* to the aryl ring, proving a single Wagner-Meerwein shift had occured, equation (5).



(5)

3. Spectra of Norbornene Oxides

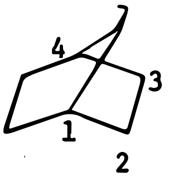
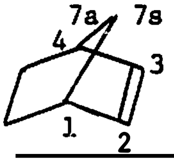
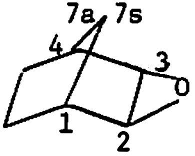
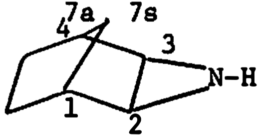
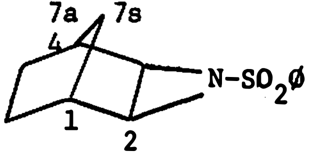
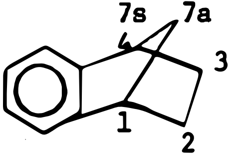
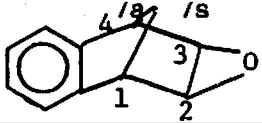
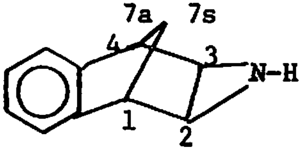
Spectroscopically, the norbornene oxides are rather simple to identify.

A characteristic absorption in the infrared, (ir), has been reported at.11.84 -.11.85 μ.[12]

In the nuclear magnetic resonance spectrum, (nmr), the 2-*endo* and 3-endo protons are characteristically the most downfield of all. The 7-*anti* proton is shifted far upfield while the 7-*syn* proton is shifted downfield by a lesser amount, relative to norbornane. In reference to the same standard, the 1 and 4 protons are also shifted downfield by virtue of the inductive electron withdrawal of the oxirane ring. In Table I are listed some chemical shift data for norbornane, norbornene, (II), norbornene oxide, (I), selected derivatives of the above, and two azo epoxides.

TABLE I

SELECTED NUCLEAR MAGNETIC RESONANCE DATA

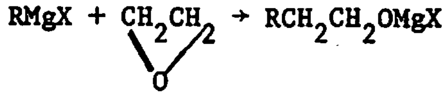
Compound	Solvent	Chemical Shift, δ			Reference
		H_2,H_3	H_1,H_4	H_{7s},H_{7a}	
	CCl_4	----	2.20	1.21	20
	CCl_4	----	2.19	1.26	21
	$CDCl_3$	----	2.20	1.20	22
	CCl_4	1.18(endo) 1.49(exo)	2.20	1.21	23,24
	CCl_4	5.93	2.83	1.32,1.07	19
	CCl_4	5.94	2.78	----	21
	CCl_4	5.95	2.83	1.32,1.07	23,24
	C_6H_6	2.70	2.13	1.44,0.43	25
	$CDCl_3$	3.16	2.44	1.35,0.70	22
	CCl_4	----	2.41	1.27,0.58	19
	CCl_4	----	2.29	1.17,0.53	19
	C_6H_6	2.84	1.97	1.38,0.30	25
	$CDCl_3$	----	3.35	1.73,1.48	22
	CCl_4	----	3.30	1.73,1.48	19
	$CDCl_3$	3.36	3.36	1.49,1.97	22
	CCl_4	----	3.31	1.47,1.93	19
	CCl_4	----	3.18	1.27,1.93	19

It would appear that no mass spectral data has been determined for norbornene oxide itself, although some work has been reported on the mass spectra of various norbornanes and norbornanols.[26,27,28] Long[26] has recorded the mass spectra of twenty norbornyl derivatives, seventeen of them aryl norbornanols. Goto, Tatematsu, et al.[27] have attempted to classify various bicyclo-[2,2,1]-heptane and bicyclo-[2,2,2]-octane derivatives into groups, the members of which undergo, more or less, a predictable mass spectral decomposition.

B. Introduction to the Problem

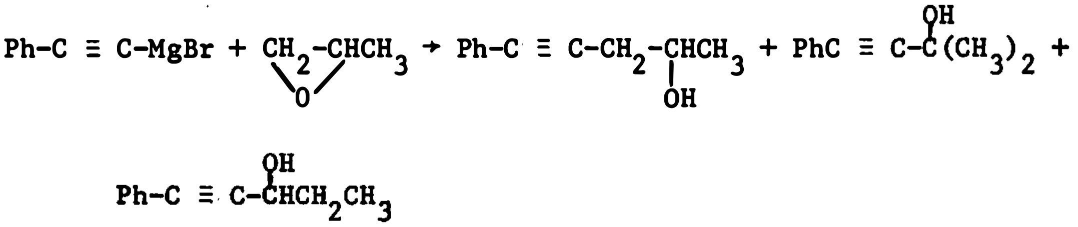
1. Chemical Reactions of Norbornene Oxide

Norbornene oxide (I) has been known since 1954 and several of its chemical reactions have been discussed in the historical section of this chapter. In view of the invaluable synthetic importance of the Grignard reaction it seems rather surprising that no reactions of norbornene oxide, or any of its derivatives, have been reported to date. The reaction of a Grignard reagent with ethylene oxide is by now of textbook importance[24] as a means of preparation of β-substitued ethanols, equation (6), and examples of reactions with other epoxides to give up to five different products have been known for some time.[30]



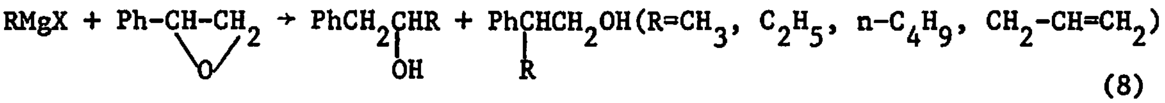
$$\mathrm{RMgX} + \underset{\mathrm{O}}{\mathrm{CH_2CH_2}} \rightarrow \mathrm{RCH_2CH_2OMgX} \qquad (6)$$

Examples of the reaction of Grignard reagents with propylene oxide,[31] and styrene oxide[32] to yield mixtures of products, by virtue of rearrangement of the epoxide skeleton, have appeared in the recent literature, as shown in equations (7) and (8).



$$\mathrm{Ph{-}C \equiv C{-}MgBr + \underset{\diagdown O \diagup}{CH_2{-}CHCH_3} \rightarrow Ph{-}C \equiv C{-}CH_2{-}\underset{OH}{C}HCH_3 + PhC \equiv C{-}\overset{OH}{C}(CH_3)_2 + Ph{-}C \equiv C{-}\overset{OH}{C}HCH_2CH_3}$$

(7)



$$\mathrm{RMgX + Ph{-}\underset{\diagdown O \diagup}{CH{-}CH_2} \rightarrow PhCH_2\underset{OH}{C}HR + Ph\underset{R}{C}HCH_2OH(R{=}CH_3,\ C_2H_5,\ n{-}C_4H_9,\ CH_2{-}CH{=}CH_2)}$$

(8)

It was seen as a distinct possibility, therefore, that the reaction of norbornene oxide with various Grignard reagents might provide an interesting comparison with the above as well as serve as an interesting, perhaps useful, synthetic route to various substituted norbornanols.

CHAPTER II

DISCUSSION OF RESULTS

A. Reactions of Norbornene Oxide, (I)

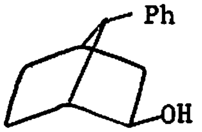
1. $LiAlH_4$ Reduction of (I)

As mentioned in the introduction, page 6, the reaction of norbornene oxide with lithium aluminum hydride in ether proceeded rather slowly and a comparatively higher boiling solvent such as THF was needed. It was also mentioned that a certain degree of confusion existed regarding product composition.

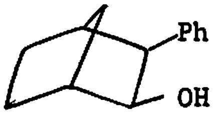
The reduction of (I) was therefore repeated, utilizing a 5:1 molar ratio of $LiAlH_4$ to epoxide in boiling THF for forty hours. The product of this reaction was proven to be a mixture of 2-*exo*- and 7-norbornanol, (XXXIV) and (XXXV). Product identification was made on the basis of the nmr spectrum of the mixture, as the spectra of both compounds have been reported.[33] Identification of both components was made on the basis of the carbinol tertiary C-H absorption of each.

2. The Action of Grignard Reagents with (I)

a. *Phenylmagnesium bromide.* An ethereal solution of (I) was added dropwise to an ethereal solution of excess phenylmagnesium bromide. Upon refluxing, cooling, hydrolysis with pure water (no acidic reagents such as dilute hydrochloric acid or ammonium chloride solution were used in view of the ease of rearrangement of norbornyl skeleton) and customary workup, a yellow oil was obtained, the glc of which indicated a binary mixture with one component much more volatile than the other. The nmr spectrum of the crude oil product revealed that two 7-norbornanols had been formed, one was olefinic, and the other a phenyl norbornanol. By means of cooling in a dry ice-acetone bath a small amount of solid material was obtained. This material proved to be a phenylnorbornanol, with the hydroxyl in the 7-position. It was felt that the hydroxyl was on the *syn* side of the 7-position because of the appearance of the aryl proton absorption in the nmr. Whereas all the 3-phenyl-2-norbornanols and 7-*syn*-phenyl-2-*exo*-norbornanol, (XXXVII), are known to display singlets in the aryl proton spectrum,[33,34] this compound displayed a rather highly complex multiplet in that region (7.19 δ). The benzylic proton absorbed at 2.89 δ as a distorted triplet, typical in shift of an *endo* proton attached to the same carbon as a phenyl group. The analogous proton in 3-*exo*-phenyl-2-*exo*-norbornanol, (XXXVIII), absorbs at 2.83 δ as two doublet pairs.[3,4]



(XXXVII)

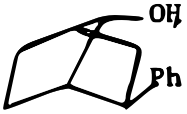


(XXXVIII)

The unusual multiplicity of the aryl proton absorption indicates that the hydroxyl might be of the *syn* orientation. However, in an expanded ir spectrum, only the free hydroxyl stretching was observed at 3623 cm^{-1}, as compared to 3591 cm^{-1} for (XXXVII).[34] This means little or no intramolecular hydrogen-pi cloud bonding is taking place. Hence, the aryl ring must be twisted on edge with respect to the hydroxyl and the multiplicity due to the nonequivalence of the aryl protons brought about by the proximity of the hydroxyl group to some of the protons.

The tosylate of the phenyl norbornanol was prepared and the nmr spectrum of this derivative revealed a value of 0.34 δ for the $\Delta\delta$ between the A and B absorptions of the AA'BB' system for the tosyl ring protons. This is to be compared to a value of 0.23 δ for the tosylate of (XXXVII), and 0.50 δ for the tosylate of 3-exo-phenyl-2-endo-norbornanol.[34] This too lends evidence that the aryl ring is on an edge to edge plane with the hydroxyl.

In view of the above data, the phenyl norbornanol is assigned structure (XXXIX), 2-exo-phenyl-7-syn-norbornanol, the nmr data of which are condensed in Table II.



(XXXIX)

The assignment of the hydroxyl group to the 7-position was further proven by chemical means. A ketone was obtained upon Sarett oxidation (CrO_3-pyridine). Three stretching vibrations attributable to a carbonyl group were observed, 1834 cm^{-1} (m), 1771 cm^{-1} (s), and 1740 cm^{-1} (w). These values are highly consistent with those reported for various 7-norbornanones.[11,35]

Lithium aluminum hydride reduction of this ketone produced the original norbornanol, (XXXIX), exclusively. This is analogous to the reduction of the ketone derivative of (XXXVII), which yields exclusively the parent alcohol.[33]

TABLE II

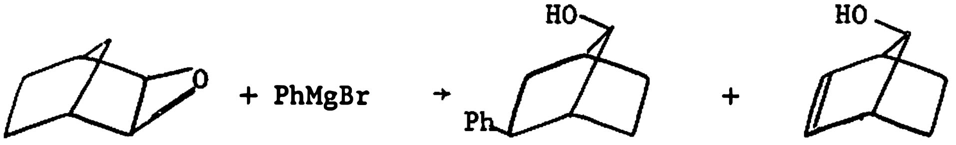
NUCLEAR MAGNETIC RESONANCE DATA FOR 2-*EXO*-PHENYL-7-*SYN*-NORBORNANOL, (XXXIX)[a]

Proton Assignment	Chemical Shift, δ	Multiplicity
Aryl	7.19	Complex
2-*endo*	2.89	Triplet
7-*anti*	3.93	Broad Singlet
1	2.41	Broad Singlet
4	~2.19	Broad Singlet
3,5,6-*exo*, *endo*	~1.18-2.02	Complex

[a] Ca. 15% (w/v) CCl_4 (60 MHz).

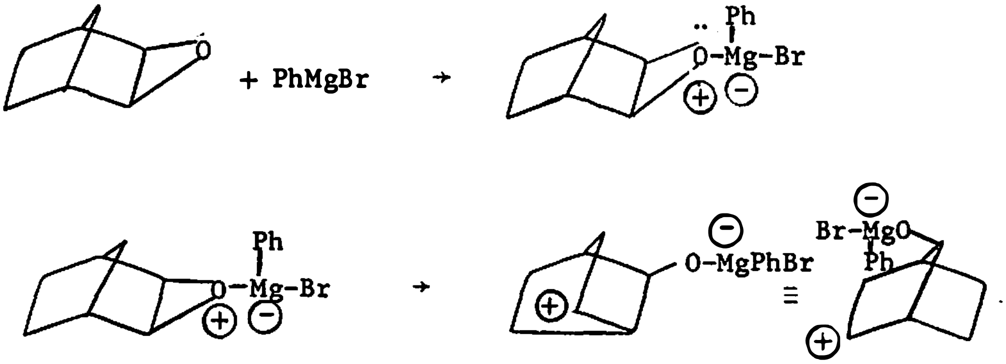
Gentle distillation of the filtrate obtained during the isolation of (XXXIX) yielded a volatile, liquidous material which solidified into a clear glassy mass upon cooling, mp 79-80°C. Infrared analysis indicated a norbornanol, but no aryl substitution, while the nmr spectrum indicated a 7-norbornenol. The preparation of the tosylate resulted in a white crystalline material of mp 66-67°C, comparable to the value given by Winstein and Stafford[17] for 7-syn-norbornenyl tosylate, mp 67-68°C.

The reaction was performed under three different concentration conditions. As may be expected in a reaction in which more than one product is obtained, each presumably by a different mechanistic scheme, altering the molar ratio of Grignard reagent to substrate (oxide) led to different product distributions. The results of this experiment are shown in Table III. The best overall yield to be achieved for the reaction was 95%. The course of the reaction is summarized in equation (9), and the reaction is mechanistically outlined in equation (10).



(9)

(I) (XXXIX) (XXXX)



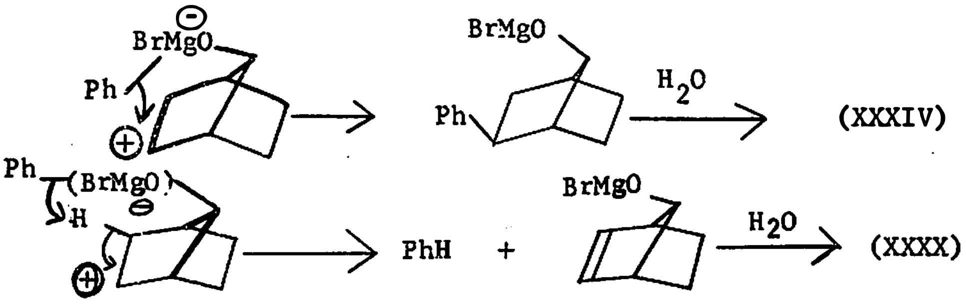
(10)

TABLE III

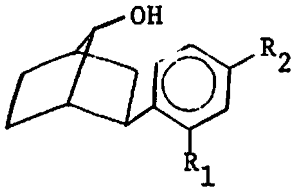
PRODUCT DISTRIBUTION DATA FOR PhMgBr + NORBORNENE OXIDE[a]

Molar Ratio of PhMgBr:(I)	% M XXXIX	% M XXXX
1.5:1.0	25	75
3.0:1.0	12	88
1.2:1.0	22	78

[a] Product distribution determined by means of quantitative glc chromatography. The column packing, dimensions and other experimental details are discussed in the experimental section.



b. *Ortho-tolylmagnesium bromide and para-tolylmagnesium bromide.* These two reactions were performed and a product analysis made for each as in the case of the phenyl reagent. By virtue of the analogy with the phenyl addition product, the aryl norbornanols formed, 2-*exo*-(2-methylphenyl)-7-*syn*-norbornanol, (XXXXI), and 2-*exo*-(4-methylphenyl)-7-*syn*-norbornanol, (XXXXII), were readily identified by virtue of their nmr spectra.



XXXXI $R_1 = CH_3$, $R_2 = H$

XXXXII $R_1 = H$, $R_2 = CH_3$

The reaction of (I) with the *ortho* Grignard gave a product distribution of 85% (XXXX) and 15% of the aryl norbornanol, (XXXXI), while that of the *para* organometallic gave 76% (XXXX), and 24% of the aryl addition compound, (XXXXII). The infrared spectrum gave a value of 3624 cm^{-1} for the free hydroxyl stretch of (XXXXII), compared to a value of 3621 cm^{-1} for (XXXXI). The optimum yield for the reaction with the *ortho*-tolyl Grignard was 83%. The reaction of the *para*-tolyl Grignard was done but once, a total yield of 40% being realized.

c. Methylmagnesium iodide. The reaction of an alkyl magnesium halide with norbornene oxide leads to results somewhat different than with the aryl organometallic reagent. In eight out of the nine determinations of this reaction three products were formed, the 7-*syn*-norbornenol, (XXXX), and two other somewhat less volatile compounds. Removal of the unsaturated norbornanol by gentle distillation left a viscous residue which was shown by ir, nmr, and glc to be a binary mixture of substituted norbornanols. Various attempts at separation such as distillation, selective crystallization, column chromatography, and derivative formation, failed. The two components were finally separated satisfactorily by preparative glc. The two components were quite different in their physical appearance, one being a white crystalline solid, mp 150-151°C, with a surprising volatility in view of its melting point, and the other an oil which solidified into a transparent glass upon standing.

The two compounds were shown to be isomeric methyl norbornanols by their mass spectra, parent ion of m/e 126.

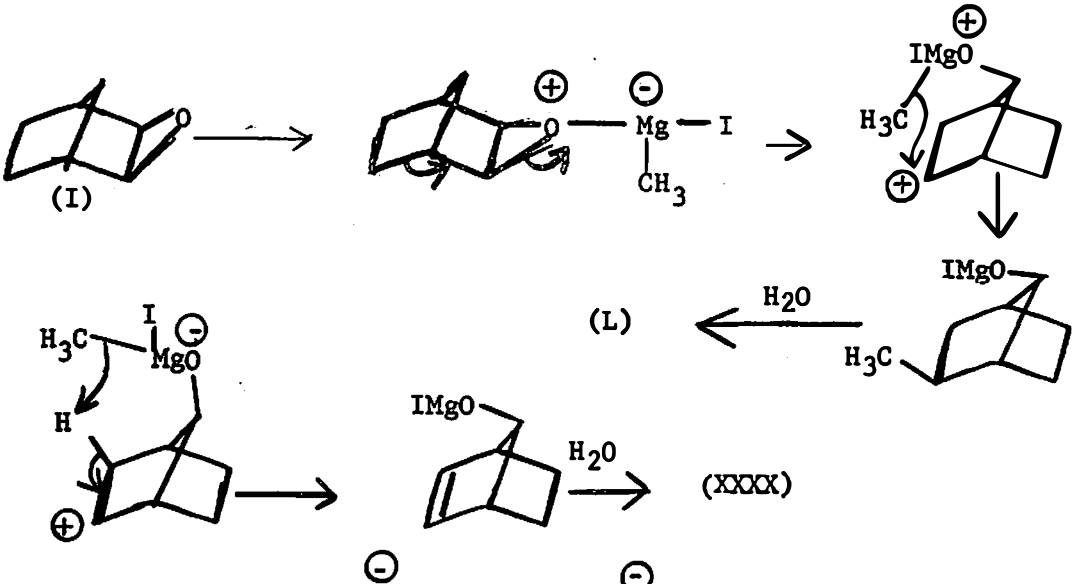
The nmr spectra of the two compounds are quite different yet they both are believed to be 7-norbornanols due to the chemical shifts of the carbinol hydrogens which absorb at 3.90 δ and 3.93 δ, respectively, for the solid and the oil. If the two isomers were analogs of the aryl addition products, i.e. 7-*syn*- and 7-*anti*-2-*exo*-methyl norbornanols, one would expect to see an intense upfield doublet due to the methyl absorption, yet this is not the case. One might conclude then that perhaps the two isomers are those with the methyl group substituted on the bridgehead position, (C_7). These structures may be discounted due to the lack of strong methyl singlets in the spectrum.

The apparent absence of methyl doublets in the nmr spectra may be rationalized by concluding that the methyl absorptions are close in chemical shift to those of the endo protons and first order analysis is inapplicable.

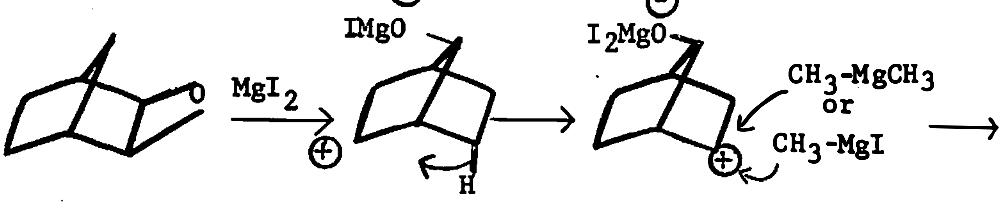
Therefore the products of the reaction are assigned the structures (XXXX), the unsaturated norbornanol, (L), and (LI), 2-exo-methyl-7-syn- and anti- norbornanol, respectively.

The above three products can be mechanistically justified by virtue of the Schlenk equilibrium[36] as shown in equations (11), (12), and (13).

$$2CH_3MgI \rightleftarrows (CH_3)_2Mg + MgI_2 \qquad (11)$$



(12)



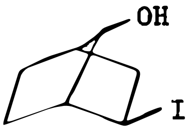
(13)

In this reaction, as with the phenyl reagent, it was found that the product distribution is highly dependent upon such conditions as reaction time, volume of solvent, concentration ratios, etc. Rather wide ranging values for the product distribution were obtained for different runs in which attempts were made to hold all variables constant. A typical run and product distribution are described in the experimental section. Total yields were between 75 and 80%.

In one of the nine runs performed for the above reaction, a white ligroin insoluble solid, mp 72-73.5°C, was obtained.

Ir and nmr analyses indicated a 7-norbornanol (C_7 proton, 4.17 δ). An anomalous single proton absorption (3.89 δ, quartet of doublets, J's = 1.2, 4.2, and 7.8 Hz) was observed in the nmr spectrum. It was reasoned such a downfield peak was probably due to a proton which shared a carbon atom with a halogen, in this case, iodine, since the compound matched none of the known norbornane diols.[6] In the infrared spectrum, two hydroxyl stretches were observed, 3620 cm^{-1} (free hydroxyl stretch), and 3574 cm^{-1}. The peak at 3574 cm^{-1} did not shift upon dilution showing it to be intramolecularly hydrogen bound rather than intermolecularly.[37]

Shaking a small amount of the compound with alcoholic silver nitrate solution produced a copious yellow precipitate, and a sodium fusion test for halogen was positive. Dehydroiodination by refluxing with pyridine led to a mixture of a diol and 7-*syn*-norbornenol, (XXXX). The structure of the compound is therefore 2-*exo*-iodo-7-*syn*-norbornanol, (LII).

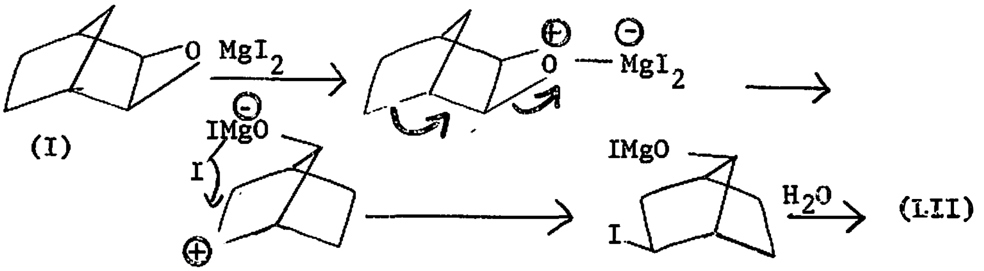


LII

Assuming that first order analysis is valid, and it rarely is for an ABX system,[33,38] the large (7.8 Hz) coupling of the downfield quartet may then be assigned to that of the 2-*endo* and 3-*endo* protons, while the 4.2 Hz and 1.2 Hz couplings may be due to the 2-*endo*, 3-*exo* and 2-*endo*, 7-*anti* interactions, respectively.[38]

The isolation of the iodonorbornanol lends further evidence to mechanisms (12) and (13), as shown in equation (14).

$2CH_3MgI \rightleftarrows (CH_3)_2Mg + MgI_2$



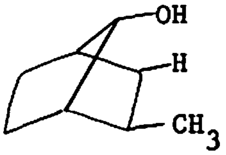
(14)

Assignment of isomeric structures to the two methyl norbornanols presented an intriguing problem. As mentioned, the methyl protons do not appear as the expected intense doublets due to non-first order character of the spectrum. If the two norbornanols are isomeric 2-*exo*-methyl-7-norbornanol one would expect basic differences in the downfield portions of the upfield complex multiplets of the nmr spectra due to the electronic deshielding influence of the hydroxyl group on the *exo* protons *syn* to it. It has been observed by

Snyder and Franzus[39] that a 7-syn hydroxyl deshields an exo proton by 0.08 δ. In the syn-norbornanol (L) one would expect to see one proton deshielded while in the anti isomer (LI) two protons would be deshielded. However, the effect of the 2-exo-methyl group must be taken into consideration. Musher[33] and Eliel[40] have commented on the shielding effect of a methyl substituent on an adjacent proton. In the syn isomer the deshielding effect of the hydroxyl group may be partially or totally compensated by the shielding of the methyl. In Figure 1 the above effects are summarized.

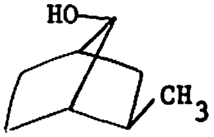
The nmr spectrum of the solid isomer showed a downfield, broad singlet centered at 1.89 δ which integrated for four protons, while the spectrum of the oil showed a one proton broad singlet at 1.97 δ. The four proton singlet may be assigned to two exo protons and the two bridgehead protons, and the one proton singlet to a bridgehead proton, characteristically somewhat downfield.[23,24] The nmr spectrum of 7-norbornanol is characterized by a broad singlet at 1.90 δ, very analogous to that of the solid compound. This evidence suggested rather convincingly that the solid isomer was of the anti orientation, (LI, 2-exo-methyl-7-anti-norbornanol), while the oil was of the syn orientation, (L, 2-exo-methyl-7-syn-norbornanol).

This tentative assignment was confirmed by examination of the nmr dilution curves of the two compounds as compared to that of 2-exo-cyclohexyl-7-syn-norbornanol, prepared by the catalytic hydrogenation of the phenyl analog, (XXXIX). Two of the dilution curves were similar, those of the cyclohexyl compound (chemical shift at infinite dilution,



SYN ISOMER, (L)

One *exo* proton deshielded and at the same time shielded by the methyl group.



ANTI ISOMER, (LI)

Two *exo* protons deshielded and unaffected by the methyl group.

Figure 1. Deshielding effects of the hydroxyl group and shielding effects of the methyl group upon adjacent protons.

0.88 , limiting slope, 0.324 δ/% M) and the liquid compound (chemical shift at infinite dilution, 0.87 δ, limiting slope 0.269 δ/% M). The dilution curve of the solid isomer was markedly different in shape with a limiting slope of 0.500 δ/% M and an infinite dilution chemical shift of 0.81 δ.

The dilution data for the three compounds are presented in Tables IV, V, and VI, and the dilution curves are shown in Figures 2, 3, and 4. The limiting slope was calculated from the second linear portion of the curve and the change that this slope represents is attributed to monomer-dimer equilibria.[26,41] The value for the chemical shift at infinite dilution was obtained by extrapolation of the second linear line to infinite dilution, (0.0%·m), and may be considered the shift of the pure monomeric species.[26]

The differences in limiting slope values are gratifying. While the two syn isomers are numerically close, (0.324 vs 0.269), the anti isomer has a much larger slope value of 0.500. One would expect on the basis of Oulette's finding,[41] the syn-norbornanols to exhibit much smaller limiting slope values than the anti isomers. Oulette found that 1-methyl-7-syn-methyl-2-exo-norbornanol displayed a limiting slope of 0.116 while 1-methyl-2-exo-norbornanol (the syn substituent absent) had a value of 0.260.

B. The Mass Spectra of Some Norbornanols

The mass spectra of six 7-norbornanols have been recorded. Each mass spectrum is presented in tabular form. Only peaks of greater than

TABLE IV

NMR DILUTION DATA FOR 2-EXO-CYCLOHEXYL-7-SYN-NORBORNANOL

Concentration, Mole %[a]	Hydroxyl Chemical Shift, δ[b]
11.71	3.10
9.15	2.96
7.97	2.73
6.84	2.55
6.18	2.42
5.70	2.36
5.16	2.22
4.72	2.15
4.24	2.03
3.88	1.96
3.53	1.88
3.39	1.83
3.09	1.73
2.93	1.71
2.68	1.63
2.56	1.61
2.41	1.57
2.29	1.50
2.16	1.47
2.03	1.40
1.79	1.35
1.39	1.23
1.26	1.18
1.15	1.17
1.05	1.14
0.969	1.13
0.895	1.12
0.823	1.11
0.745	1.07
0.694	1.05
0.633	1.05
0.582	1.03
0.516	1.02
0.464	1.02
0.419	1.01

[a] CCl_4 solution.

[b] Chemical shift measured vs TMS internal standard at probe temperature at 60 MHz.

TABLE V

NMR DILUTION DATA FOR 2-EXO-METHYL-7-SYN-NORBORNANOL (LIQUID)

Concentration, Mole %[a]	Hydroxyl Chemical Shift, δ[b]
8.31	2.85
7.26	2.72
6.80	2.64
6.25	2.55
5.75	2.43
5.25	2.33
4.82	2.24
4.39	2.14
4.04	2.05
3.75	1.95
3.48	1.88
3.22	1.81
2.95	1.72
2.72	1.66
2.52	1.60
2.37	1.54
2.21	1.48
2.03	1.43
1.93	1.42
1.76	1.38
1.59	1.32
1.38	1.25
1.08	1.20
0.985	1.16
0.799	1.11
0.727	1.08
0.639	1.07
0.479	1.05
0.447	1.04

[a] CCl_4 solution.

[b] Chemical shift measured vs TMS internal standard at probe temperature at 60 MHz.

TABLE VI

NMR DILUTION DATA FOR 2-EXO-METHYL-7-ANTI-NORBORNANOL (SOLID)

Concentration, Mole %[a]	Hydroxyl Chemical Shift, δ[b]	Concentration, Mole %[a]	Hydroxyl Chemical Shift, δ[b]
11.3	3.77	3.38	2.49
10.6	3.75	3.15	2.38
10.1	3.69	2.91	2.32
8.64	3.63	2.70	2.25
8.27	3.60	2.51	2.18
7.96	3.52	2.33	2.10
7.59	3.47	2.21	2.03
7.18	3.41	2.06	1.93
6.85	3.37	1.97	1.88
6.72	3.33	1.84	1.81
6.41	3.29	1.69	1.73
6.05	3.23	1.55	1.65
5.76	3.18	1.43	1.58
5.46	3.09	1.32	1.51
5.15	3.03	1.20	1.46
4.88	2.97	1.06	1.37
4.64	2.91	0.941	1.28
4.39	2.80	0.845	1.23
4.11	2.74	0.762	1.18
3.93	2.71	0.695	1.17
3.61	2.58		

[a] CCl_4 solution.

[b] Chemical shift measured vs TMS internal standard at probe temperature at 60 MHz.

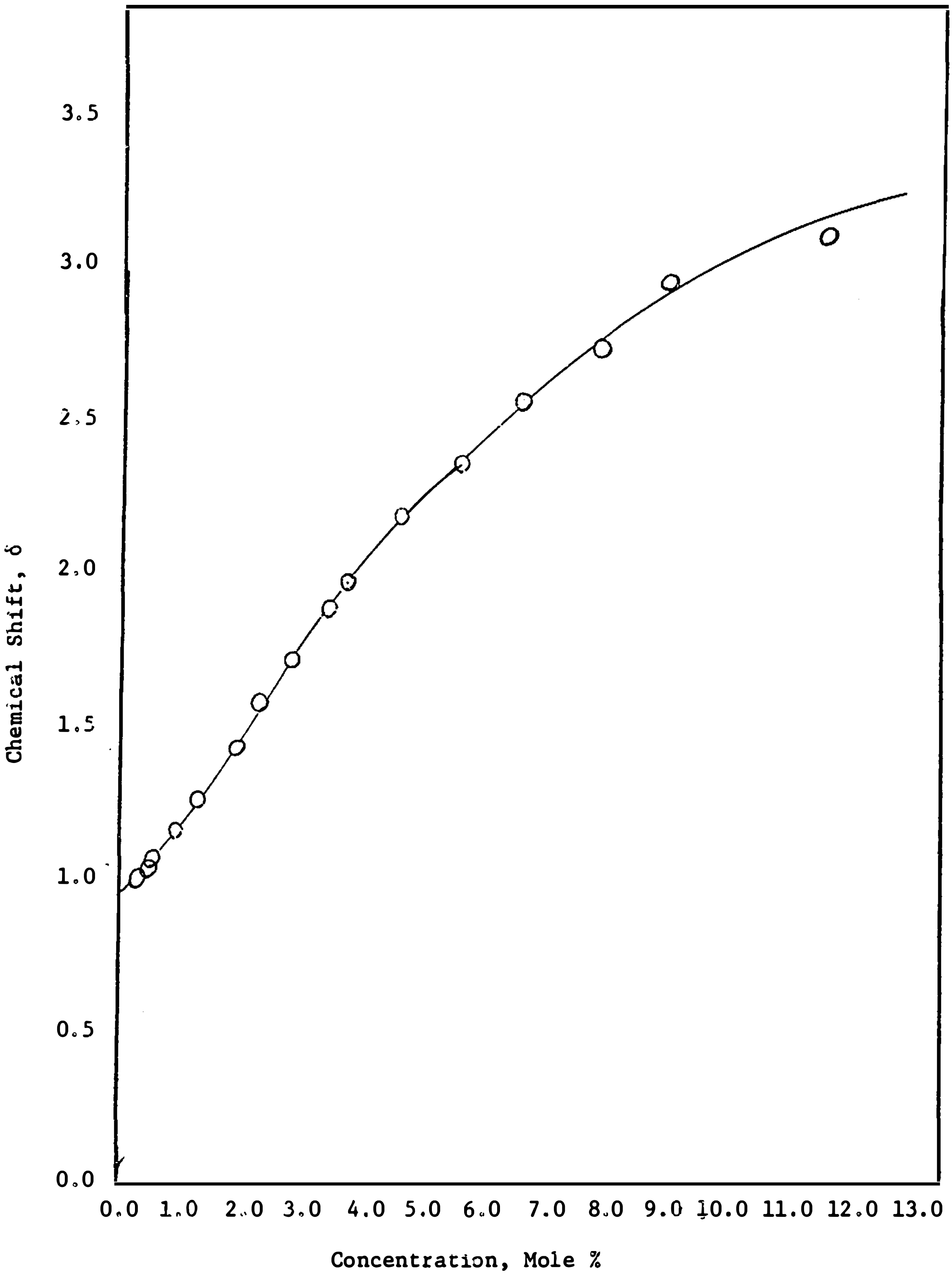


Figure 2. Dilution curve for 2-exo-cyclohexyl-7-syn-norbornanol.

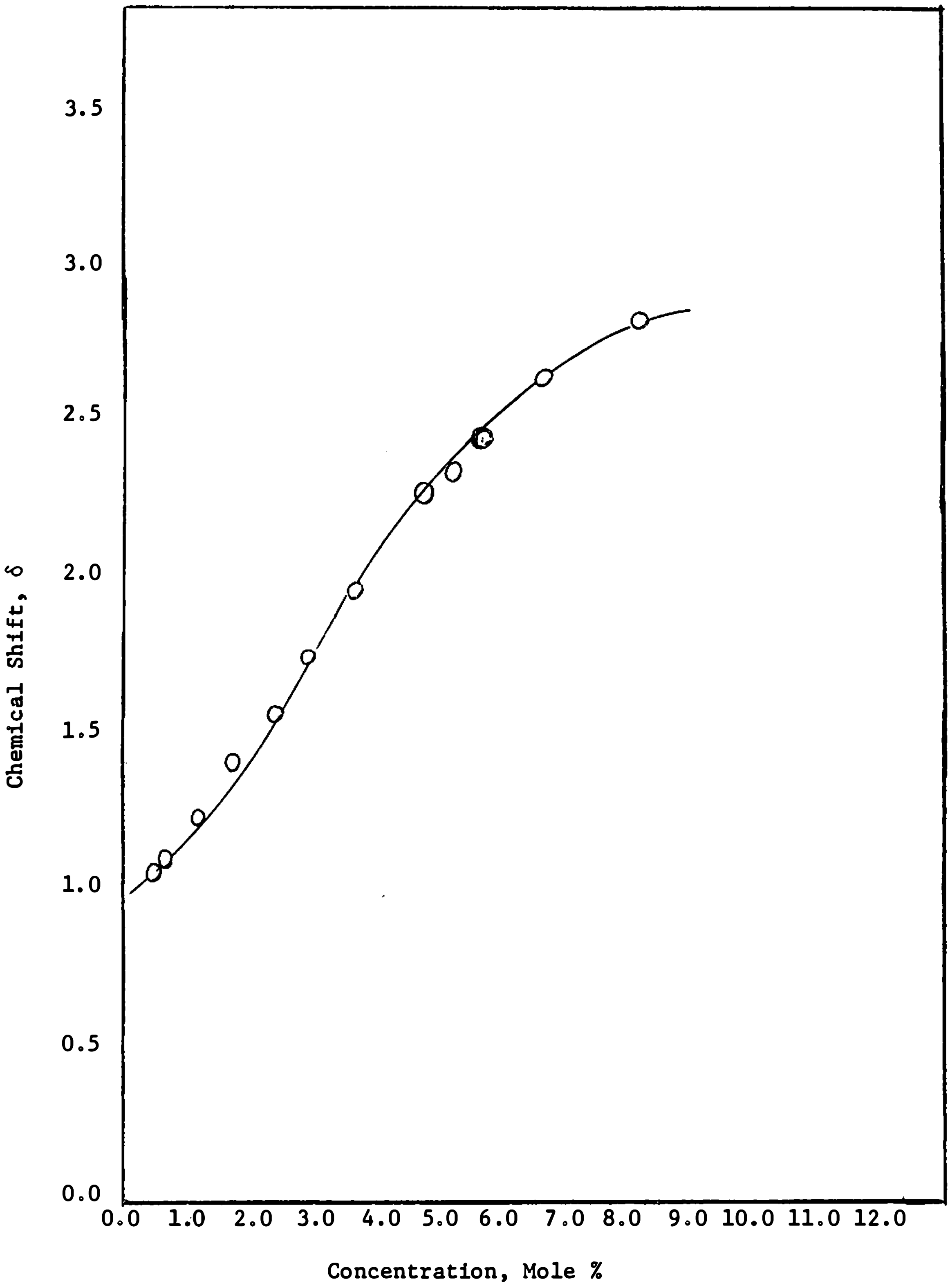


Figure 3. Dilution curve for 2-exo-methyl-7-syn-norbornanol.

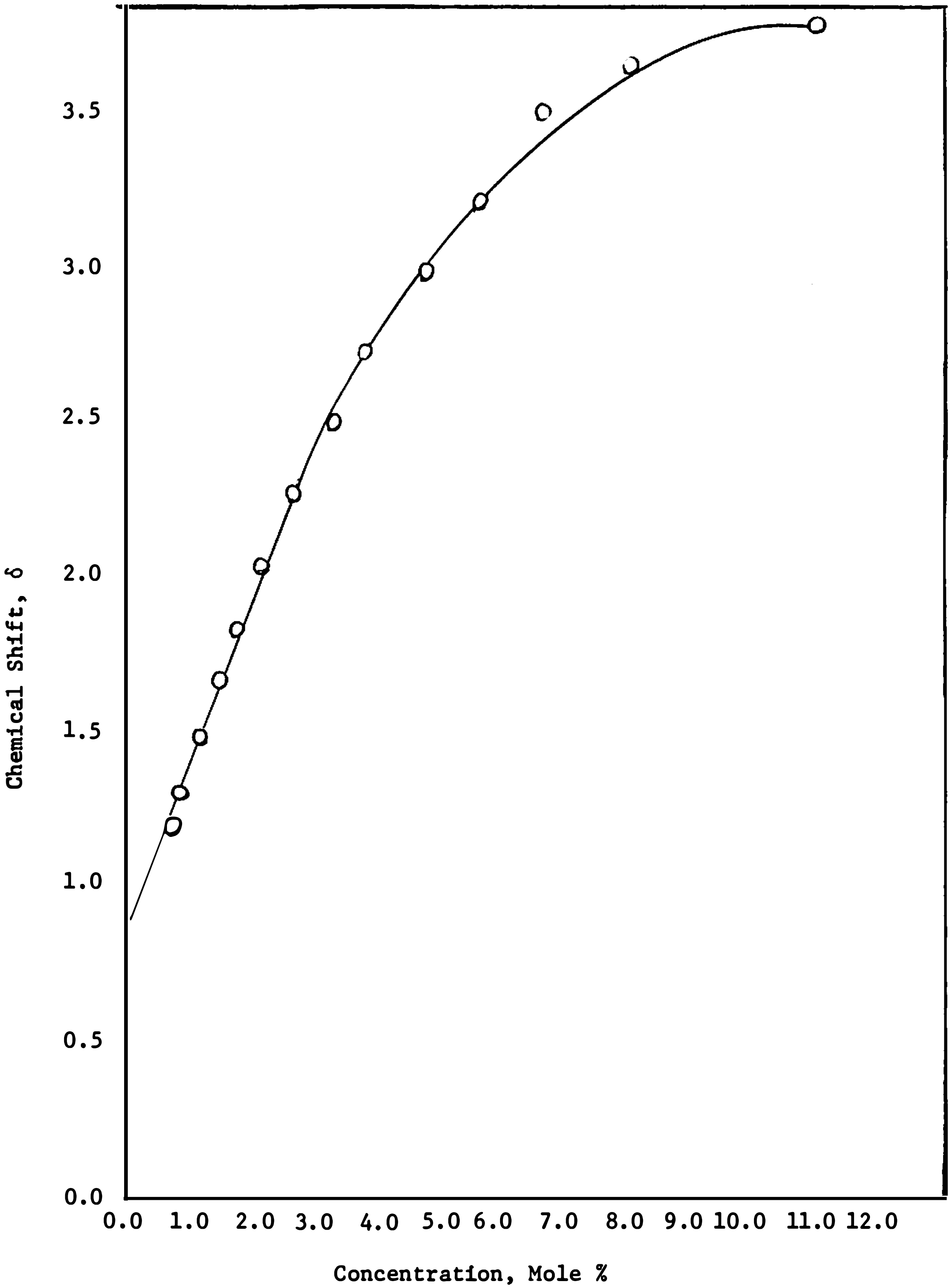


Figure 4. Dilution curve for 2-exo-methyl-7-anti-norbornanol.

five per cent abundance are listed except those of the parent ions which are reported if observable.

Limited interpretations are forwarded for 2-*exo*-phenyl-7-*syn*-norbornanol, Table VII, Figure 5, 2-*exo*-cyclohexyl-7-*syn*-norbornanol, Table VIII, Figure 6, 2-*exo*-methyl-7-*syn*- and *anti*-norbornanols, Tables IX and X, Figures 7 and 8, respectively, and 7-norbornanol, Table XI, Figure 9, and 7-*syn*-norbornanol, Table XII, Figure 10.

TABLE VII

MASS SPECTRUM OF 2-EXO-PHENYL-7-SYN-NORBORNANOL

m/e	% Abundance	m/e	% Abundance
189 (P + 1)	14.01	104	89.20
188 (P)	96.50	103	20.36
187	7.30	102	6.93
171	15.33	97	9.64
169	10.95	96	5.47
156	7.30	93	6.42
155	18.25	92	29.34
145	6.93	91 (Base)	100.00
144	12.26	89	6.64
143	12.26	84	42.55
142	21.75	83	23.94
134	7.23	82	10.51
133	21.68	81	18.98
132	7.66	80	6.57
131	22.63	79	44.53
130	14.60	78	23.43
129	40.73	77	36.50
128	21.53	71	8.03
127	8.18	70	16.20
121	6.57	69	5.77
120	20.44	67	29.20
119	10.80	66	21.17
118	28.61	65	17.59
117	94.82	63	8.61
116	18.98	57	20.36
115	46.35	55	25.55
109	5.55	54	5.04
108	52.92	53	17.15
107	90.51	52	5.91
106	10.07	51	19.34
105	53.28	50	5.18

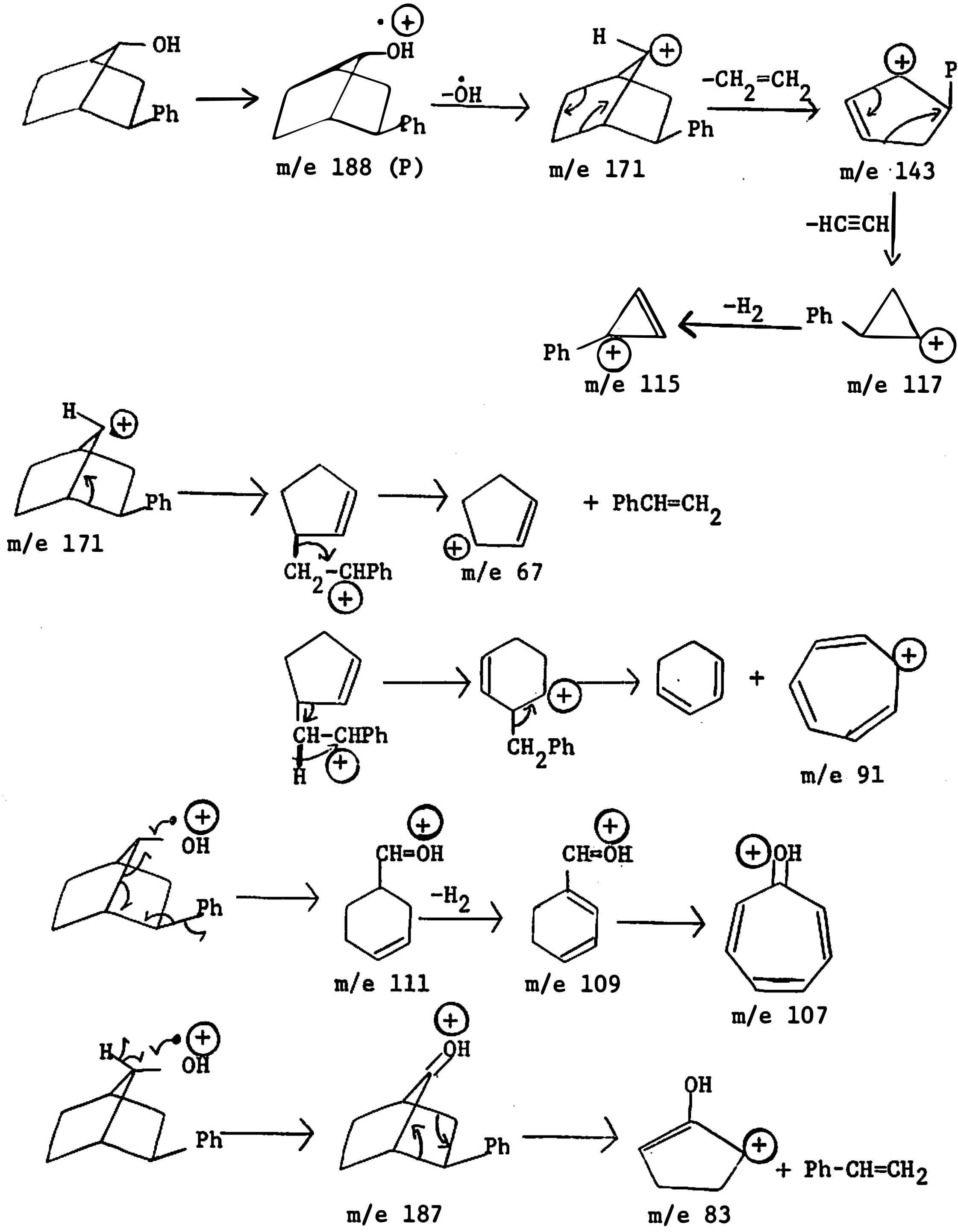


Figure 5. Mass spectral degradation of 2-exo-phenyl-7-syn-norbornanol.

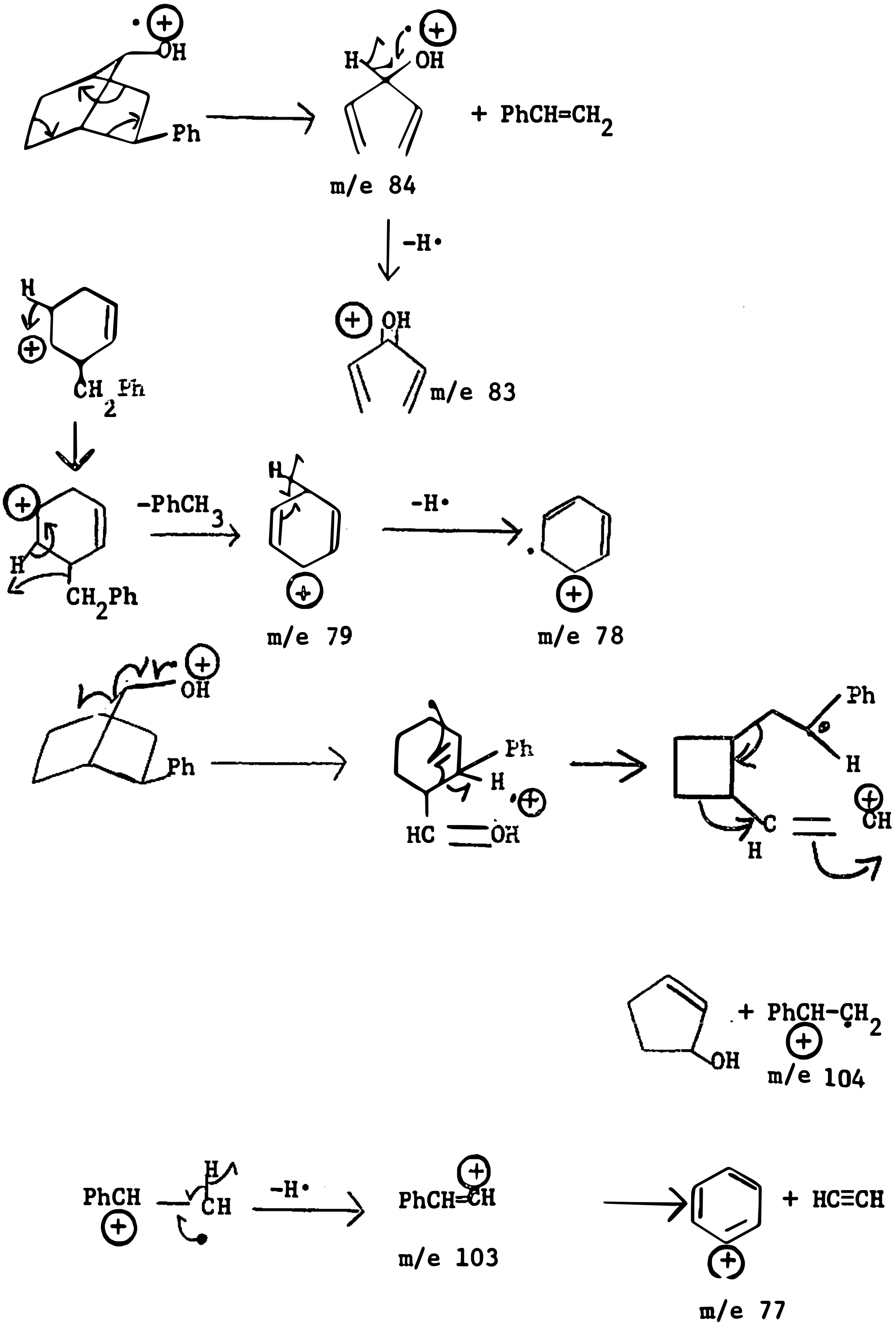


Figure 5 (continued)

TABLE VIII

MASS SPECTRUM OF 2-EXO-CYCLOHEXYL-7-SYN-NORBORNANOL

m/e	% Abundance	m/e	% Abundance
196 (P + 2)	0.65	84	7.56
195 (P + 1)	6.01	83	37.58
194 (P)	34.48	82	20.61
176	11.74	81	62.94
164	8.41	80	35.30
163	59.18	79	36.12
150	5.07	78	7.51
148	11.93	77	19.09
147	5.92	71	8.22
135	6.11	70	45.91
133	6.11	69	18.33
125	9.51	68	13.45
124	5.17	67	82.67
122	8.16	66	28.33
121	5.97	65	9.21
112	8.73	57	37.58
111	29.09	56	8.08
110	10.99	55	77.76
109	22.09	54	23.33
108	11.08	53	22.12
107	7.12	51	5.45
105	5.92	43	19.39
98	5.50	42	9.16
97	12.68	41 (Base)	100.00
96	10.71	40	6.20
95	29.33	39	34.55
94	28.79	31	10.99
93	37.58	29	38.79
92	10.24	28	21.52
91	17.73	27	29.55

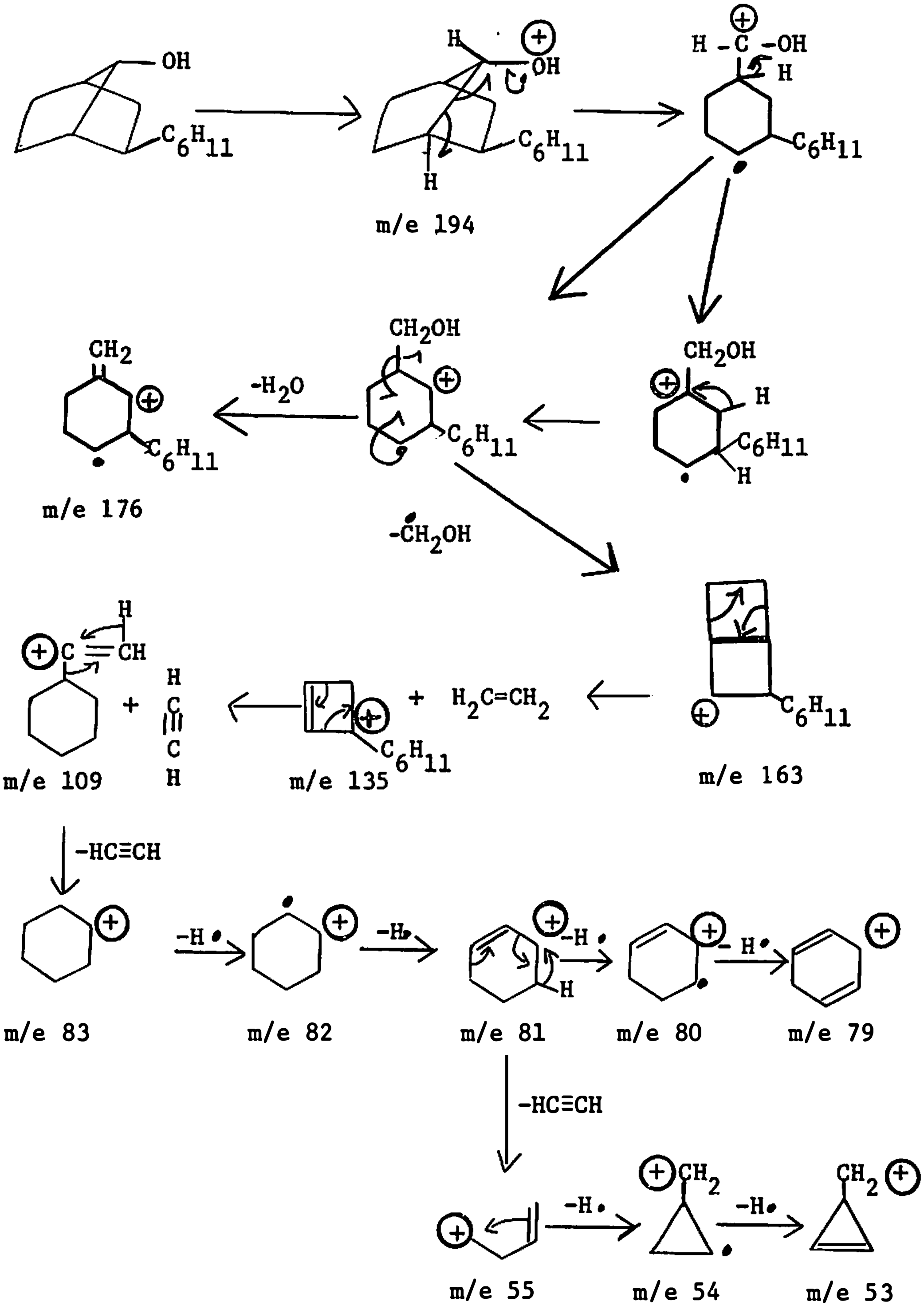
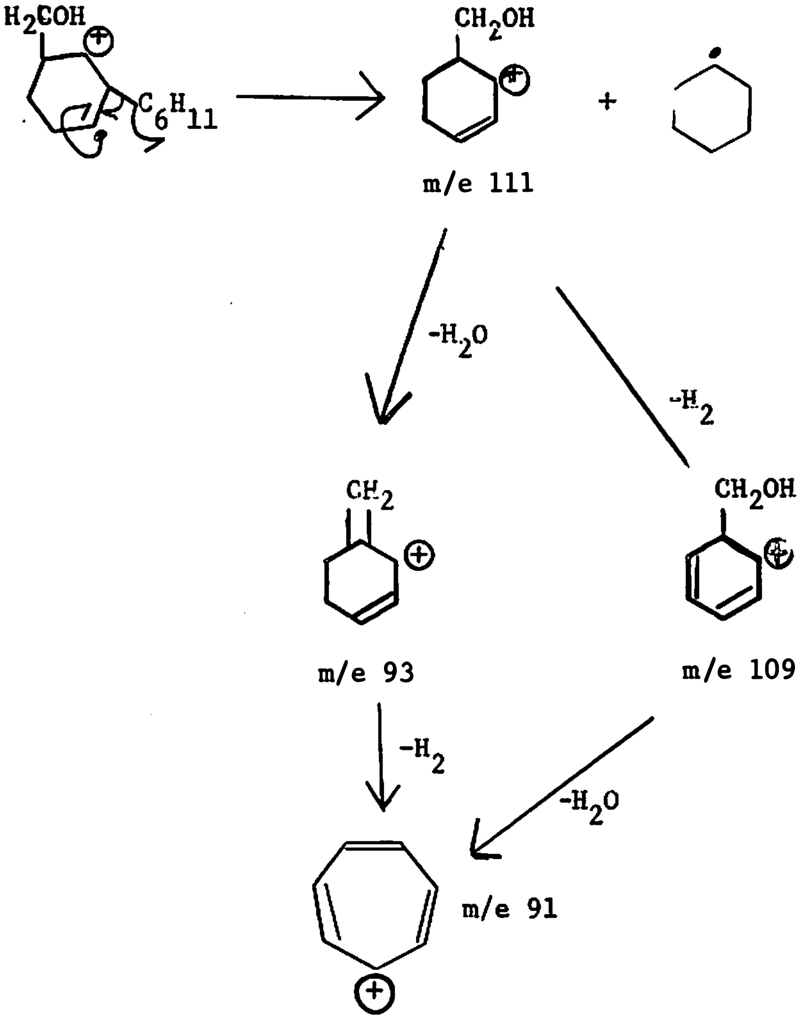


Figure 6. Mass spectral degradation of 2-*exo*-cyclohexyl-7-*syn*-norbornanol.



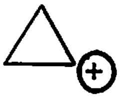
m/e	Suggested Fragment Structure
41	

Figure 6 (continued)

TABLE IX

MASS SPECTRUM OF 2-*EXO*-METHYL-7-*SYN*-NORBORNANOL

m/e	% Abundance	m/e	% Abundance
128 (P + 2)	0.28	70 (Base)	100.00
127 (P + 1)	1.58	69	27.86
126 (P)	11.95	68	18.97
111	15.42	67	58.85
109	6.39	66	11.71
108	46.41	65	7.91
98	6.54	58	10.49
97	23.73	57	56.25
96	6.94	56	14.37
95	62.76	55	64.06
94	11.30	54	15.44
93	58.33	53	26.04
91	9.28	52	7.78
85	6.81	51	11.48
84	16.63	50	5.09
83	21.15	45	7.02
82	27.08	44	7.51
81	19.21	43	29.58
80	15.34	42	15.58
79	35.94	41	71.61
78	6.78	40	10.66
77	13.64	39	60.49
71	33.33	38	5.09

TABLE X

MASS SPECTRUM OF 2-EXO-METHYL-7-ANTI-NORBORNANOL

m/e	% Abundance	m/e	% Abundance
126 (P)	0.46	67	37.94
112	10.63	66	29.97
111	3.17	65	8.65
110	6.04	58	8.54
97	11.83	57	75.52
95	14.47	56	19.83
94	88.91	55	48.35
93	10.47	54	24.19
91	7.81	53	28.90
84	13.01	52	6.17
83	37.77	51	13.65
82	11.06	50	7.49
81	64.58	45	5.00
80	12.66	44	8.18
79 (Base)	100.00	43	34.27
78	6.25	42	18.17
77	14.57	41	73.13
71	17.94	40	12.50
70	61.46	39	76.04
69	16.47	38	7.59
68	58.53		

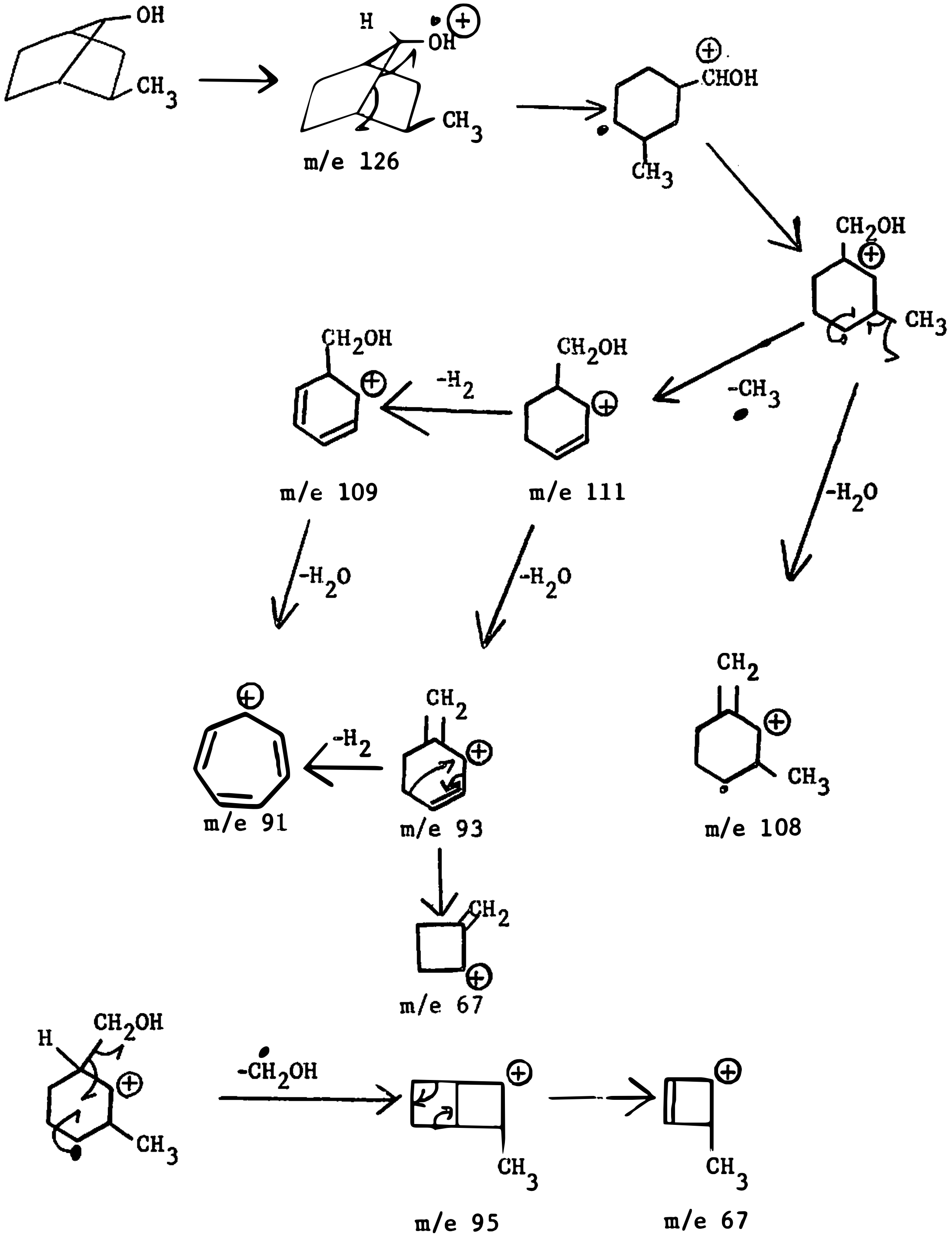


Figure 7. Mass spectral degradation of 2-exo-methyl-7-syn-norbornanol.

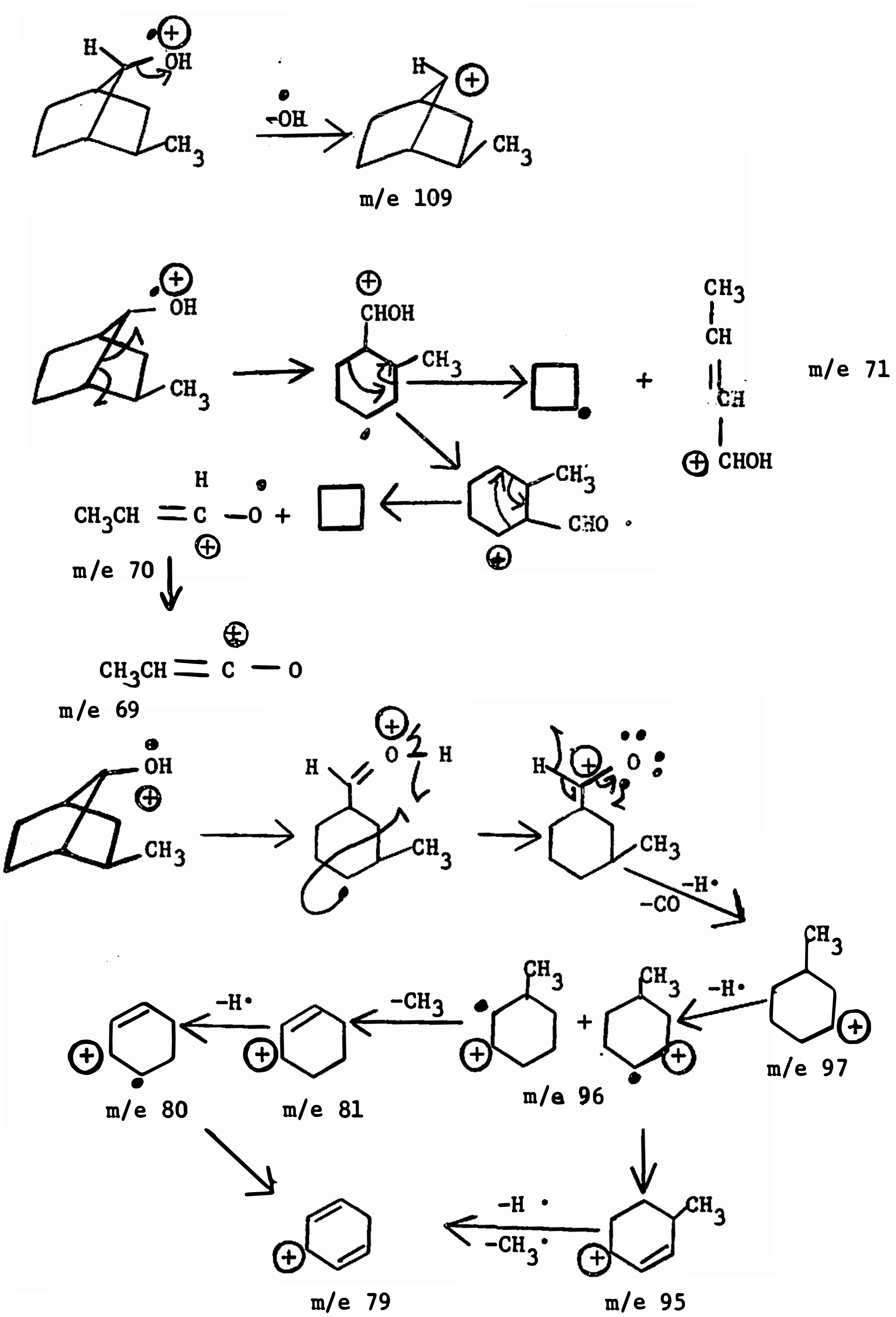


Figure 7 (continued)

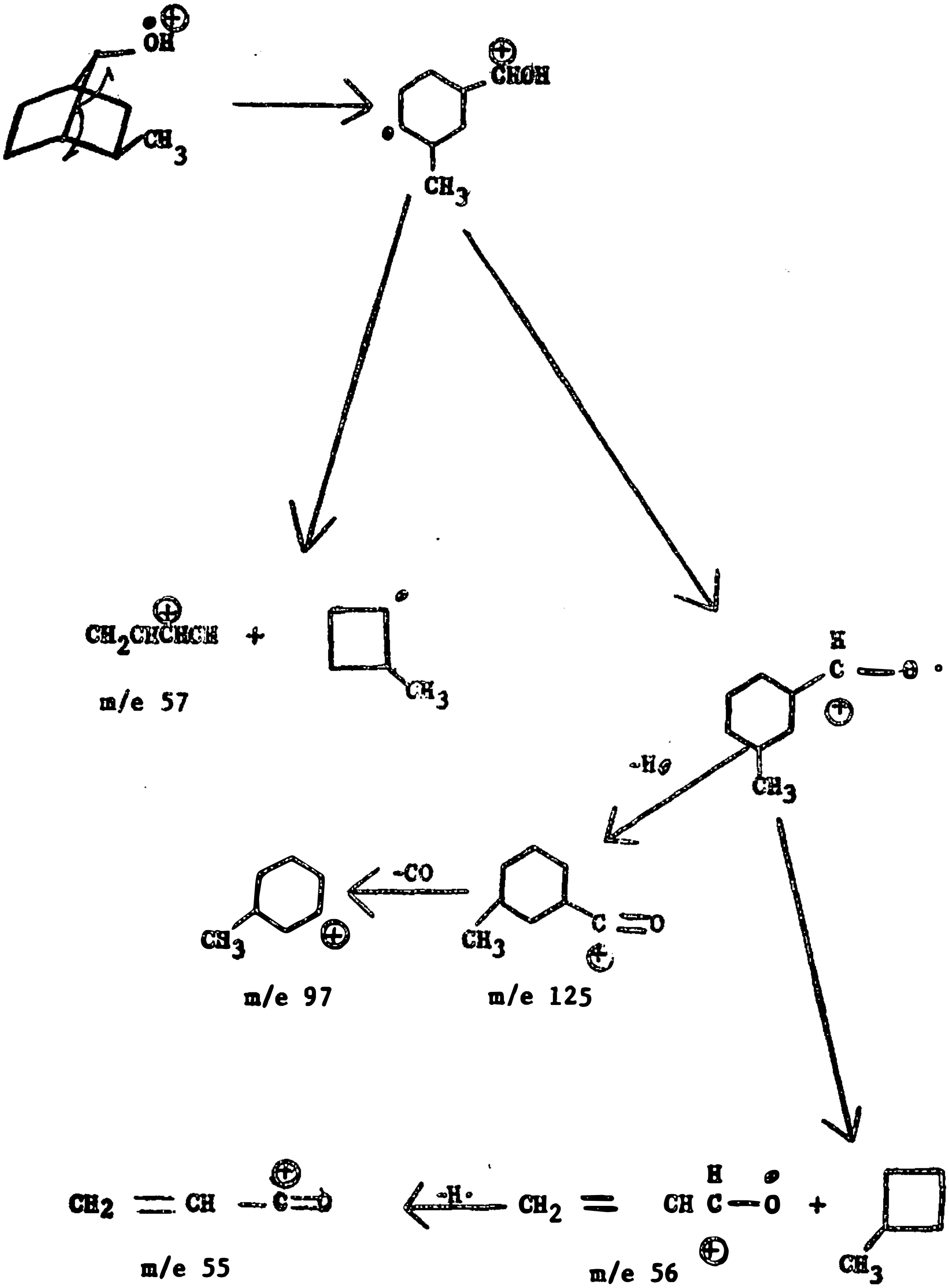


Figure 7 (continued)

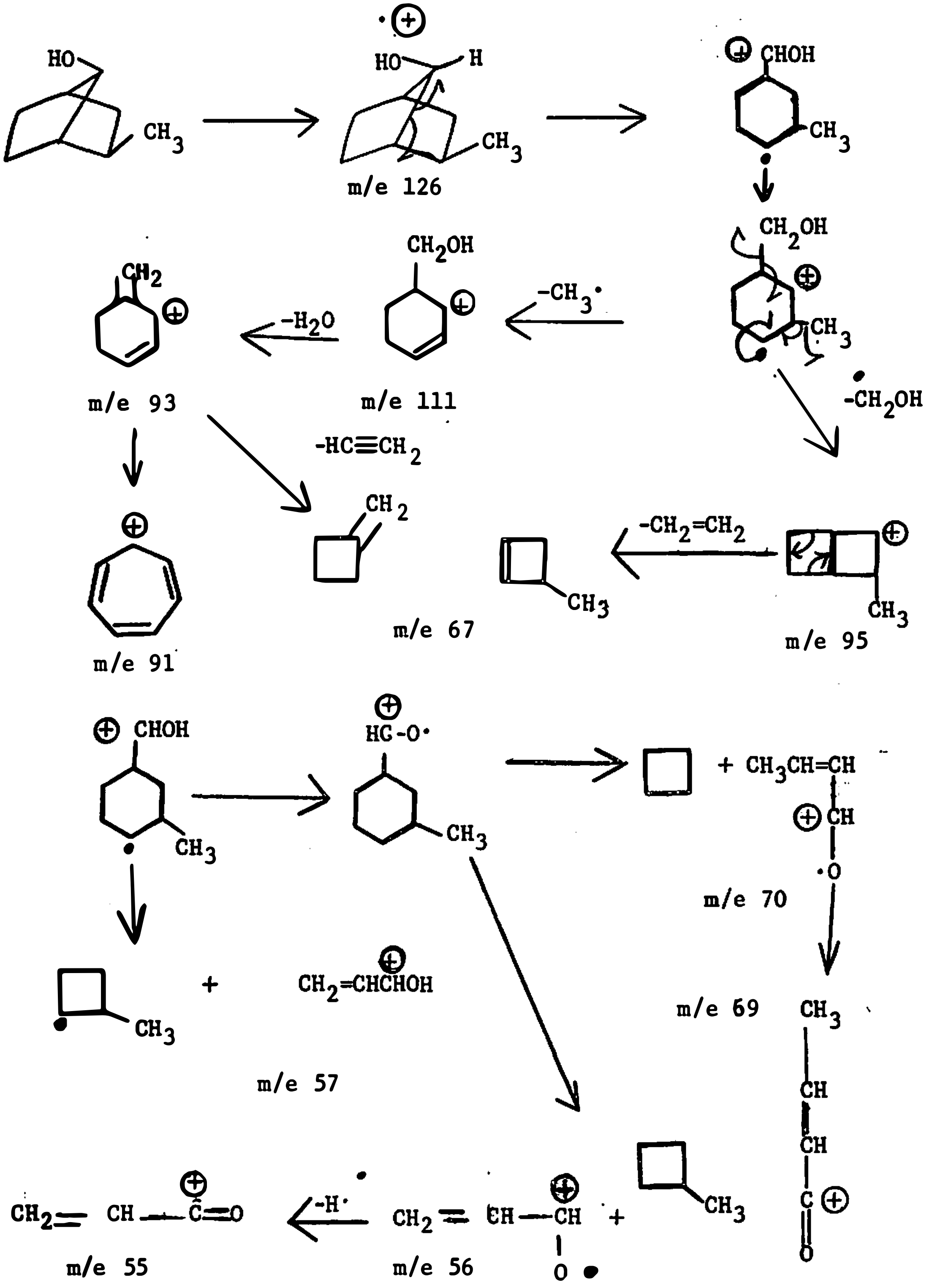


Figure 8. Mass spectral degradation of 2-exo-methyl-7-anti-norbornanol.

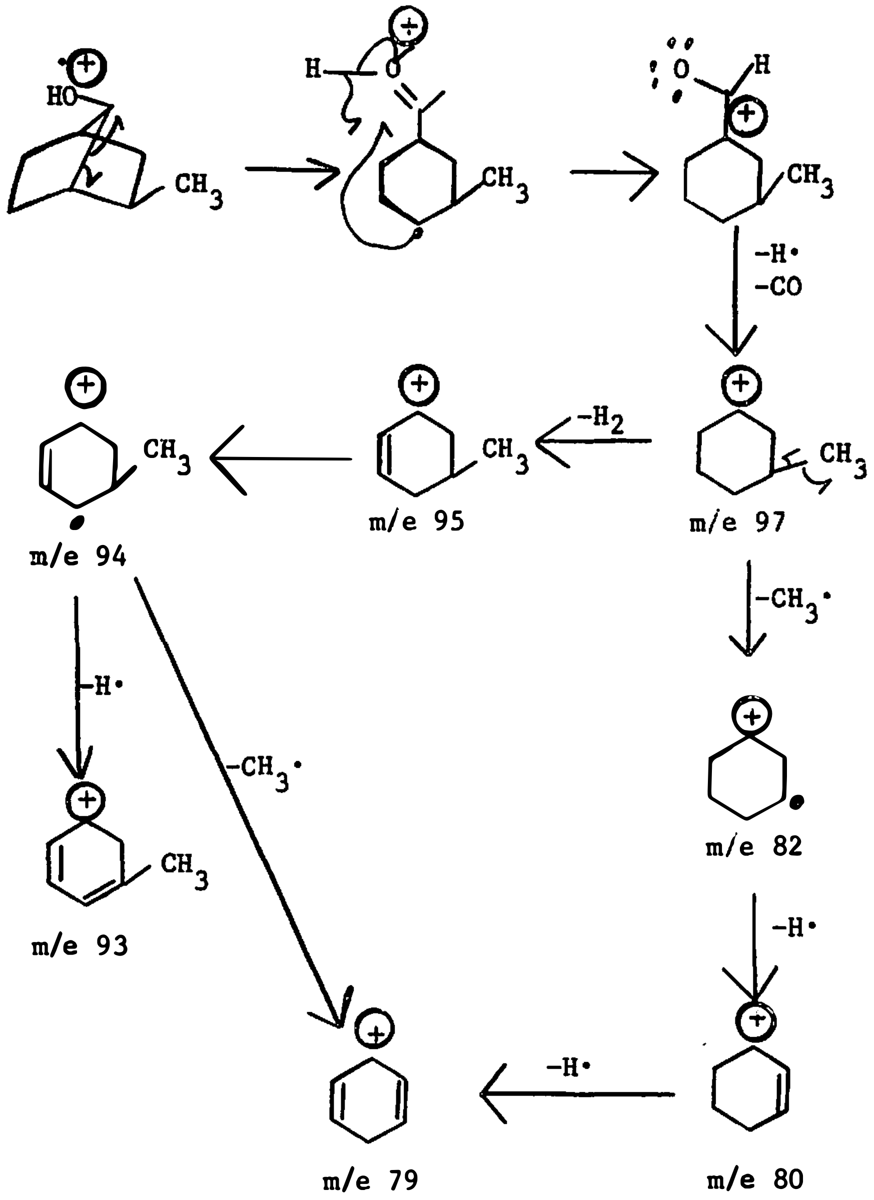


Figure 8 (continued)

TABLE XI

MASS SPECTRUM OF 7-NORBORNANOL

m/e	% Abundance	m/e	% Abundance
113 (P + 1)	2.89	58	8.67
112 (P)	17.34	57	75.14
111	10.11	56	27.45
110	5.78	55	56.64
108	9.39	54	23.84
97	23.84	53	33.95
94 (Base)	100.00	52	6.50
93	20.23	51	26.73
91	11.56	50	12.28
87	26.01	49	24.56
85	60.26	48	28.17
84	17.34	47	66.47
83	87.42	45	11.27
82	15.89	44	7.51
81	70.80	43	27.16
80	18.78	42	16.61
79	85.26	41	70.08
78	7.94	40	13.72
77	17.91	39	52.74
71	23.12	38	7.94
70	72.97	37	10.83
69	20.52	36	20.95
68	68.20	35	20.95
67	38.29	32	30.34
66	28.03	31	24.56
65	11.56		

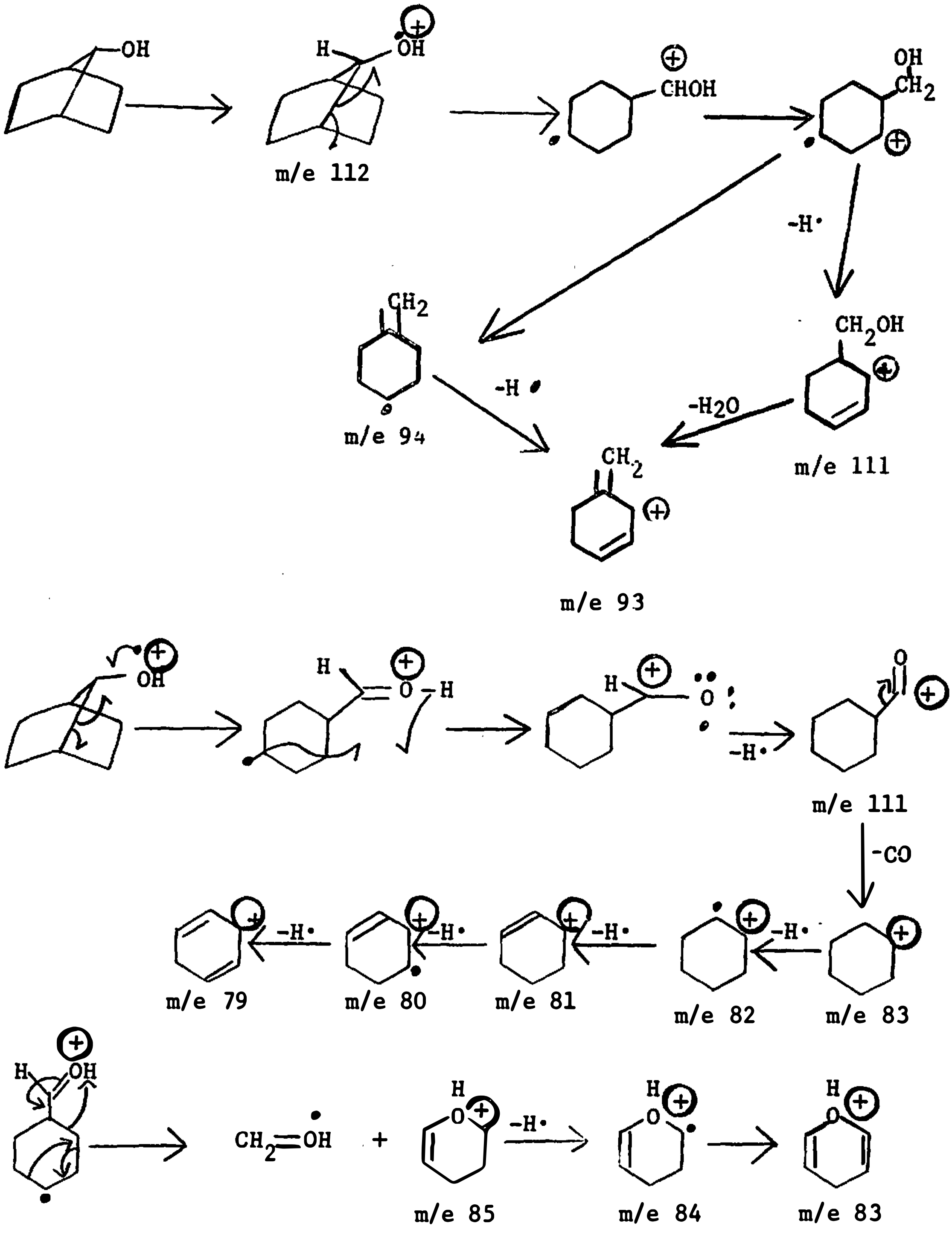


Figure 9. Mass spectral degradation of 7-norbornanol.

TABLE XII

MASS SPECTRUM OF 7-SYN-NORBORNENOL

m/e	% Abundance
111 (P + 1)	6.23
110 (P)	46.29
109	11.43
95	34.86
94	8.00
93	9.71
92	33.14
91	38.86
83	8.00
82	18.51
81	69.71
80	16.00
79 (Base)	100.00
78	20.00
77	37.14
70	9.71
69	9.14
68	13.71
67	37.71
66	19.43
65	13.71
57	12.57
55	24.23
54	18.86
53	16.57
52	8.46
51	16.00
50	9.14
43	10.86
41	34.06
40	8.57
39	42.29
38	6.29
31	4.57

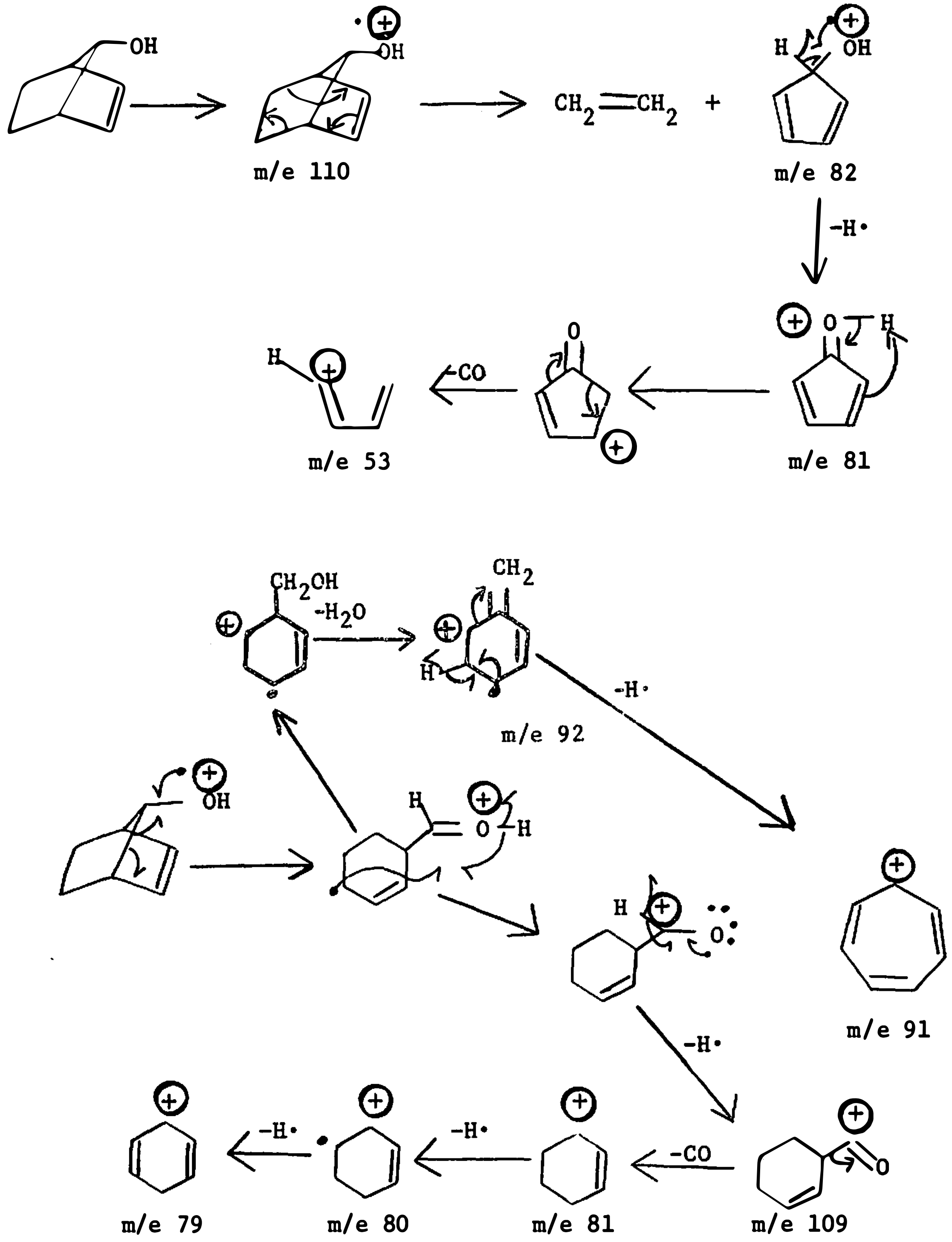


Figure 10. Mass spectral degradation of 7-*syn*-norbornenol.

CHAPTER III

EXPERIMENTAL

A. Introduction

Melting points were determined in soft glass capillary tubes with a Mel-Temp apparatus, and they are presumed to be correct to ±1°C. The routine infrared spectra were recorded on a Beckman Model 5A infrared spectrometer. The infrared spectra for hydrogen bonding were obtained with a Perkin-Elmer Model 257 grating spectrometer. Ultraviolet spectral data were obtained with a Cary Model 14 spectrometer. Nmr spectra were recorded with a Varian A-60 nmr spectrometer, calibrated with tetramethylsilane (TMS), 0.0 Hz vs chloroform, 436.5 Hz. Chemical shifts are reported in ppm, δ, downfield from TMS. The mass spectra were obtained with a Hitachi Perkin-Elmer RMU-6E recording mass spectrometer, (the University of Tennessee, Mr. Bill Peed, operator), or with Consolidated Electronics Corporation 21-104 (for volatile samples), or Consolidated Electronics Corporation 21-110 (for non-volatile samples), recording mass spectrometers, (Phillip Morris Research Laboratories, Richmond, Va., Dr. Paul H. Chen, operator). Glc analyses were run on a Varian A90-P3 gas chromatograph equipped with a 6' x 1/4" 20% SE-30 on Chromosorb-W column, (typical flow rate 50-75 cc min^{-1} helium, column temperature of 130-185°C) or on a Varian A600-D flame ionization detector gas chromatograph equipped with a 5' x 1/8" 3% SE-30 on Chromosorb-W column. Preparative scale glc separations were carried out with an Aerograph Autoprep

A-700 gas chromatograph equipped with a 20' x 3/8" 30% SE-30 on Chromosorb P column, typical flow rate 100 cc min^{-1} helium, and column temperature of 120-160°C. Microanalyses were carried out by Dr. F. B. Strauss, Microanalytical Laboratory, 10 Carlton Road, Oxford, England, or by Gailbraith Laboratories, Inc., Knoxville, Tenn.

Unless otherwise stated, all ether, chloroform, and ligroin solutions were dried over anhydrous sodium sulfate prior to solvent removal. Ligroin was distilled over potassium permanganate and had a bp 40-50°C.

B. Preparation and Reactions of Norbornene Oxide

1. Preparation of Norbornene Oxide

The method of Walborsky and Loncrini[2] was employed. 47.0 g (0.500 mole) norbornene dissolved in 30 ml anhydrous chloroform was placed in a one liter three neck flask equipped with a magnetic stirrer, alcohol thermometer, large dry ice-acetone bath, condenser, and dropping funnel. The solution was cooled to -20°C and then there was added through a dropping funnel a slurry of 25 g anhydrous sodium acetate and 125 ml 40% peracetic acid (50.0 g, 0.660 mole). The temperature was maintained below 0°C during the addition and when completed, the mixture was allowed to warm up slowly until the reaction initiated and then was cooled down rapidly with addition of dry ice. Then, the acetic acid and excess peracetic acid were neutralized with 40% sodium hydroxide solution. The resulting mixture was extracted with ca. 500 ml chloroform, the extracts washed with water, and dried. The mixture was distilled, the oxide distilling at 150-155°C. Care was taken that the distilling adaptor did not become clogged at this point. 38.6 g (70.5%) of pure white glassy crystalline material was obtained, mp 125-126°C, (lit mp 125-127°C).[2] Glc analysis revealed a single component.

2. $LiAlH_4$ Reduction of Norbornene Oxide

To 0.50 g (0.0045 mole) norbornene oxide in 20 ml THF in a round bottomed flask equipped with condenser and magnetic stirrer was added carefully 1.0 g (0.03 mole) lithium aluminum hydride. The mixture was heated to reflux and maintained at that temperature for 50 hrs. Hydrolysis with saturated sodium sulfate solution, extraction with ether, drying, and flash evaporation yielded an oil (0.40 g). Nmr analysis of the mixture showed it to be a mixture of 2-*exo*-norbornanol (carbinol C-H, 3.50 δ) and 7-norbornanol (carbinol C-H, 3.60 δ). The yield was 80% crude oil.

3. Reaction of Phenylmagnesium Bromide with Norbornene Oxide

The Grignard reagent was prepared by placing 2.01 g (0.0840 mole) magnesium turnings in a 500 ml round bottomed three neck flask equipped with a magnetic stirrer, a condenser capped with a calcium chloride drying tube, a dropping funnel, and a heating mantle. To the magnesium was added 50 ml sodium dried ether and 2.0 ml bromobenzene. As soon as the reaction had initiated the remainder of the bromobenzene, 5.2 ml, dissolved in 10 ml dry ether were added dropwise at a rate sufficient to maintain reflux. The total amount of bromobenzene was 10.7 g (0.0700 mole). Upon addition of the bromobenzene, the flask was equipped with the heating mantle and reflux maintained for three hours. The solution was cooled in an ice bath and 6.60 g (0.0600 mole) norbornene oxide were added as a solution in 100 ml dry ether. Reflux was initiated and maintained for three more hours. Then the solution was cooled in ice and hydrolyzed with water. The mixture was stirred overnight, the ether layer decanted, and the aqueous layer diluted and extracted with ether. The combined extracts were washed with water, and the solvent removed with an aspirator vacuum and gentle heat from a warm water bath. This yielded 7.19 g yellow oil. Glc analysis indicated two products in the ratio of 2.13:1.00.

These products were identified as 2-exo-phenyl-7-syn-norbornanol, and 7-syn-norbornenol. For the nmr data of the phenyl norbornanol, see the discussion, p. 17, ir, (3623 cm^{-1}, 2900 cm^{-1}, 1155 cm^{-1}, 1065 cm^{-1}, 748 cm^{-1}, 693 cm^{-1}). The nmr of the 7-syn-norbornenol showed peaks at 6.07 δ (olefinic), 3.72 δ (H_7), 2.69 δ (H_1,H_4), 0.70-1.85 δ (H_5,H_6), while the ir showed significant bands at 3571, 2930, 1408, 1290, 1150, 1132, and 725 cm^{-1}.

The unsaturated norbornanol was isolated from the phenylnorbornanol by gentle distillation under vacuum. Addition of 60-80° bp ligroin to the residue affected crystallization of the phenylnorbornanol. The 7-norbornenol, upon glc purification,melted at 79-80°C. The tosylate was prepared, it's melting point, 66-67°C, was comparable to that reported for 7-syn-norbornenyl tosylate, 67-68°C.[17] Recrystallization of the 2-exo-phenyl-7-syn-norbornanol from ligroin gave a white powdery solid, mp 75-77°C. A tosylate of the phenyl-norbornanol was prepared in the usual manner,[42] and a white, crystalline derivative was obtained, mp 78-79°C.

In all, 4.77 g 7-syn-norbornenol and 2.34 g 2-exo-phenyl-7-syn-norbornanol were obtained, for an overall yield of 93%.

Anal. Calcd. for $C_{13}H_{16}O$ for the phenyl norbornanol: C, 82.94; H, 8.57. Found: C, 83.16; H, 8.39.

Anal. Calcd. for $C_{20}H_{22}SO_3$ for the tosylate of the phenyl norbornanol: C, 70.16; H, 6.48. Found: C, 69.96; H, 6.47.

4. Reaction of p-Tolylmagnesium Bromide with Norbornene Oxide

The Grignard reagent was prepared in the same manner as with the phenyl reagent with 27.4 g (19.7 ml, 0.160 mole) p-bromotoluene and 4.80 g (0.200 mole) magnesium. The solution was refluxed for two hours and then cooled and charged with an ethereal solution of 8.80 g (0.0800 mole) norbornene oxide in anhydrous ether. The adduct solution was refluxed for three hours, cooled, and hydrolyzed. Work up in the usual manner yielded 14.5 g crude oil. Glc analysis indicated a mixture of toluene, di-p-tolyl, 7-syn-norbornenol, and 2-exo-(4-methylphenyl)-7-syn-norbornanol. The product distribution was 76% of the unsaturated compound and 24% of the arylnorbornanol. After distillation, as in the case of the phenyl Grignard reaction, 1.83 g of the p-tolylnorbornanol was obtained as a white solid. Recrystallization from high boiling ligroin gave a mp 70-71°C. Total yield was 44.0%.

Infrared data: 3624 (±2 cm^{-1}), (CCl_4), 2950, 1150, 1075, and 805 cm^{-1} (CS_2).

Nmr data, (ca 10% (w/v) CCl_4): 7.04 δ, (AA'BB' quartet, aryl protons), 3.81 δ (H_7), ~ 2.88 δ (distorted triplet,(H_2-endo), 2.27 δ (CH_3), 2.02 δ (bridgehead), 1.15 -1.88 δ (H_5, H_6).

Anal. Calcd. for $C_{14}H_{18}O$: C, 83.12; H, 8.97. Found: C, 8.97; H, 8.86.

5. *Reaction of o-Tolylmagnesium Bromide with Norbornene Oxide*

The organometalic reagent was prepared in a manner similar to above utilizing 27.4 g (19.6 ml, 0.160 mole) *o*-bromotoluene and 4.80 g (0.200 mole) magnesium turnings. Upon addition of all the bromide and a reflux period of 2.5 hrs the solution was cooled and 8.80 g (0.0800 mole) norbornene oxide were added as a solution in ether. The adduct solution was refluxed overnight, then cooled and hydrolyzed with water. The ether layer was separated and the aqueous layer separated and extracted further with ether. The combined ether layers were washed with water, dried and worked up in the usual manner. This resulted in 11.16 g crude yellow oil, the glc of which revealed toluene, di-*ortho*-tolyl, the 7-*syn*-norbornenol, and 2-*exo*-(2-methylphenyl)-7-*syn*-norbornanol. The product distribution was 91.4% of the norbornenol, and 8.6% of the arylnorbornanol. Gentle distillation to remove the unsaturated norbornanol and toluene and cooling to remove the coupling product resulted in the isolation of the arylnorbornanol as a yellow oil. The total yield of the reaction was 66.0%.

Infrared data: 3621 (±2 cm^{-1}), (CCl_4), 2900, 1148, 1070, 752, and 717 cm^{-1} (CS_2).

Nmr data, (ca 10% (w/v) CCl_4): 7.22 δ (multiplet, aryl protons) 3.87 δ (H_7), 2.90 δ (distorted triplet, H_2-*endo*), 2.29 δ (CH_3), 2.03 δ (bridgeheads), 1.08 δ-1.88 δ (H_5 H_6).

A tosylate derivative was prepared in the usual manner[42] and upon recrystallization from ether-ligroin a white crystalline solid, mp 110-112° C, was obtained.

Anal. Calcd. for $C_{21}H_{24}SO_3$ for the tosylate of the o-tolylnorbornanol: C, 70.78; H, 6.74. Found: C, 70.64; H, 6.72.

6. Reaction of p-Anisylmagnesium Bromide with Norbornene Oxide

The organometallic reagent was prepared in the usual manner from 56.1 g (37.4 ml, 0.300 mole) p-bromoanisole and 9.60 g (0.400 mole) magnesium. Upon refluxing for one hour the solution was cooled and 10.0 g (0.0990 mole) norbornene oxide were added as an ethereal solution. Reflux was initiated and maintained for seven hours and then the solution was cooled and hydrolyzed with water. The ether layer was separated, washed, dried and gently distilled yielding 5.44 g of 7-syn-norbornenol. The residue resisted all attempts at purification and appeared to be a mixture of two or more anisyl adducts. No further attempt at characterization was made.

7. Reaction of Methylmagnesium Iodide with Norbornene Oxide

The Grignard reagent was prepared by the addition of 8.70 ml (19.6 g, 0.140 mole) of iodomethane dissolved in 40.0 ml sodium dried ether to 7.25 g (0.300 mole) magnesium turnings in 20.0 ml dry ether in a 500 ml 3-neck flask equipped with a magnetic stirrer, condenser capped with a calcium chloride tube, and a heating mantle. An ice bath was used to maintain gentle reflux during this exothermic step. Upon addition, the heating mantle was fitted to maintain reflux for two hours. Next, this solution was cooled and 10.0 g (0.0900 mole) norbornene oxide were added as a solution in ether. Upon addition, reflux was initiated and maintained for two hours; then the solution was cooled and hydrolyzed with cold water. The resultant mixture was allowed to stand until the magnesium salts settled out, the ether layer decanted and the aqueous slurry greatly diluted and extracted twice with 100 ml USP ether. The ether extracts were combined, washed with water, and dried. Removal of the solvent yielded 7.96 g pale yellow oil, the glc analysis of which revealed three products which were identified as 7-syn-norbornenol, and 2-exo-methyl-7-syn , and anti-norbornanol. The product distribution was found to be rather dependent on several factors such as time and concentration. In this particular determination the distribution was 22.8% of the unsaturated norbornenol, 35.0% of the anti-norbornanol, and 42.2% of the syn isomer. In one of the nine runs four products were observed, the three mentioned above and a white, ligroin insoluble substance identified as 2-exo-iodo-7-syn-norbornanol, mp 72-73.5°C from 95% ethanol. In this instance the product distribution was 29.2% of the norbornenol, 10% of the anti-norbornanol, 49.2% of the syn-norbornanol, and 11.5% of the iodo compound.

The unsaturated norbornanol was isolated from the other products by gentle distillation and trapping in a dry ice-acetone bath. The two methylnorbornanols resisted attempts at separation by means such as distillation, column chromatography, selective crystallization, and derivative formation. They were separated utilizing a 20' x 3/8" 30% SE-30 on Chromosorb P column with a temperature of 130°C and a flow rate of helium of 125 cc min^{-1}. The 2-*exo*-methyl-7-*syn*-norbornanol was a clear glassy solid of low melting point, while the *anti* isomer was a white crystalline solid of mp 150-151°C (recrystallized from ligroin). The iodonorbornanol crystallized preferentially out of the crude oil and was filtered and washed with ligroin.

Infrared data: 2-*exo*-iodo-7-*syn*-norbornanol, 3620 (ν_f), 3574 (ν_b), (CCl_4); 2924, 1312, 1221, 1145, 1124, 1075, 985, 890, 845, 785, and 754 cm^{-1} (CS_2).

Nmr data: (ca 10% (w/v), CCl_4):

(1) 2-*exo*-iodo-7-*syn*-norbornanol, 4.17 δ (H_7), 3.89 δ (doublet of quartets, H_2-*endo*), 1.00-2.85 δ (H_1, H_3, H_4, H_5, H_6).

(2) 2-*exo*-methyl-7-*syn*-norbornanol, 3.92 δ (H_7), 1.97 δ (H_4), 0.9-1.82 δ (H_1, H_2-*endo*, H_3, H_5, H_6).

(3) 2-*exo*-methyl-7-*anti*-norbornanol, 3.88 δ (H_7), 1.89 δ (H_1, H_4, $H_{5\text{-}exo}$, $H_{6\text{-}exo}$), 0.85-1.70 δ ($H_{2\text{-}endo}$, H_3, $H_{5\text{-}endo}$, $H_{6\text{-}endo}$).

Anal. Calcd. for $C_8H_{14}O$ for 2-*exo*-methyl-7-*syn*-norbornanol: C, 76.14; H, 11.18. Found: C, 75.90; H, 11.05.

Calcd. for $C_8H_{14}O$ for 2-*exo*-methyl-7-*anti*-norbornanol: C, 76.14; H, 11.18. Found: C, 75.90; H, 10.92.

Calcd. for $C_7H_{11}IO$ for 2-*exo*-iodo-7-*syn*-norbornanol: C, 35.29; H, 4.62. Found: C, 35.04; H, 4.58.

8. Reaction of *n*-Butyllithium with Norbornene Oxide

In a three neck flask equipped with septum, dry nitrogen inlet, magnetic stirrer, and a condenser topped with a drying tube were placed 2.2 g (0.020 mole) norbornene oxide and 20 ml dry benzene. By means of an hypodermic syringe 15.0 ml of 1.6 molar n-butyllithium in cyclohexane solution were added dropwise, (0.024 mole). This step was quite exothermic, and when the reaction had subsided, reflux was initiated and maintained overnight. Next, the solution was cooled, the adduct hydrolyzed with water, and the resulting two layers separated. The organic extracts were washed with water and dried. Flash evaporation of the solvent gave 2.0 g (90%) of a white oil, the nmr analysis of which indicated nortricyclenol.

Nmr data (ca 15% (w/v) CCl_4): 4.38 δ (carbinol H), 2.42 δ (bridgehead, syn proton), 1.25 - 2.16 δ (other protons).

9. Catalytic Reduction of 7-syn-Norbornenol

The reduction was accomplished utilizing a Parr hydrogenator with 42 psi pressure of hydrogen. The norbornenol (0.30 g, 0.0030 mole) was dissolved in 25 ml ethylacetate and 0.01 g platinum oxide (89.01%) catalyst added. This mixture was shaken for one hour, filtered, and the solvent removed by flash evaporation. No olefinic absorption was observed in the nmr, and the parent peak in the mass spectrum was at m/e 112 for 7-norbornanol. The yield was 94%.

Nmr data (ca 10% (w/v) CCl_4): 3.89 δ (H_7), 1.90 δ ($H_{2\text{-exo}}$, $H_{3\text{-exo}}$, H_1, H_4), 0.70 δ-1.73 δ ($H_{2\text{-endo}}$, $H_{3\text{-endo}}$, H_5, H_6).

10. Preparation of 2-exo-Cyclohexyl-7-syn-norbornanol

The cyclohexyl compound was prepared by catalytic hydrogenation of 2-exo-phenyl-7-syn-norbornanol. The phenyl-norbornanol (1.0 g, 0.0053 mole) was dissolved in 30 ml glacial acetic acid and placed in a Parr hydrogenation bottle along with 0.20 g platinum oxide catalyst. The mixture was shaken under a pressure of 45 psi hydrogen for ten hours. Then the mixture was poured into water. The resulting precipitate was filtered and taken up into ether and filtered through celite to remove the catalyst. The filtrate was washed with sodium bicarbonate solution, then with water, and dried. This ethereal solution was placed in an erlenmeyer flask equipped with a magnetic stirrer and condensor. To this was added 0.75 g $LiAlH_4$ to reduce any acetate which may have formed during the hydrogenation. The mixture was stirred at room temperature for six hours, hydrolyzed with saturated sodium sulfate solution and filtered. The filtrate was washed with water and the ether layer was dried and flash evaporated. A white crystalline solid was obtained, 0.82 g (80% yield) of mp 75-77°C (recrystallized from ligroin).

Infrared data: 3635, 3627 (±2 cm^{-1}), (CCl_4), 2899, 1263, 1152, 1071, and 925 cm^{-1} (CS_2).

Nmr data, (ca 10% (w/v) CCl_4): 3.87 δ (H_7), 0.7-2.5 δ (complex multiplet).

Anal. Calcd. for $C_{13}H_{22}O$: C, 80.35; H, 11.41. Found: C, 80.13; H, 11.28.

11. Sarett[43] Oxidation of 2-*exo*-Phenyl-7-*syn*-norbornanol

The method described by Gassman and Pape was employed.[11] Analytical grade chromium trioxide, (2.0 g, 0.020 mole) was dissolved in 20 ml dry pyridine in a small erlenmeyer flask. To this solution was added 1.0 g (0.0053 mole) of the norbornanol dissolved in 20 ml pyridine. The mixture was stirred at room temperature for twenty four hours by means of a magnetic stirrer, then poured into water, filtered over celite and the filtrate extracted with benzene. The organic layer was washed with water, dried and flash evaporated. The oily product was subjected to a stream of air to remove residual traces of pyridine. An oil was obtained, 1.4 g, for a yield of 69%. The ir spectrum was characterized by a lack of a hydroxyl peak and an intense carbonyl peak was observed. Nmr analysis indicated this to be the pure ketone, and glc analysis revealed a single component.

Infrared data: 1834 (m), 1771 (s), 1740 (w), (±2 cm^{-1}), (CCl_4), 2924, 1258, 1134, 1027, 753, and 696 cm^{-1} (CS_2).

Nmr data, (ca 10% (w/v) CCl_4): 7.11 δ (aryl protons), 2.95 δ (H_2-*endo*), 1.5-2.4 δ (H_1, H_3, H_4, H_5, H_6).

12. Lithium Aluminum Hydride Reduction of 2-*exo*-Phenyl-7-Norbornanone

The ketone, 1.35 g (0.0140 mole) was dissolved in 20 ml anhydrous ether and the solution was placed in a small round bottomed flask equipped with a magnetic stirrer, heating mantle, and condensor. To this solution was added 0.266 g (0.00700 mole) lithium aluminum hydride. The mixture was stirred and refluxed overnight, then was cooled, hydrolyzed with saturated sodium sulfate soltuion, and extracted with ether. The extracts were washed with water and dried. Flash evaporation of the solvent gave 1.14 g (84.0%) white crystalline material, mp 74-76°C, the ir of which was identical to that of 2-*exo*-phenyl-7-*syn*-norbornanol.

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PART B

ARYLNORBORNENE OXIDES

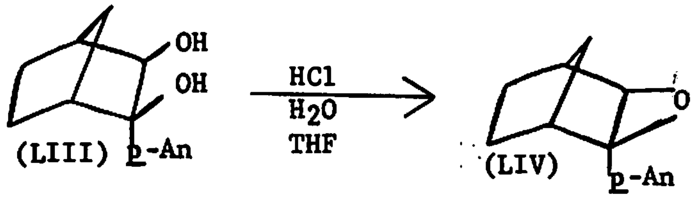
CHAPTER I

INTRODUCTION

A. History

1. Synthesis of 2-p-Anisylnorbornene-2,3-exo Oxide

In 1969 Kleinfelter and Long[1] reported the isolation of a high melting solid upon the treatment of 2-p-anisylnorbornane-2,3-cis-exo-diol (LIII) with aqueous hydrochloric acid, using THF as solvent, equation (15). The structure of this compound, (LIV) was determined on the basis of its elemental analysis ($C_{14}H_{16}O_2$), a Rast molecular weight determination (somewhat less than 200), mass spectral analysis (parent m/e = 216), and its unusual nmr spectrum.



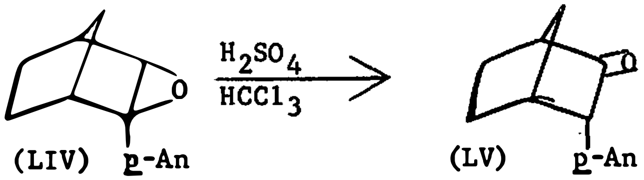
(15)

A complex multiplet was observed in the aryl region of the proton spectrum rather than the characteristic AA'BB' "quartet" common to p-anisyl derivatives. A single proton absorption centered at 3.53 δ was assigned to the 3-endo proton, analogous to the 2- and 3-endo protons of norbornene oxide (I) at 3.16 δ.[2] A doublet of triplets centered at 2.62 δ was ascribed to the 7-syn proton (exo-norbornene oxide, 1.35 δ),[2] and a doublet of triplets far upfield at 0.74 δ was assigned to the 7-anti proton, practically identical to that of norbornene oxide.[2]

The uncommon multiplicity of the aryl proton absorptions was attributed to restricted rotation about the sp^2-sp^3 carbon-carbon bond.

In the uv spectrum absorption maxima were observed at 229 (ε = 11,300), 277 (ε = 1550), and 284 mμ (ε = 1450).[3] These data are nearly identical to those of *p*-methoxystyrene oxide;[4] 230 (ε = 12,400), 276 (ε = 1710), 279 (ε = 1610), and 284 mμ (ε = 1610).

Chemically, (LIV) was found to be unreactive toward $LiAlH_4$ in refluxing THF,[3] a surprising observation in view of the reduction of norbornene oxides in this and related systems. The compound was also found to be unaffected by buffered and unbuffered peracetic acid, aqueous 0.2 m perchloric acid, and only partially affected by concentrated sulfuric acid to give the ketone (LV),[3] equation (16).



(16)

B. Introduction to the Problem

Before and since the report of Kleinfelter and Long,[1] 2-arylnorbornene oxides have not been reported. The photosynthetic irradiation of 2-phenylnorbornene-2,3-*exo*-oxide was mentioned by Kropp at the 1969 meeting of the Southeastern Regional Section of the American Chemical Society but no published data have appeared yet on this subject.

In view of the unqiue nmr spectrum of (LIV), i.e., evidence of a rather high barrier to rotation of the *endo*-aryl ring, it would seem profitable to investigate more fully the spectrum, and, if possible, to compute the barrier to rotation by high temperature nmr techniques. Kessler,[7] in an excellent review states that restricted rotation about the single bond between sp^2 and sp^3 hybridized carbon atoms can be hindered by bulky substituents. Indeed, this is the case when the _ortho_ positions flanking the restricted bond are substituted with large alkyl groups, but only one case has been reported in which the two _ortho_ positions were unsubstituted, that being of an extremely bulkyl di-t-butyl-_p_-anisylcarbinol.[8]

It would appear from models that (LIV) is not so different sterically from the diol, (LIII), which demonstrates no restricted rotation, and hence the barrier to rotation may be, in part, due to electronic factors.

Woodbrey and Rogers[9] have developed a technique whereby a close approximation of the thermodynamic energy parameters can be determined by the intensity ratios of the spectral lines near the coalesence temperature. The line intensity ratio, r, is determined as shown in the idealized case depicted in Figure 11. $\Delta\nu$ is the separation in Hz of the two peak centers of the maxima.

The defining equations are (17), (18), and (19), where ΔG^* is the free energy barrier to rotation in kcal mole,$^{-1}$ k is the rotational rate constant in sec^{-1}, R, the thermodynamic gas law constant, 1.9872 cal mole^{-1} °K^{-1}, T the corrected temperature in °K, h, Planck's constant, 6.6256×10^{-27} erg sec, and N is Avogadro's constant, 6.0225×10^{23} mole^{-1}.

$$r = MAX/MIN \qquad (17)$$

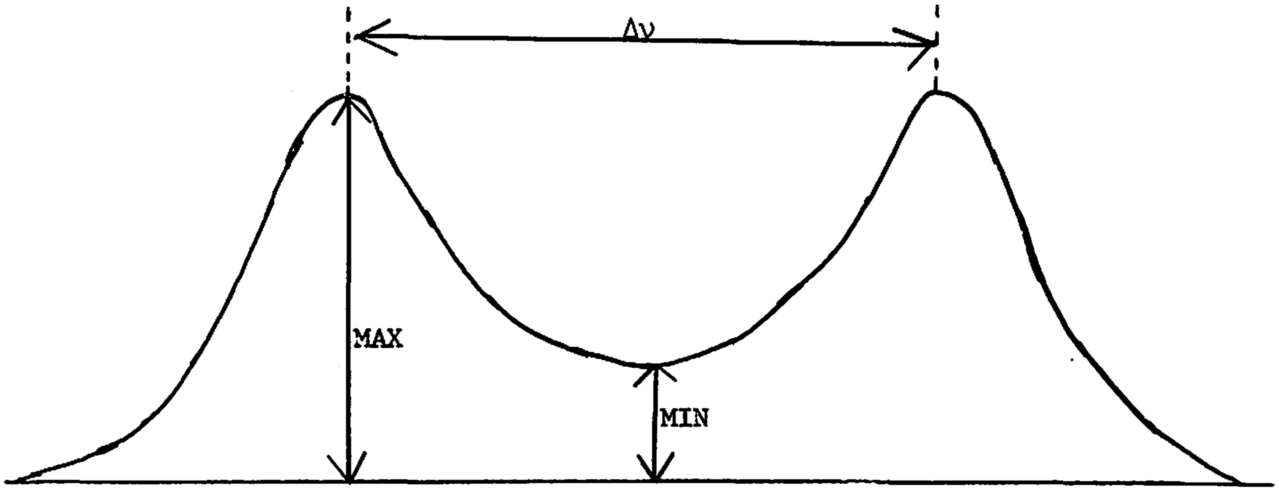


Figure 11. Ideal nmr spectrum for intensity ratio method of Woodbrey and Rogers.

Source: M. T. Rogers and J. C. Woodbrey, *J. Phy. Chem.*, *66*, 540 (1962).

$$k = \pi \Delta \nu (2)^{-1/2} \left[r + (r^2 + r)^{1/2} \right]^{-1/2} \qquad (18)$$

$$\begin{aligned} -\Delta G^{*} &= 2.303\ RT \log \left[kNh(RT)^{-1} \right] \qquad (19) \\ &= 4.577\ T \log \left[kT^{-1}(4.8 \times 10^{-11}) \right] \text{cal mole}^{-1} \end{aligned}$$

An unequivocal proton assignment to each of the peaks in the aryl region of the spectrum would be desirable. This could be accomplished by a least squares comparison of the actual spectrum with that of the theoretical spectrum.

The transition energies (chemical shifts) and transition probabilities (line intensities) associated with spin-spin interactions have a quantum mechanical basis,[10] and an exact correspondence between experiment and prediction has been achieved. Therefore, a theoretical spectrum may be generated from a set of parameters, (chemical shifts and coupling constants), and the values of these parameters can be altered in an iterative, least squares sense until the theoretical spectrum is superimposable upon the experimental spectrum within established error limits. This, of course, requires correct proton assignment to the experimental lines.[11] Such a correct proton assignment should not be too difficult in the case of a four spin system with widely separated lines as is the case of the aryl protons of the compound in question.

Such a comparison is tenable by use of an iterative computer program written by Bothner-By and Castellano[12,13] of the Mellon Institute. This program is available to all users and is entitled "LAOCN3, Least Squares Adjustment of Calculated On Observed Nmr Spectra, Version 3."

Further chemical characterization of the title compound would be interesting. Long[3] noted its evident inertness to hydride reduction and its nonreactivity to all but strong mineral acids. It might be informative to test its chemical "inertness" with strong nucleophiles such as Grignard reagents and organolithium compounds.

It was felt that the restricted rotation of the aryl ring might be due to considerable steric interaction between the ortho ring hydrogens and the 6-endo proton of the norbornyl group. In such an event, other aryl-2,3-exo-norbornene oxides should reveal a similar, if not equal, barrier to rotation. Kleinfelter and Long[1] have demonstrated that attempts to generate the phenyl or p-chlorophenyl analogs of (LIV) by a similar route were unsuccessful. Other methods of epoxidation are known,[14,15,16] and an attempt to prepare the two analogs by one of these procedures seemed to hold promise.

CHAPTER II

DISCUSSION OF RESULTS

A. The Chemical Behavior of LIV

A full discussion of the attempted reactions of (LIV) will not be attempted here. However, a brief account of the unsuccessful attempts at ring opening will be presented.

1. Reaction with Phenylmagnesium Bromide

This reaction was attempted five times in different solvent systems. In each case an equimolar quantity of Grignard reagent and substrate were mixed, and upon normal hydrolysis with water, usual workup and evaporation of the solvent, starting material was recovered in yields greater than 90%. The solvent systems employed and reaction times were: anhydrous ether-THF (2 hrs), ether-benzene (24 hrs), THF (72 hrs), ether-xylene (36 hrs), and di-n-amyl ether (72 hrs.).

3. Reaction with Methylmagnesium Iodide

The compound was added as a solution in xylene to the methyl reagent in ether and refluxed for 120 hrs. A 90% recovery of the starting material was accomplished.

3. Reaction with Phenyllithium and n-Butyllithium

The phenyllithium was prepared in ether and the substrate added as a benzene solution and refluxed for 102 hrs. The n-butyllithium was commercially prepared and used as a solution in hexane, to which the compound was added as a benzene solution. Refluxing for 48 hrs and hydrolysis yielded the unchanged starting material as was the case with the phenyl reagent. Hydrolysis in the case of the phenyllithium with 99.5% deuterium oxide affected no detectable deuterium incorporation in the aromatic ring.

4. Potassium Hydroxide-Ethylene Glycol Reduction

A reduction of the type utilized by Kleinfelter[17] for aryl norbornanones was attempted. This resulted in a 75% recovery of starting material.

5. Lithiumdiethylamide Reduction

A reaction analogous to that performed by Crandall[18] with norbornene oxide (I) was attempted. A 75% recovery of starting material was accomplished.

6. Dimethylsulfoxide-borontrifluoride Oxidation

Cohen and Tsuji[19] have reported the oxidation of epoxides to hydroxy ketones. This reaction was attempted utilizing a small amount of diglyme as solvent owing to the insolubility of the substrate in dimethylsulfoxide. A 70% recovery of starting material was realized.

B. The Nmr Spectrum of LIV

A near total nmr analysis of the compound was undertaken. The results of this analysis are given under the various headings which relate to the method by which unequivocal assignment was made.

1. Accurate Chemical Shift Data

The HA-100 NMR Spectrometer offers greatly enhanced signal to noise ratio, increased "first order character" of multiplicity, greater field stability due to its mode of operation, i.e., a field position "lock" on a suitable standard, usually TMS, and a digital read out of field frequency. Hence, the exact chemical shift of a given proton can be readily determined if the peak center is known.

Kleinfelter and Long[1] reported the 60 MHz data of the title compound, and described the aryl proton absorption as a doublet of quartets at 7.49 δ, the same pattern at 6.92 δ, and a doublet of triplets at 6.48 δ. A separation of the upfield aryl proton absorption in the 100 MHz spectrum enabled further chemical shift assignment. This was due to the increased resolving power of the larger spectrometer which showed the aryl region to be represented as a set of AX doublets split again into doublets, centered at 7.47 and 6.93 δ, respectively, and further upfield, a set of AB doublets further split into doublets at 6.54 and 6.42 δ, Figure 12.

2. Multiple Irradiation Experiments

Spin decoupling experiments were devised to test the empirical assignments made earlier.[1,3]

Irradiation of the 2.61 δ peak, assigned to the 7-<u>syn</u> proton produced no change in the appearance of the 0.74 δ doublet, previously assigned to the 7-<u>anti</u> proton. In view of the large geminal coupling of 9.3 Hz for the 7-<u>syn</u>, 7-<u>anti</u> coupling in norbornene oxide (I),[2] it must be assumed that one of the assignments is incorrect. It was observed, however, that this double resonance did cause collapse of a "doublet" to a singlet centered at 1.31 δ. Irradiation of this 1.31 δ "doublet" likewise caused the collapse of the 2.61 δ peak to a singlet, a marked effect

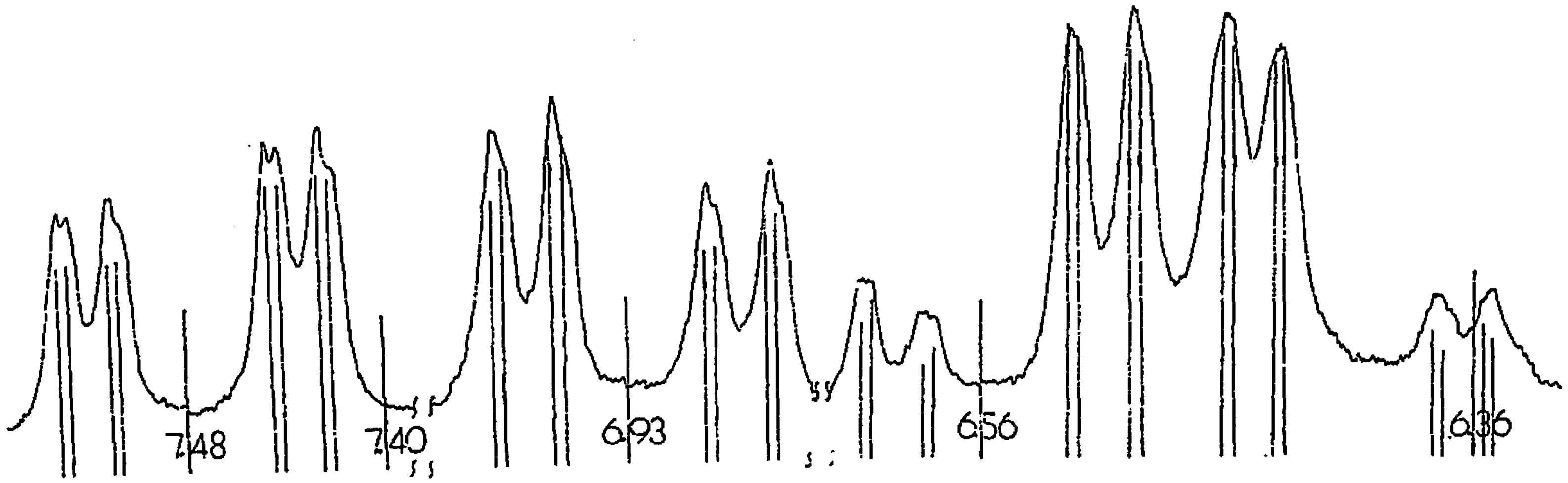


Figure 12. Aryl proton spectrum of LIV (ca 10% (w/v) $CDCl_3$, 100 MHz nmr).

on the broad multiplet at 2.29 δ, and a noticeable narrowing of the 3.55 δ peak. This implies that the 1.31 δ proton is coupled to three other protons, whose assignments are virtually certain, i.e., 3.55 δ (3-*endo* proton), 2.61 δ (7-*syn* proton), and 2.29 δ (bridgehead protons). There is literally only one proton to fit this description, the 7-*anti* proton. *Syn,anti* coupling has been shown to be large in norbornene oxide, (9.3 Hz).[2] Herein it is 8.8 Hz. At the same time, the coupling between the 7-*anti* proton and the 3-*endo* proton would be expected to be rather small, i.e., line broadening, since this involves long range coupling over four bonds in the required "W" configuration,[20] and 3-*endo*, 4-bridgehead coupling also is not nearly so large as the 7-*syn*, 7-*anti* value. Irradiation of the 2.29 δ peak (bridgehead protons) would, therefore, be expected to eliminate 3-*endo*, 4-bridgehead coupling, giving rise to a doublet for the 3-*endo* proton absorption, revealing the 7-*syn*, 3-*endo* coupling. This was just the case, the value of the coupling constant being 1.2 Hz. This is somewhat smaller than the 3-4 Hz seen in some norbornyl derivatives[20] but this may be due to steric "warping" of the norbornyl framework by the large substituents.

Finally, irradiation of the most downfield absorption in the aryl region (7.47 δ) gave rise to the collapse of the small coupling in the most upfield absorption (6.42 δ), proving these two peaks to be *meta* coupled.

3. The Computer Generated and Experimental Spectra for the Aryl Protons

Assuming that rotation about the aryl-norbornyl bond is indeed restricted and that the greater population of molecules reside in the less strained conformation, four possible proton assignments may be made. These four possibilities are listed in Figure 13, where W_1 through W_4 are the chemical shifts from the most downfield, 7.47 δ (W_1), to the most upfield, 6.42 δ (W_4).

Structures (13b) and (13d) may be immediately eliminated on the basis of the spin decoupling experiments, which showed the most downfield proton, W_1, to be meta coupled with the most upfield proton, W_4. This leaves two possibilities, one of which is more attractive than the other. In structure (13c) the most downfield proton, W_1, is ortho to the methoxyl group. The shielding effect of a methoxyl group upon ortho protons is well known,[21] and this structure is tentatively discounted on that basis.

A careful HA-100 nmr spectrum of the aryl region is scanned and chemical shifts and coupling constants are determined. These are the input parameters for the computer program, which is self-contained and compatible with any computer system utilizing a Fortran IV compiler. In Table XIII the input and output are listed. The input data are the shifts and coupling constants as measured directly from the experimental spectrum. The output data are the best values fit, in a least squares sense, of the theoretically generated spectrum to the experimental data. As can be seen, an excellent fit between the theoretical and experimental spectra has been obtained lending great credibility to structure (13a) as being the closest to the true structure. In Table XIV the theoretical spectrum is tabulated, along with error data, and in Figure 12, page 76, the theoretical line spectrum is superimposed upon the experimental spectrum. In Table XV the accumulated data of this and the preceeding two sections are tabulated.

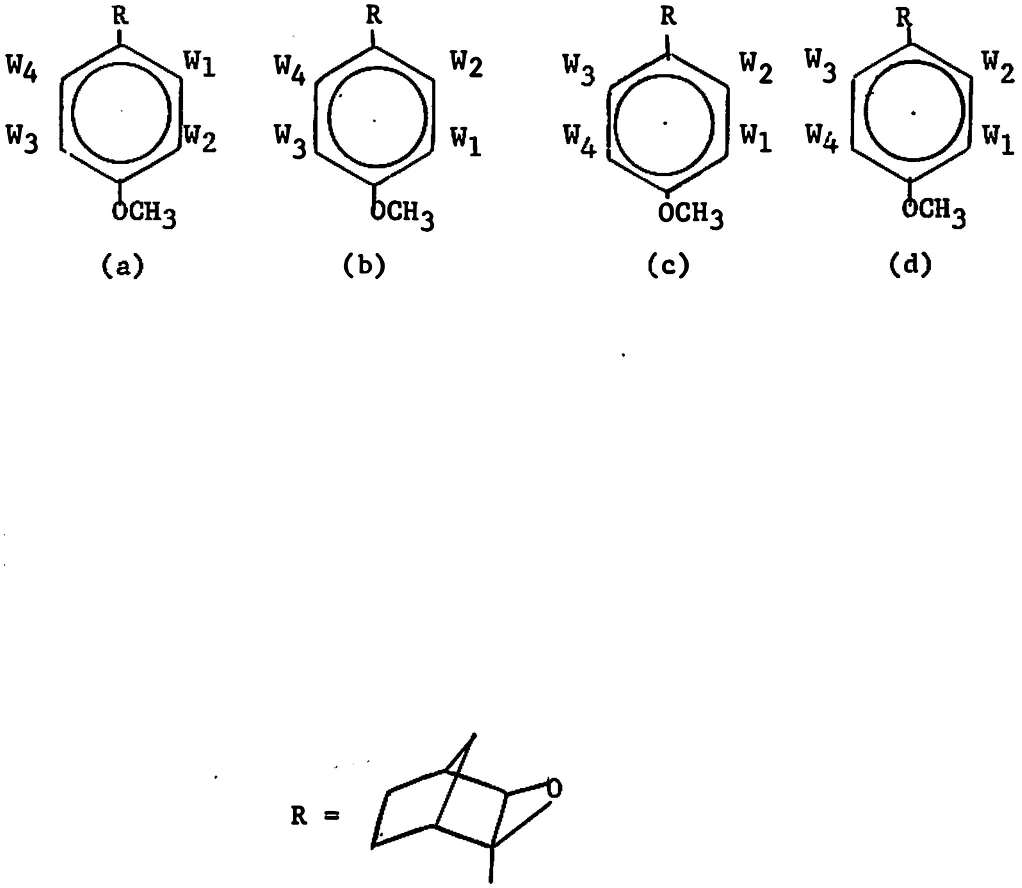


Figure 13. Possible proton assignments for the aryl nmr spectrum of (LIV).

TABLE XIII

INPUT AND OUTPUT DATA FOR LAOCN3 EVALUATION OF ARYL PROTONS IN (LIV)

Input Data		Output Data Best Value Case, Hz	Probable Error
Chemical Shift, Hz:			
H(1)	641.8	641.824	0.018
H(2)	653.4	653.488	0.018
H(3)	693.2	693.490	0.015
H(4)	747.8	747.473	0.015
Coupling Constants, Hz:			
J(1,2)	8.70	8.360	0.021
J(1,3)	0.50	0.130	0.025
J(1,4)	2.10	2.289	0.024
J(2,3)	2.60	2.761	0.024
J(2,4)	0.50	0.173	0.024
J(3,4)	8.70	8.586	0.021

TABLE XIV

THEORETICAL SPECTRUM AND COMPARISON TO THE LEAST SQUARES FITTED EXPERIMENTAL SPECTRUM FOR (LIV), AS OBTAINED BY LAOCN3

Experimental Frequency	Calculated Frequency	Intensity	Error
635.000	635.053	0.405	-0.053
635.400	635.425	0.466	-0.025
637.100	637.096	0.351	0.004
637.500	637.525	0.430	-0.025
643.400	643.399	1.538	0.001
643.800	643.773	1.506	0.027
645.500	645.447	1.665	0.053
645.900	645.877	1.627	0.023
649.200	649.162	1.498	0.038
649.600	649.591	1.605	0.009
651.700	651.691	1.583	0.041
652.100	652.059	1.662	-0.008
657.500	657.508	0.360	-0.043
657.900	657.943	0.289	-0.038
660.000	660.038	0.548	-0.011
660.400	660.411	0.466	-0.061
687.400	687.461	0.912	-0.033
687.800	687.833	0.909	-0.091
689.900	689.991	0.776	-0.064
690.300	690.364	0.770	0.061
696.100	696.039	1.230	0.032
696.500	696.468	1.196	0.094
698.600	698.506	1.109	0.094
699.000	698.936	1.082	0.064
742.400	742.300	1.186	0.100
742.800	742.730	1.174	0.070
744.400	744.343	1.134	0.057
744.800	744.778	1.128	0.022
750.800	750.878	0.862	-0.078
751.200	751.245	0.852	-0.045
752.900	752.977	0.831	-0.077
753.300	753.350	0.824	-0.050

TABLE XV

NMR SPECTRAL DATA FOR (LIV)

Chemical Shift,	Proton Assignment	Coupling Constants, Hz
6.42	H_{Ar1}	$J_{1,2}$ 8.70
6.53	H_{Ar2}	$J_{1,3}$ 0.50
6.93	H_{Ar3}	$J_{1,4}$ 2.10
7.47	H_{Ar4}	$J_{2,3}$ 2.60
		$J_{2,4}$ 0.50
		$J_{3,4}$ 8.70
3.80	H_{OCH_3}	-----
3.55	$H_{3\text{-}\underline{endo}}$	$J_{7\text{-}\underline{anti},3\text{-}\underline{endo}}$ 1.20
2.61	$H_{7\text{-}\underline{syn}}$	$J_{7\text{-}\underline{syn},7\text{-}\underline{anti}}$ 8.80
2.29	$H_{1,4}$	-----
1.31	$H_{7\text{-}\underline{anti}}$	See Above

4. Elevated Temperature Nmr

Since it was felt that the complex aryl absorption was due to somewhat restricted rotation, monitoring the nmr absorption at temperatures higher than ambient should reveal a gradual change and ultimately a classical AA'BB' pattern should emerge.

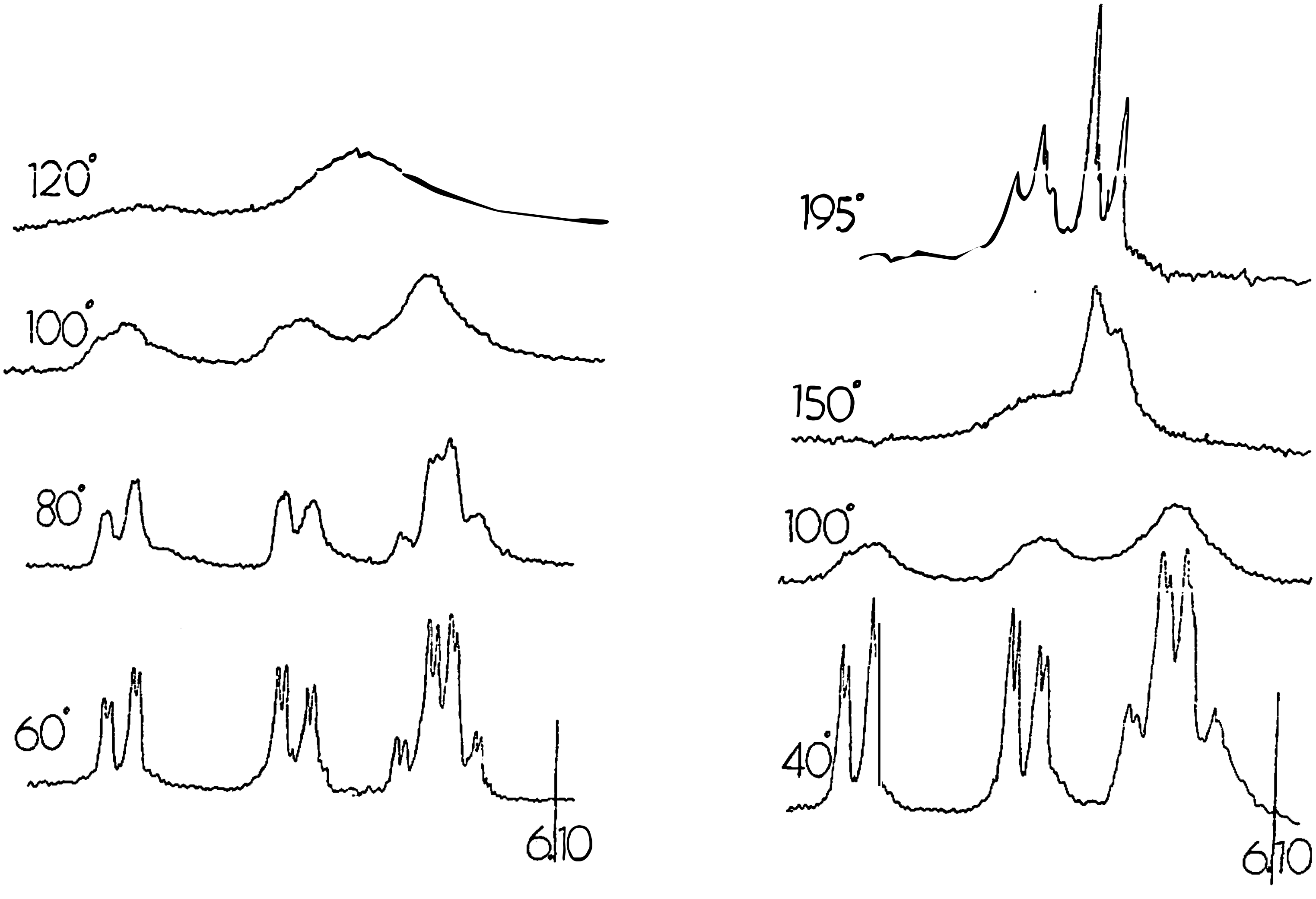
Choosing a proper solvent proved more difficult than anticipated owing to the insolubility of the compound in common solvents. First diglyme was chosen as the oxide is soluble to the extent of about 10% (w/v) at room temperature. This solvent choice proved to be inadequate; however, coalescence of the signals did not occur until between 110° and 130°C, and boiling of the solution initiated just as the anticipated quartet pattern began to be barely discernible.

An attempt at heating the solution above 160°C in a sealed tube proved abortive as eventual reflux somewhat above 160°C caused instrument failure due to loss of the lock signal.

Success was finally achieved by use of a 9% (w/v) solution of (LIV) in triglyme, with hexamethyldisiloxane, (HMDS), as an internal standard and lock. In Figure 14, traces over a wide range of temperature are reproduced, showing the "normal" spectrum, coalescence, and finally, the near AA'BB' multiplicity.

5. Determination of the Free Energy Barrier to Rotation in (LIV)

As suggested in the introduction (p. 69), determinations of certain thermodynamic parameters are possible if a few certain criteria are met. The spectrum must demonstrate coalescence at a temperature attainable within the heating or cooling capacity of the variable temperature probe device, the compound must not undergo any chemical change



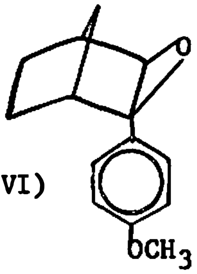
ca 10% (w/v) in diglyme

ca 9% (w/v) in triglyme

Figure 14. Variable temperature nmr spectra of the aryl protons of LIV.

at this temperature, and the spectrum should be simple, such that a simple maximum-minimum pattern exists as in Figure 11, (p. 69). One could expect the nmr spectrum of a 3,5-dideuterio analog of (LIV), such as (LVI), to display a simple AX doublet of doublets pattern. This compound was prepared and the prediction proved correct. From the spectrum, the

(LVI)



meta coupling constant was determined to be 2.1 Hz, further proof that this coupling should be smaller than the other meta coupling which spans the electronegative methoxyl substituent. The chemical shifts were just as predicted, 7.48 δ and 6.42 δ.

The high temperature nmr spectra were run by S. Sternhell and G. C. Brophy, of the Department of Organic Chemistry, The University of Sidney, Sidney, Australia. The results of this excellent work are contained in Table XVI, which show the average value of ΔG^* (free energy barrier to rotation) to be 19.7±0.1 kcal $mole^{-1}$.

C. 2-Phenylnorbornene-2,3-exo-Oxide, (LVII), and 2-(4-Chlorophenyl)-norbornene-2,3-exo-Oxide, (LVIII)

1. Preparation of LVII and LVIII

The two epoxides were prepared from the corresponding olefins (LIX), and (LX), by the method of Payne.[16] The phenyl compound (LVII) was a clear colorless oil, while (LVIII) was a white solid.

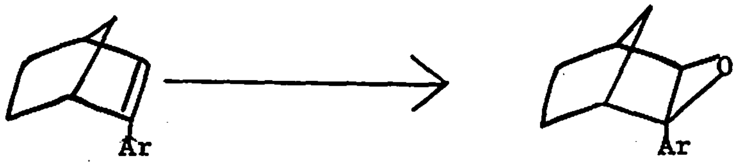
TABLE XVI

HIGH TEMPERATURE NUCLEAR MAGNETIC RESONANCE DATA[a] FOR LVI

Reading on Temperature Scale, °C	Corrected[b] Temperature, °C	Max/Min Ratio, r	Rate Constant k, sec^{-1}	Free Energy Barrier to Rotation, ΔG^*, kcal $mole^{-1}$
110	113.5	4.38±0.47	79.5±4.6	19.5
114	117.5	3.57±0.28	88.6±3.8	19.6
116	120	2.77±0.11	101.8±2.3	19.6
118	122	2.36±0.12	111.5±3.3	19.6
120	124	2.04±0.05	121.5±1.8	19.7
122	126	1.89±0.06	127.3±2.5	19.8
124	128	1.82±0.07	130.2±3.1	19.8

[a] Ca 10% (w/v) diglyme solution, with Varian HA-100 NMR Spectrometer.

[b] Temperature correction made by checking temperature immediately after scanning by the "Varian Method," i.e., with an ethylene glycol standard, the hydroxyl chemical shift being a function of temperature, and by the "melting point method," in which samples of known melting points are placed in sealed capillaries and immersed in DMSO in an nmr tube. The temperature is determined by the appearance of the nmr signal upon melting.



(20)

(LIX) Ar = C_6H_5

(LX) Ar = *p*ClC_6H_4

(LVII) Ar = C_6H_5

(LVIII) Ar = *p*ClC_6H_4

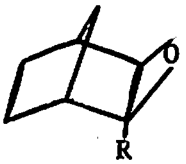
2. Nmr, Uv, and Mass Spectral Data for (LVII) and (LVIII)

The most significant feature of the nmr spectra of the two oxides is their difference from that of the *p*-anisyl compound, (LIV). Whereas the latter compound displayed restricted rotation of the aryl group, these two compounds, from all spectral appearances, display little or no such restriction. The nmr data are almost totally analogous to that of norbornene oxide, (I), itself. In Table XVII, the data for (I), (LVII), and LVIII) are summarized. The chemical shifts of most protons are shifted downfield somewhat, due to the inductive electron withdrawing effect of the aryl substituent. The 7-*syn* proton absorption of (LVII) was obscured due to the absorption of the 5- and 6-protons. The chemical shift was pinpointed by double irradiation of the 7-*anti* proton absorption and scanning the upfield multiplet. The large 7-*syn*,7-*anti* coupling was eliminated and the chemical shift was pinpointed by virtue of this fact. This same double irradiation collapsed the 3-*endo* proton absorption to a doublet; $J_{3\text{-}\mathit{endo},7\text{-}\mathit{anti}}$ = 1.3 Hz.

It was determined by a 50 Hz expansion spectrum with the 100 MHz nmr spectrometer that the multiplet absorption of the 7-*anti* proton was actually a doublet of sextets and all coupling constants were determined. Figure 15 demonstrates this 50 MHz expansion, and the theoretical splitting pattern is superimposed.

TABLE XVII

NMR SPECTRAL DATA FOR (I),[a] (LVII),[b] AND (LVIII)[c]



Proton	Chemical Shift, δ	Coupling Constant, Hz	
R=H:[d]			
1,4	2.44		
2,3	3.16		
7-*syn*	1.35		
7-*anti*	0.70		
R= C_6H_5:			
1	2.78	$J_{1,7\text{-}anti}$	1.5
4	2.50	$J_{4,3\text{-}endo}$	1.3
3	3.32	$J_{3\text{-}endo,7\text{-}anti}$	0.8
7-*syn*	1.62	$J_{7\text{-}anti,7\text{-}syn}$	9.5
7-*anti*	0.82	$J_{7\text{-}anti,4}$	1.5
aryl (singlet)	7.30		
R = 4-ClC_6H_4:			
1	2.82		
4	2.58		
3	3.36		
7-*anti*	0.87		
aryl (singlet)	7.30		

[a] $CDCl_3$ solvent.

[b] HA-100 Nmr Spectrometer (ca 15% (w/v) $CDCl_3$).

[c] A-60 Nmr Spectrometer (ca 15% (w/v) $CDCl_3$).

[d] K. Tori, K. Kitahonoki, Y. Takano, H. Tanida, and T. Tsuji, *Tetrahedron Letters*, *11*, 559 (1964).

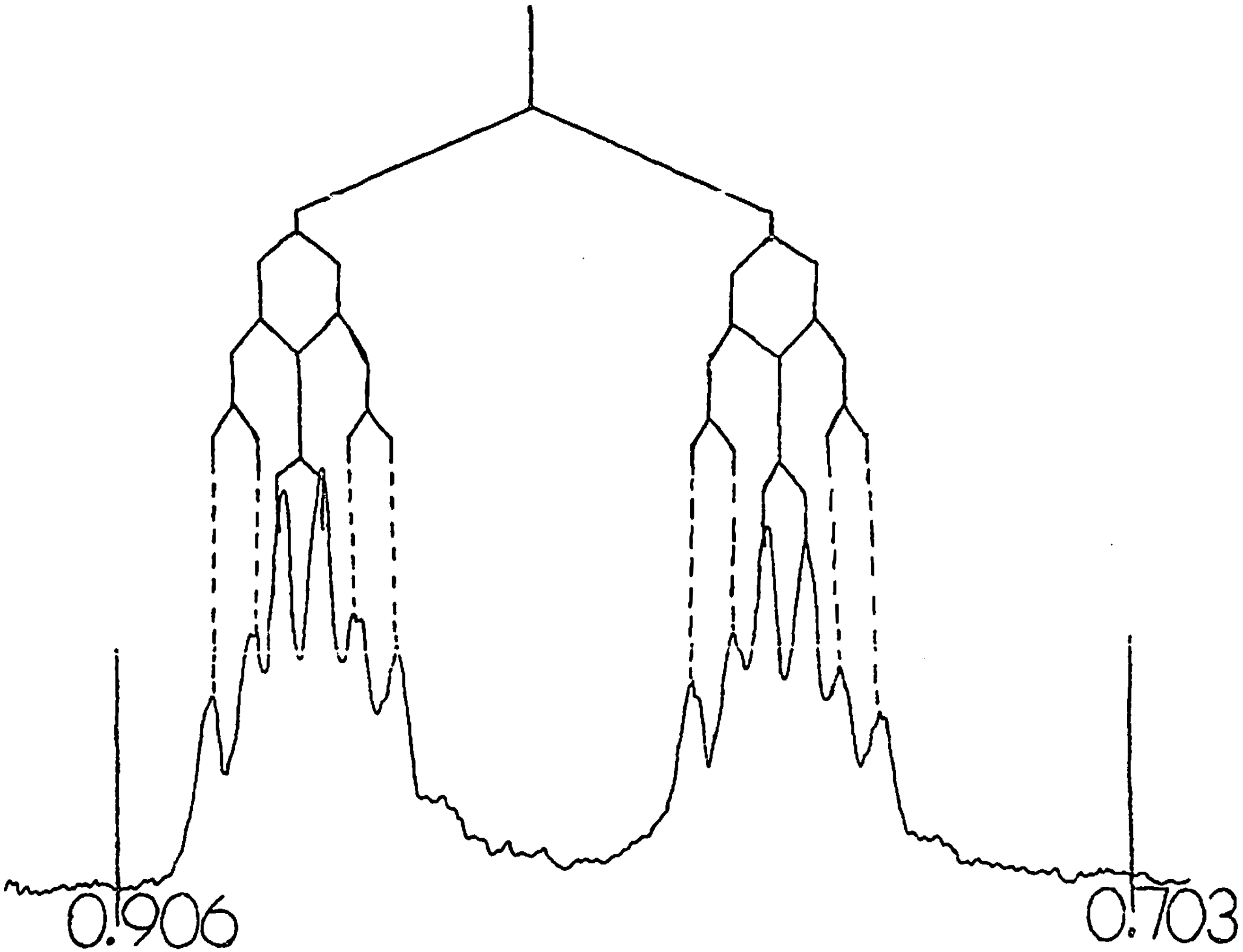


Figure 15. Nmr spectrum of 7-*anti* proton of 2-phenylnorbornene-2,3-*exo* oxide (50 Hz expansion on HA-100 nmr spectrometer, ca 15% (w/v) CCl_4).

The ultraviolet spectral data for the two aryl substituted norbornene oxides were obtained utilizing cyclohexane as a solvent. These data are listed in Table XVIII.

According to Rogers,[22] styrene displays an absorption maximum at 2460Å, and styrene oxide, 2120Å, (hexane solution). Therefore, it may be inferred that substitution of an oxirane ring for the double bond leads to a hypsochromic shift of 340Å. This observation was noted by Long[3] in his studies of 2-*p*-anisylnorbornene and its oxide (LIV). Kleinfelter[23] reports a value of 2625Å for 2-phenylnorbornene, (LIX), and 2670Å for 2-(4-chlorophenyl)-norbornene giving rise to hypsochromic shifts of 370 and 340Å, respectively, for the oxides.

The mass spectra of the phenyl and *p*-chlorophenyl norbornenenes and their respective oxides, (LVII), and (LVIII) have been obtained with the help of Dr. Paul Chen of the Phillip Morris Research Laboratories in Richmond, Virginia. These are included in Tables XIX, XX, XXI, and XXII, and Figures 16, 17, 18, and 19, respectively. For comparative purposes, the mass spectral data and fragmentation patterns for norbornene oxide, (I, p. 2), and 5-*endo*-acetoxynorbornene oxide, (IX, p. 3) have been recorded also in Tables XXIII AND XXIV and Figures 20 and 21, respectively.

3. The Chemical Behavior of LVII

Chemically, the phenylnorbornene oxide behaves as one would expect for a strained epoxide. In direct contrast to the *p*-anisyl compound, (LIV), the oxirane ring of (LVII) is opened with amazing ease, under such mild conditions as stirring at room temperature with

TABLE XVIII

ULTRAVIOLET SPECTRAL DATA FOR 2-PHENYLNORBORNENE-2,3-*exo*-OXIDE,[a] AND 2-(4-CHLOROPHENYL)-NORBORNENE-2,3-*exo*-OXIDE[b]

λ_{max}(Å)	ε
Ar = C_6H_5:	
2584	139
2256	7970
2098	6590
Ar = 4-ClC_6H_4:	
2633	863
2340	10,100
2070	4970

[a] The data were obtained at a concentration of 9.92 mg l^{-1} (4.80×10^{-5} M) in cyclohexane.

[b] The data were obtained at a concentration of 9.84 mg l^{-1} (4.80×10^{-5} M) in cyclohexane.

TABLE XIX

MASS SPECTRUM OF 2-PHENYLNORBORNENE

m/e	% Abundance
172 (P + 2)	0.38
171 (P + 1)	4.60
170 (P)	30.59
155	7.48
154	15.71
153	6.62
152	6.43
143	20.62
142 (Base)	100.00
141	54.72
140	7.91
139	6.12
129	5.60
128	8.79
115	31.27
102	6.27
91	9.07
89	5.26
77	10.28
76	5.63
64	5.47
62	9.40
49	12.46
48	7.52
39	7.98

TABLE XX

MASS SPECTRUM OF 2-(4-CHLOROPHENYL)-NORBORNENE

m/e	% Abundance
207 (P' + 1)	0.75
206 (P')	5.01
205 (P + 1)	2.54
204 (P)	15.15
178	31.04
177	13.44
176 (Base)	100.00
169	13.55
153	6.83
152	5.32
151	17.10
149	5.15
142	5.05
141	34.69
139	9.46
115	15.48
75	6.72
70	6.77
63	7.37
51	6.81
40	5.04
38	12.18

TABLE XXI

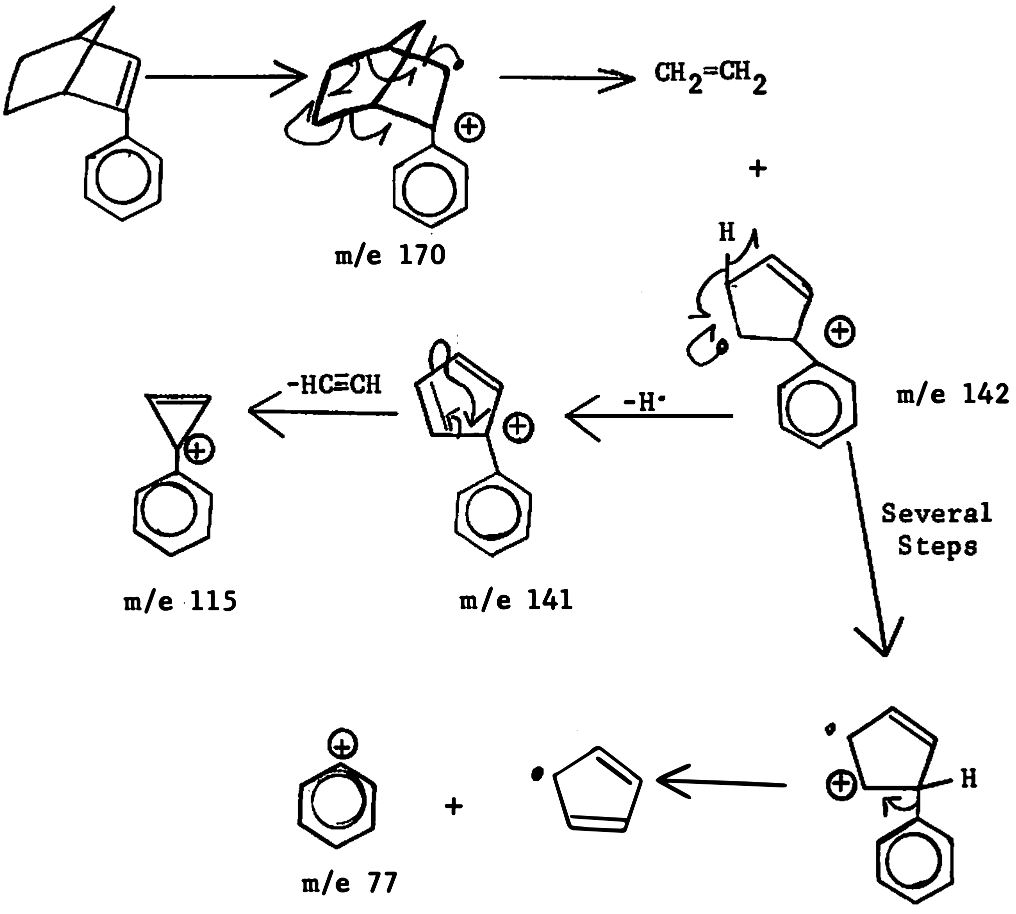
MASS SPECTRUM OF 2-PHENYLNORBORNENE-2,3-*exo*-OXIDE

m/e	% Abundance
187 (P + 1)	3.52
186 (P)	22.02
170	8.57
158	32.29
157	17.50
155	20.55
154	100.00
153	27.71
152	24.78
151	6.69
143	5.40
142	26.01
141	10.63
130	12.39
129	20.43
128	18.08
127	9.39
118	8.51
117	66.64
116	8.22
115	34.58
103	46.15
102	7.28
101	27.59
100	11.74
91	26.42
89	8.69
79	6.56
77	36.52
75	25.83
73	10.27
72	8.51
67	11.68
65	10.22
63	17.61
62	6.46
53	5.87
52	8.81
51	32.41
50	18.49
41	11.51
39	29.77
38	5.46

TABLE XXII

MASS SPECTRUM OF 2-(4-CHLOROPHENYL)-NORBORNENE-2,3-*exo*-OXIDE

m/e	% Abundance	m/e	% Abundance
222 (P')	8.85	114	9.14
221 (P + 1)	4.68	113	10.28
220 (P)	26.04	111	14.97
206	8.45	103	6.28
204	22.55	102	10.56
194	13.42	101	13.70
193	10.73	99	6.28
192	40.08	91	13.30
191	20.90	89	19.64
189	8.56	88	7.59
179	6.28	87	7.54
178	33.80	86	5.02
177	16.16	84	5.14
176	94.94	83	5.14
175	6.57	82	5.08
169	19.70	81	8.56
167	6.39	79	10.45
165	7.94	78	10.22
164	5.14	77	21.64
163	8.05	76	13.65
162	5.14	75	27.58
157	13.42	74	10.96
155	5.48	73	5.25
154	19.64	70	12.28
153	43.68	69	9.42
152	24.15	67	25.58
151 (Base)	100.00	66	7.99
149	14.22	65	11.99
142	12.56	64	11.42
141	63.62	63	26.26
140	10.28	62	9.71
139	61.17	57	11.13
138	9.02	56	11.99
137	5.71	55	15.99
136	8.28	53	11.13
129	32.26	52	7.99
128	28.72	51	29.86
127	25.69	50	19.01
126	7.71	44	25.41
125	26.38	43	15.30
117	11.42	42	9.71
116	31.00	41	37.11
115	71.37	40	7.94
		39	52.81
		38	8.11



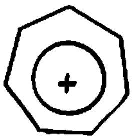
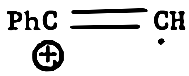
m/e	Suggested Fragment Structure
91	
102	 $\underset{\oplus}{PhC}\equiv\underset{\bullet}{CH}$

Figure 16. Mass spectral degradation of 2-phenylnorbornene.

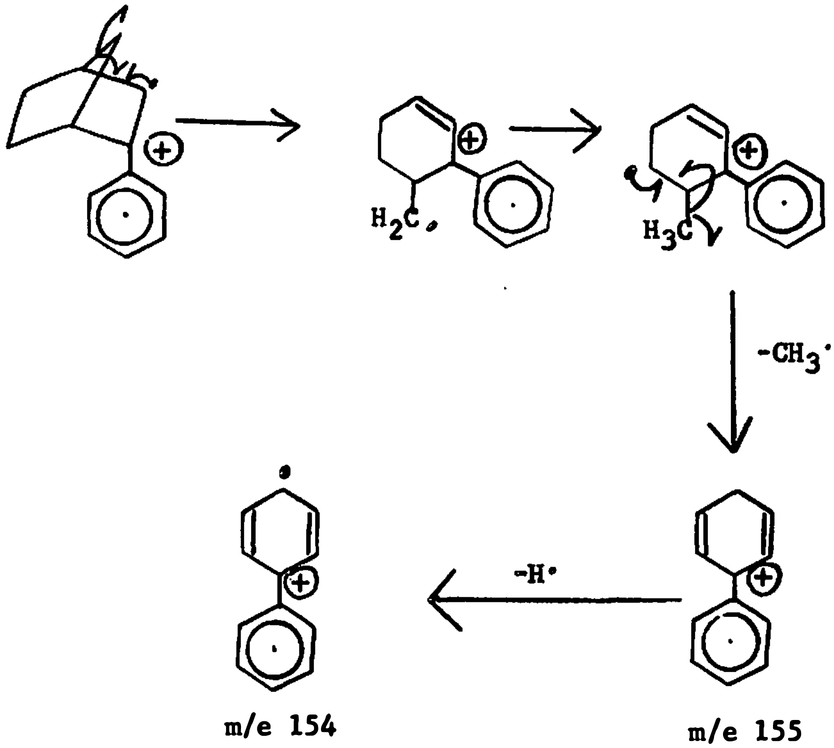


Figure 16 (CONTINUED)

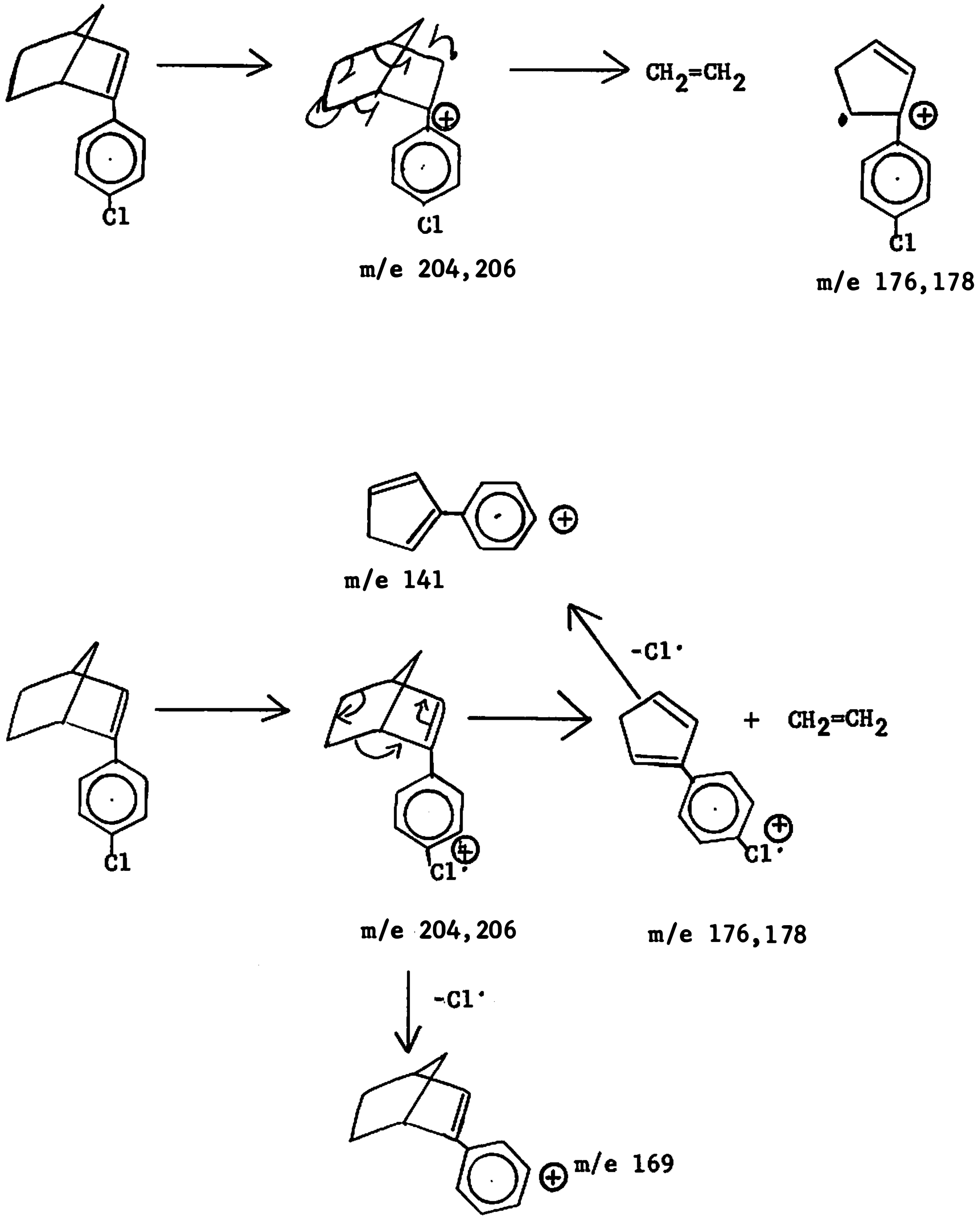
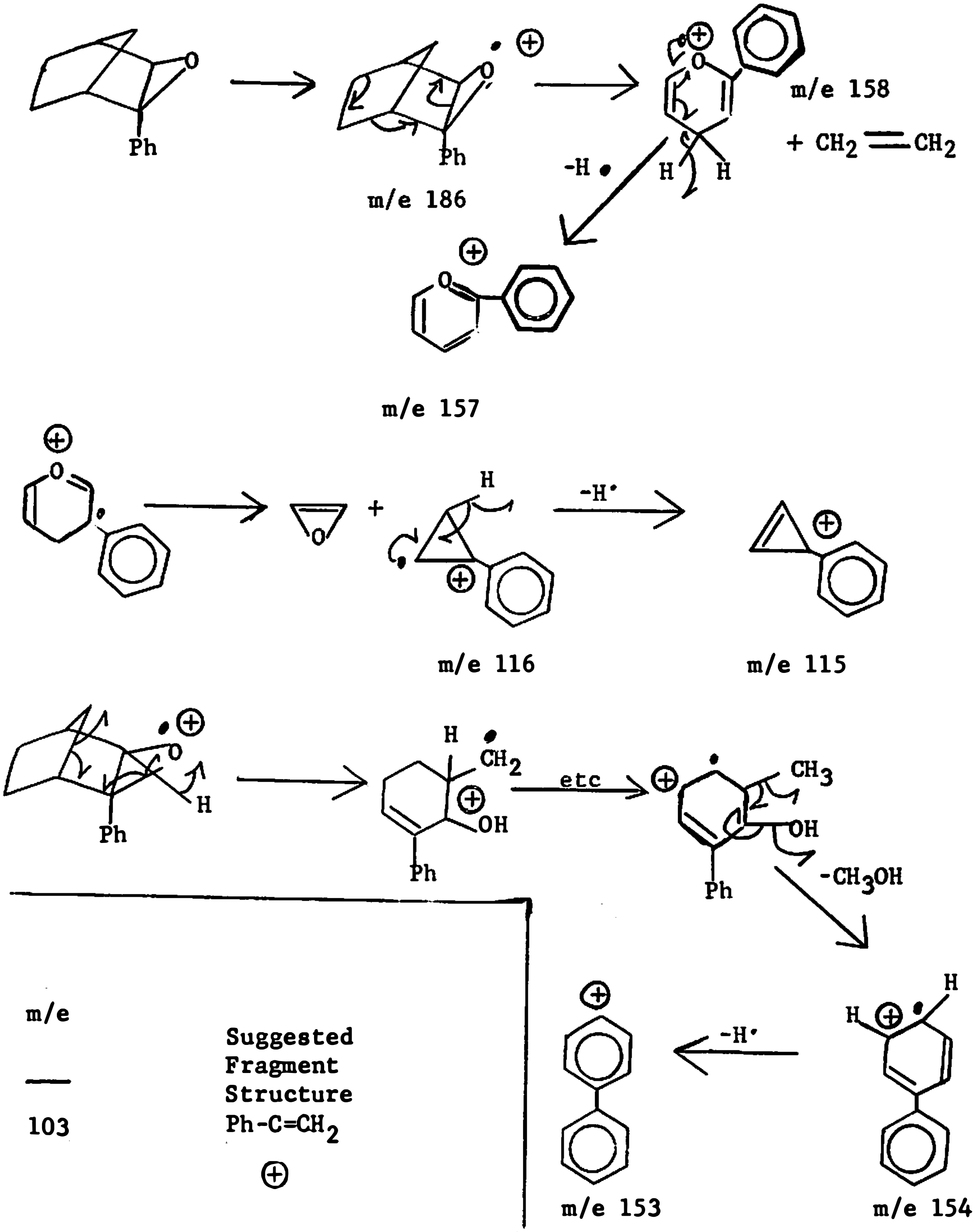


Figure 17. Mass spectral degradation of 2-(4-chlorophenyl)-norbornene.



m/e	Suggested Fragment Structure
103	Ph-C=CH_2 ⊕

Figure 18. Mass spectral degradation of 2-phenylnorbornene-2,3-exo-oxide.

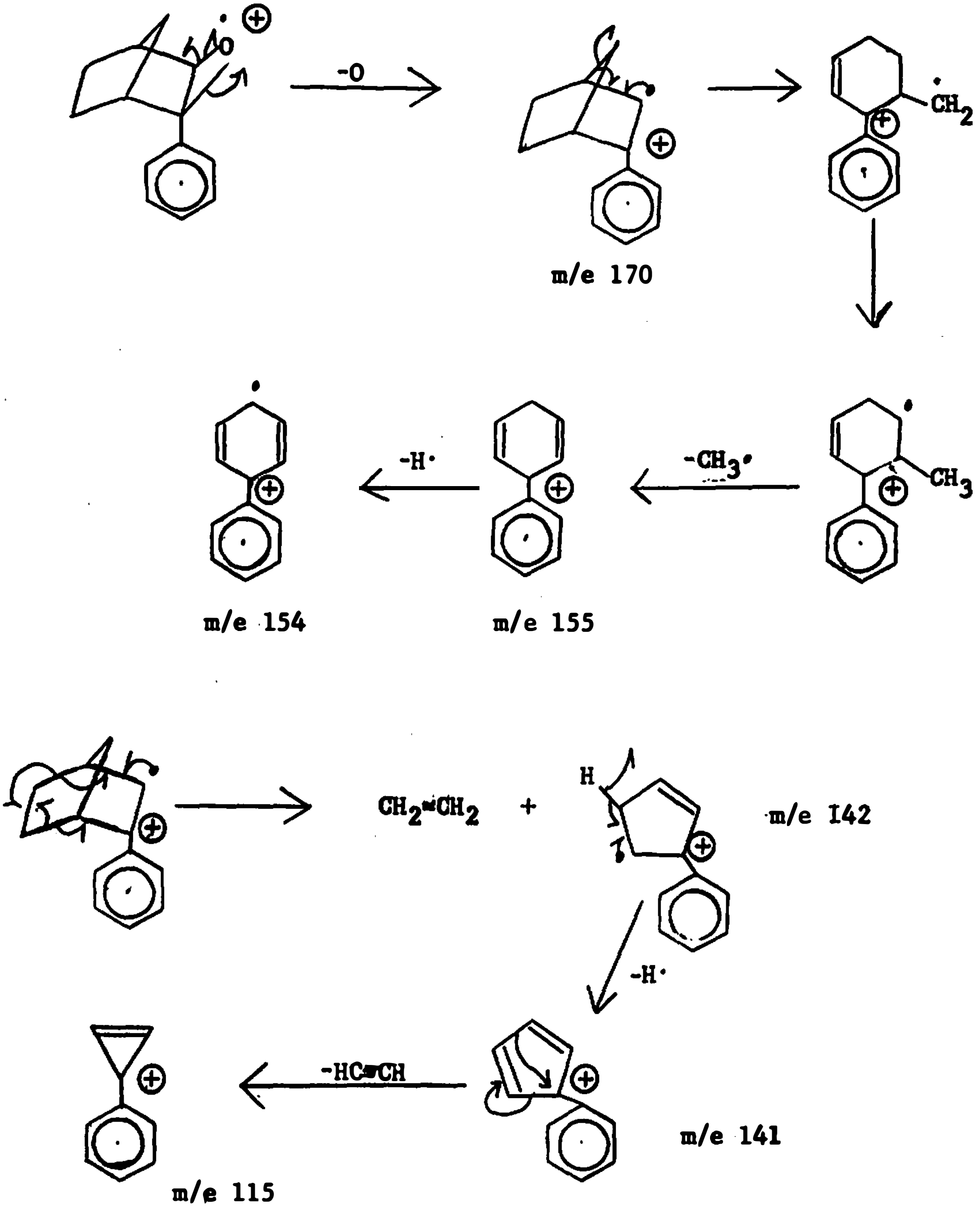


Figure 18 (continued)

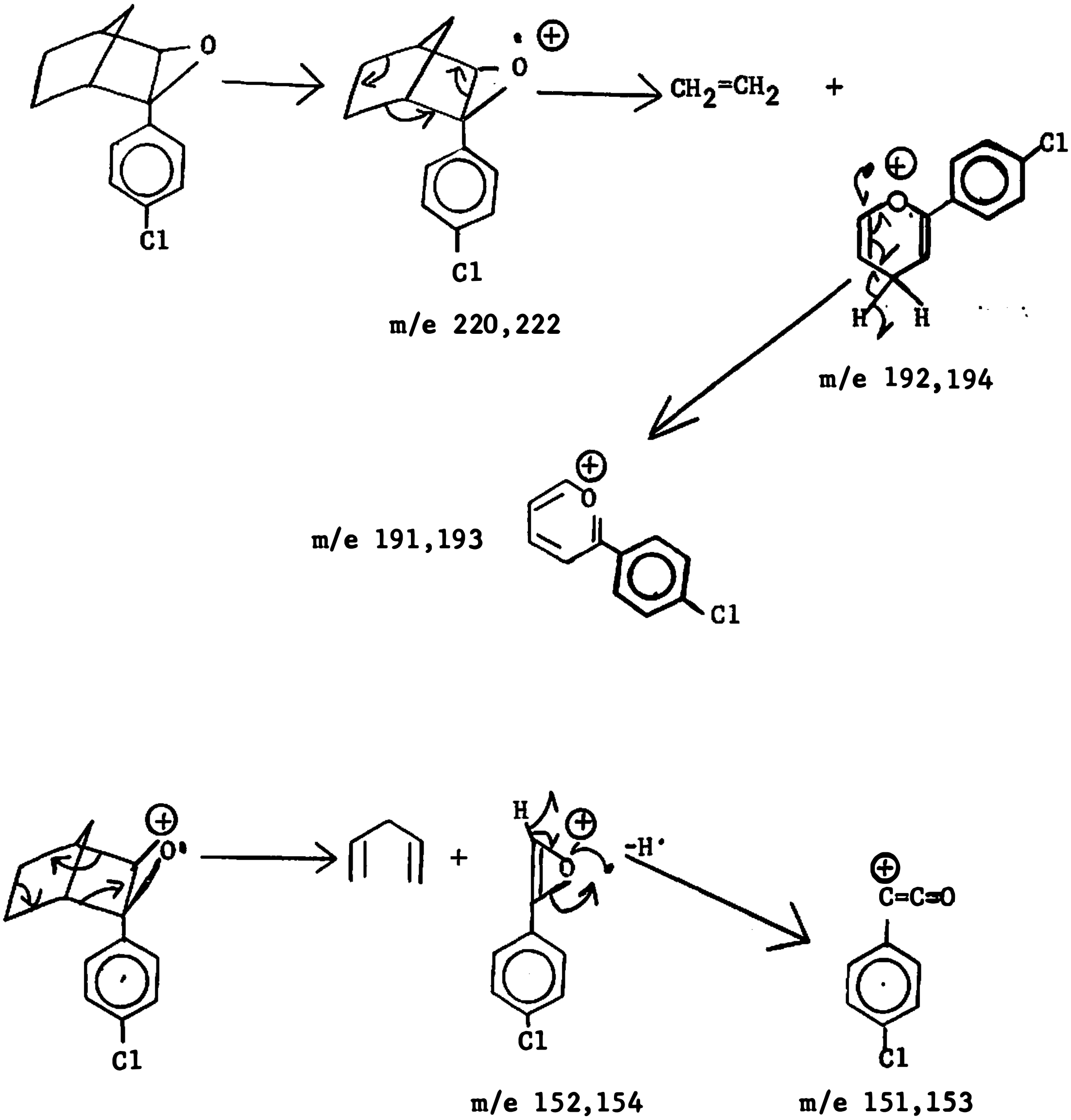


Figure 19. Mass spectral degradation of 2-(4-chlorophenyl)-norbornene-2,3-exo-oxide.

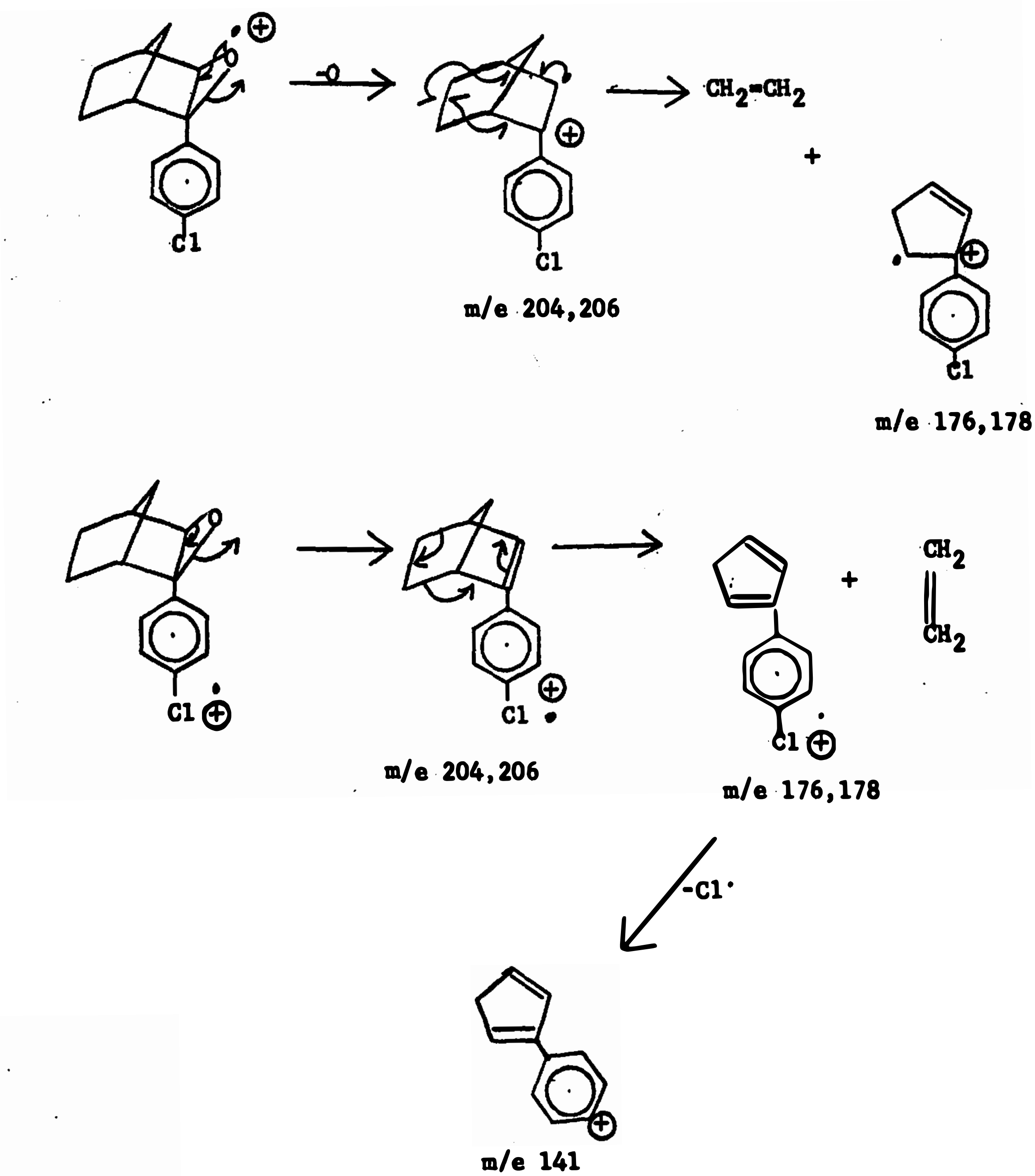


Figure 19 (continued)

TABLE XXIII

MASS SPECTRUM OF NORBORNENE-2,3-*exo*-OXIDE

m/e	% Abundance
111 (P + 1)	7.27
110 (P)	76.92
109	12.47
95	35.64
93	7.26
92	36.38
91	23.38
83	27.33
82	28.58
81	96.15
80	15.07
79 (Base)	100.00
78	19.23
77	28.06
69	9.87
68	19.85
67	70.68
66	68.71
65	12.47
55	29.10
54	52.49
53	47.81
52	8.31
51	16.63
50	10.39
43	14.13
42	6.17
41	63.40
40	12.47
39	60.81
38	7.27
29	14.55

TABLE XXIV

MASS SPECTRUM OF 5-*endo*-ACETOXYNORBORNENE 2,3-*exo*-OXIDE

m/e	% Intensity
169 (P + 1)	0.20
168 (P)	0.40
126	7.69
108	22.24
107	8.00
97	8.73
83	12.26
82 (Base)	100.00
81	67.56
80	38.46
79	61.53
78	5.40
77	13.61
70	14.13
69	6.02
67	10.60
66	13.92
61	6.44
57	7.90
55	9.97
54	12.68
53	11.22
51	5.71
44	7.69
43	47.60
42	5.40
41	23.90
39	23.90

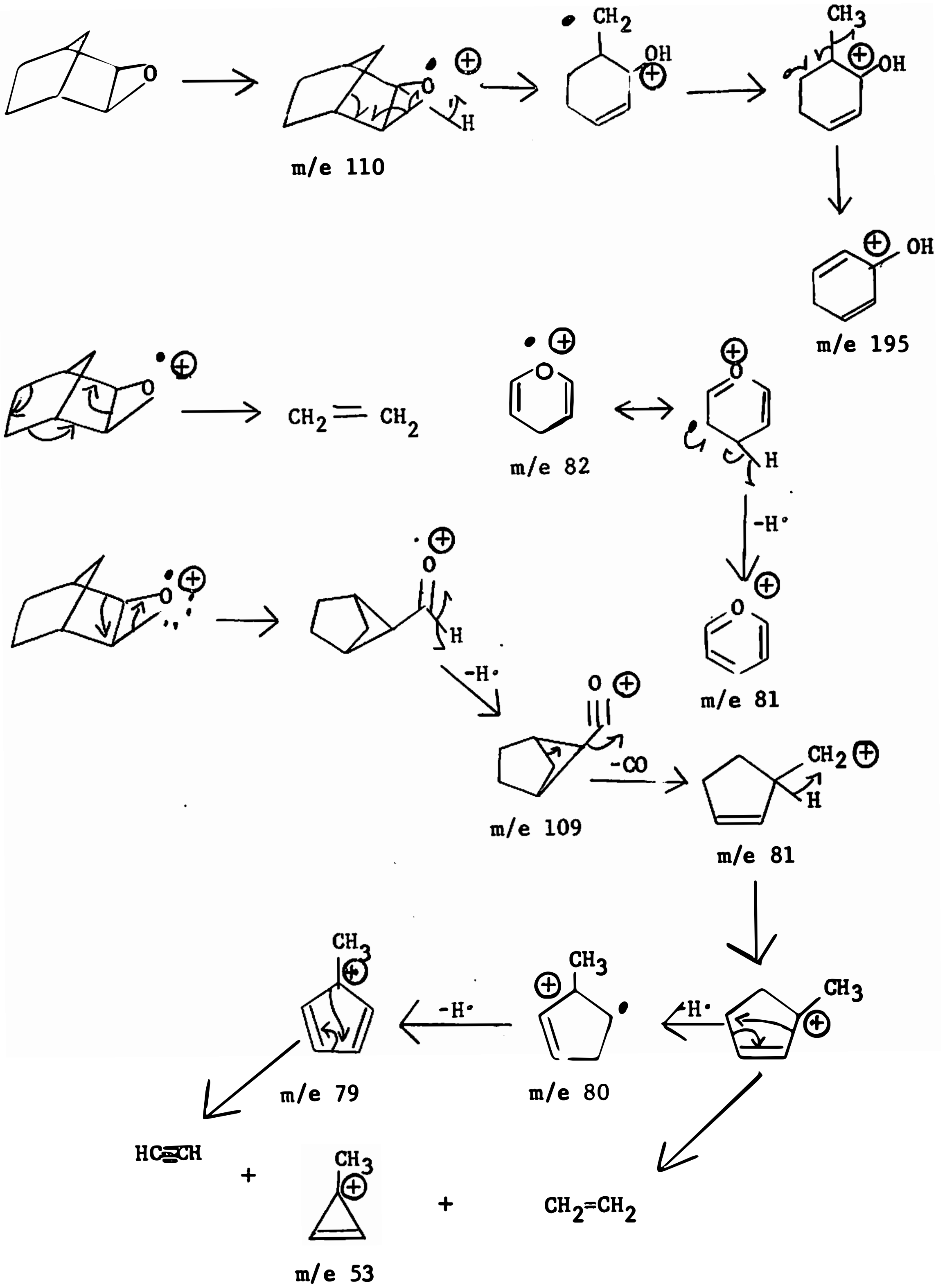


Figure 20. Mass spectral degradation of norbornene-2,3-exo-oxide.

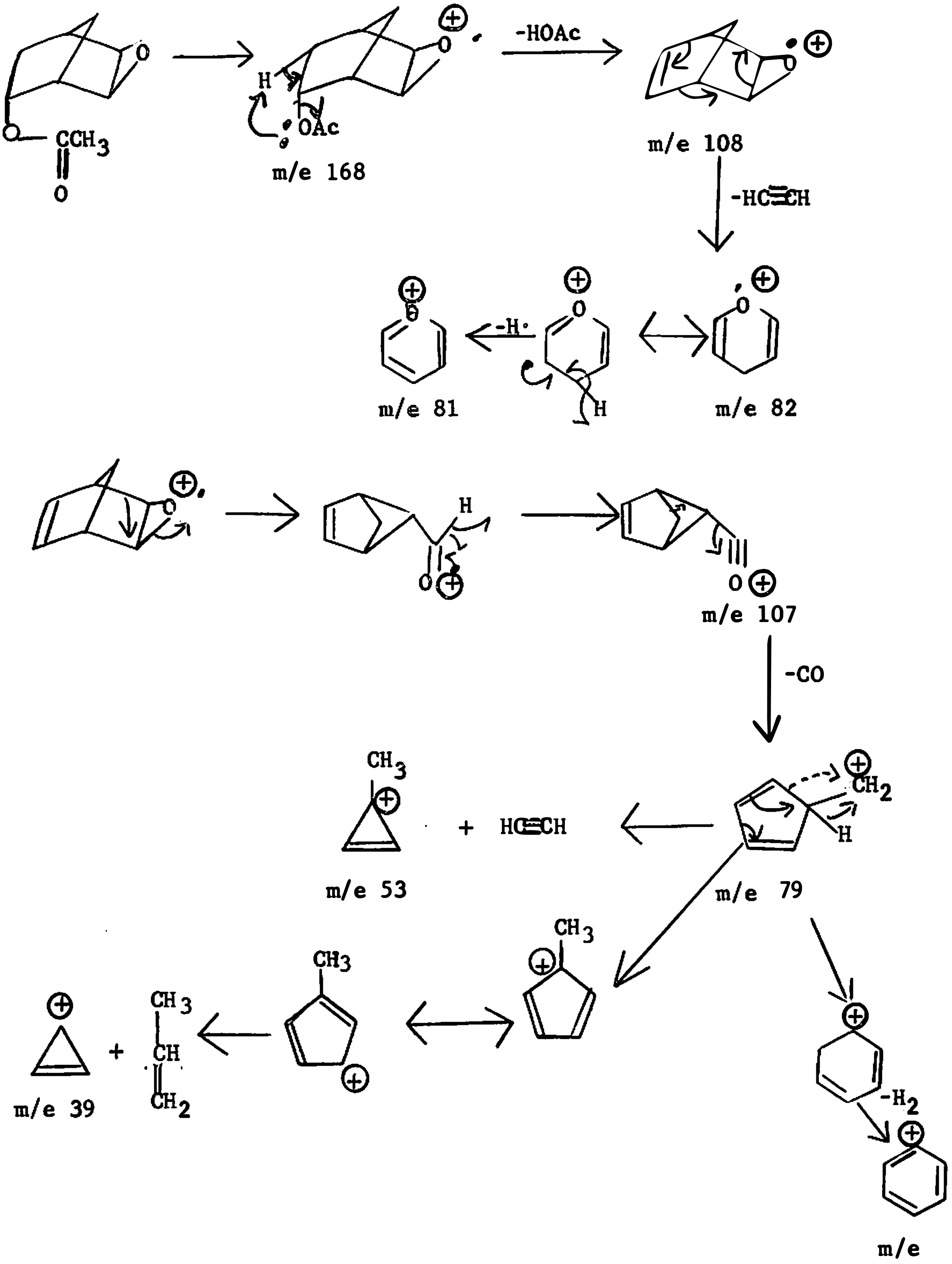
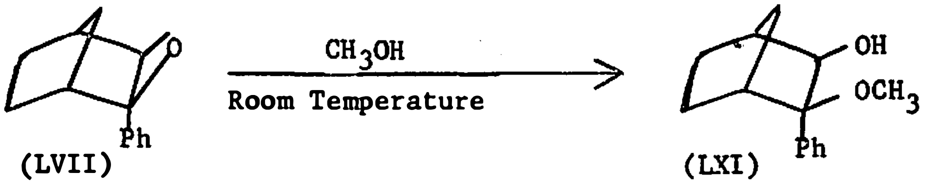


Figure 21. Mass spectral degradation of 5-endo-acetoxynorbornene 2,3-exo-oxide.

absolute methanol to yield the methoxyhydrin, (LXI) as shown in equation 21.



(LVII) (LXI) (21)

The compound is a colorless oil, and structure (LIX) was confirmed on the basis of its remarkable nmr spectrum. Being analogous to a diol, one might expect it to exhibit a great deal of hydrogen bonding between the hydroxyl hydrogen and methoxyl oxygen which lie in a *cis*-*exo* orientation favorable for such an interaction. The hydrogen bond in question is so strong that the proton spectrum in a non-protic solvent, CCl_4, displays an AB quartet for the $\text{-OH,H}_{2\text{-}\mathit{endo}}$ proton absorptions. This portion of the nmr spectrum is shown in Figure 22. By use of expanded scale 60 MHz nmr, coupling constants were determined. Coupling between the hydroxyl proton and the 2-*endo* proton is 7.8 Hz, and the 2-*endo* absorption is further split into doublets, revealing a 2-*endo*,7-*anti* coupling of 1.5 Hz. This confirms structure (LXI) rather than 2-*endo*-phenyl-3-*exo*-methoxy-2-norbornanol, because in such a compound hydroxyl, 3-*endo* coupling would be unlikely and certainly not of the magnitude 8 Hz.[20] The methoxy methyl protons absorb at 2.93 δ, considerably upfield as compared to that of benzyl methyl ether, 3.25 δ,[25] due to the shielding effect of its position with respect to the aromatic ring, an orientation required for the -O-H, $O\text{-}CH_3$ hydrogen bonding alignment.

In the infrared no-free hydroxyl stretching vibration is discernible, the hydroxyl stretch occurring at 3516 cm^{-1}, for a $\Delta\nu$ value of 104 cm^{-1} compared to the free hydroxyl stretch of 2-*exo*-norbornanol.[23]

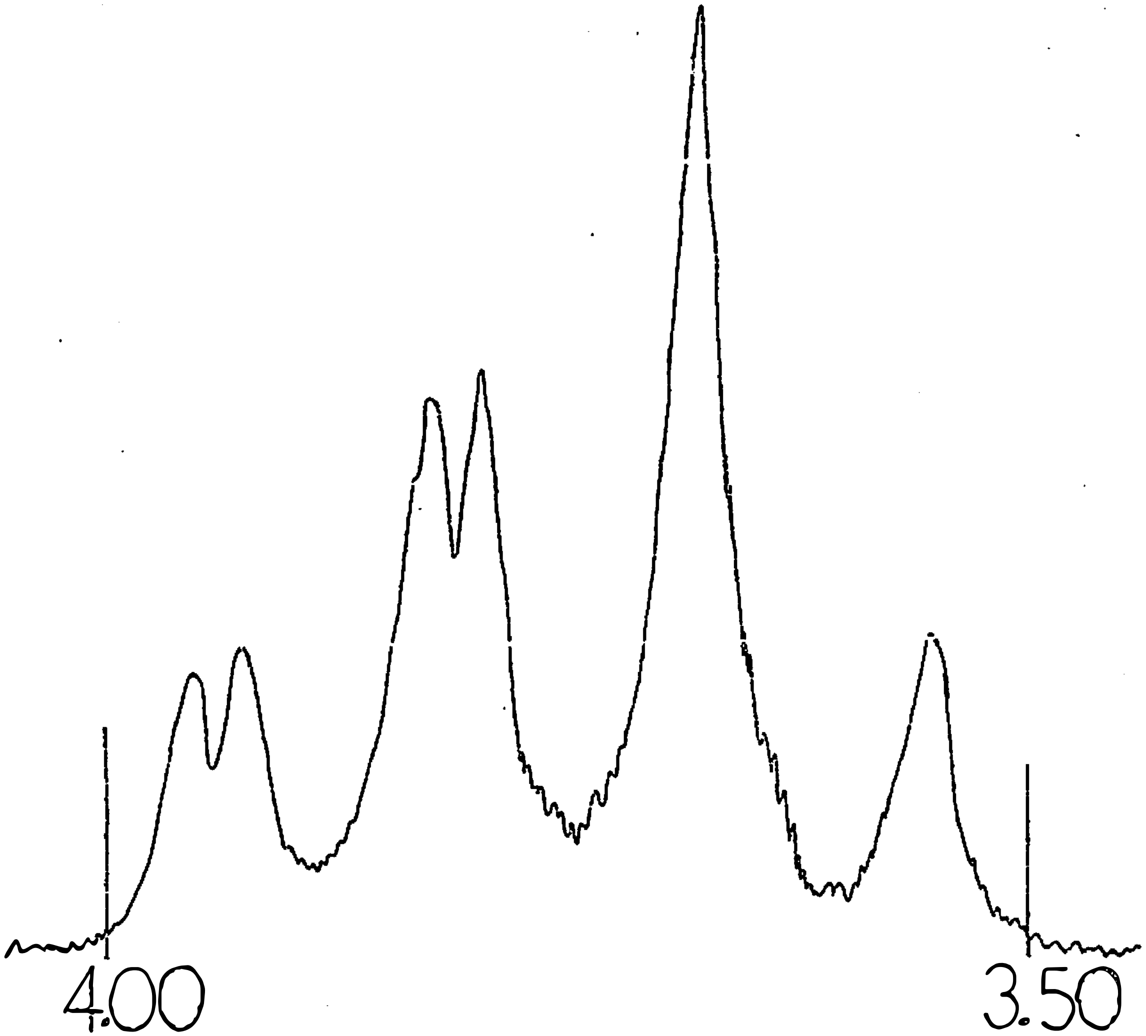
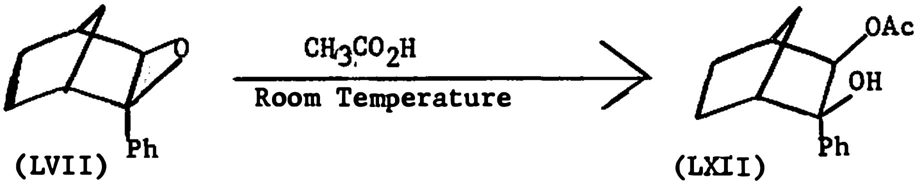


Figure 22. Hydroxyl and 2-endo proton absorptions in the nmr spectrum (100 Hz expansion, A60 nmr spectrometer) of 3-exo-methoxy-3-endo-phenyl-2-exo-norbornanol.

Reaction of the epoxide with acetic acid for six hours at room temperature afforded the hydroxyacetate, (LXII), as depicted in equation (22).



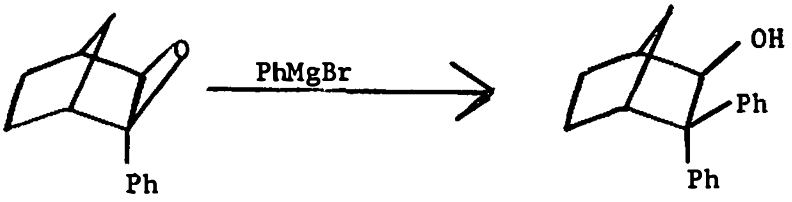
(LVII) (LXII) (22)

Assignment of structure (LXII) rather than the 2-acetoxy-3-hydroxy isomer was made on the basis of the nmr spectrum. The 3-*endo* proton absorbs at 5.17 δ while the 3-*endo* proton of 2-phenylnorbornane-2,3-*cis-exo*-diol absorbs at 3.98 δ.[26] One may expect a downfield shift of 1.-1.5 δ for the carbinol C-H upon going from the secondary alcohol to the acetate.[27] Hence, the acetate group is more than likely on the secondary carbon atom and the hydroxyl is on the tertiary carbon atom.

The reaction of 2-phenylnorbornene with buffered peracetic acid yielded (LXII), analogous to the same reaction with 2-*p*-anisylnorbornene.[28]

The phenyl epoxide reacted easily with lithium aluminum hydride in ether solvent, somewhat surprising in view of the difficulty of reduction of norbornene oxide itself. The reaction goes cleanly to yield 3-*endo*-phenyl-2-*exo*-norbornanol, a compound which has been reported.[29]

The reaction of phenylmagnesium bromide with (LVII) yielded 3,3-diphenyl-2-*exo*-norbornanol, (LXIII), in good yield, as shown in equation 23. Assignment of structure (LXIII) was made in view of the lack of a benzylic proton absorption in the nmr spectrum. A hydroxyl stretch is observed in the infrared at 3586 cm^{-1}, no free hydroxyl stretch being seen. This amounts to a $\Delta\nu$ value of 33 cm^{-1}, (relative to *exo*-norbornanol[33]) comparable to the value of 30 cm^{-1} for 3-*exo*-phenyl-2-*exo*-norbornanol.[30]



(LVII) (LXIII) (23)

D. *p*-Anisylcyclohexene Oxide

In view of the differences in chemical and spectral behavior of (LIV), (LVII), and (LVIII) it was felt that the *p*-methoxy substituent may exert some powerful influence upon the oxirane ring by virtue of extended conjugation.

p-Anisylcyclohexene, supplied by Dr. M. Watsky of this department yielded a hydroxyacetate upon reaction with buffered peracetic acid, and saponification afforded a diol; the first of these reactions being analogous to that of *p*-anisylnorbornene.[28] Reaction of the diol with hydrochloric acid in THF, however, led to the pinacol rearrangement product, 2-*p*-anisylcyclohexanone.

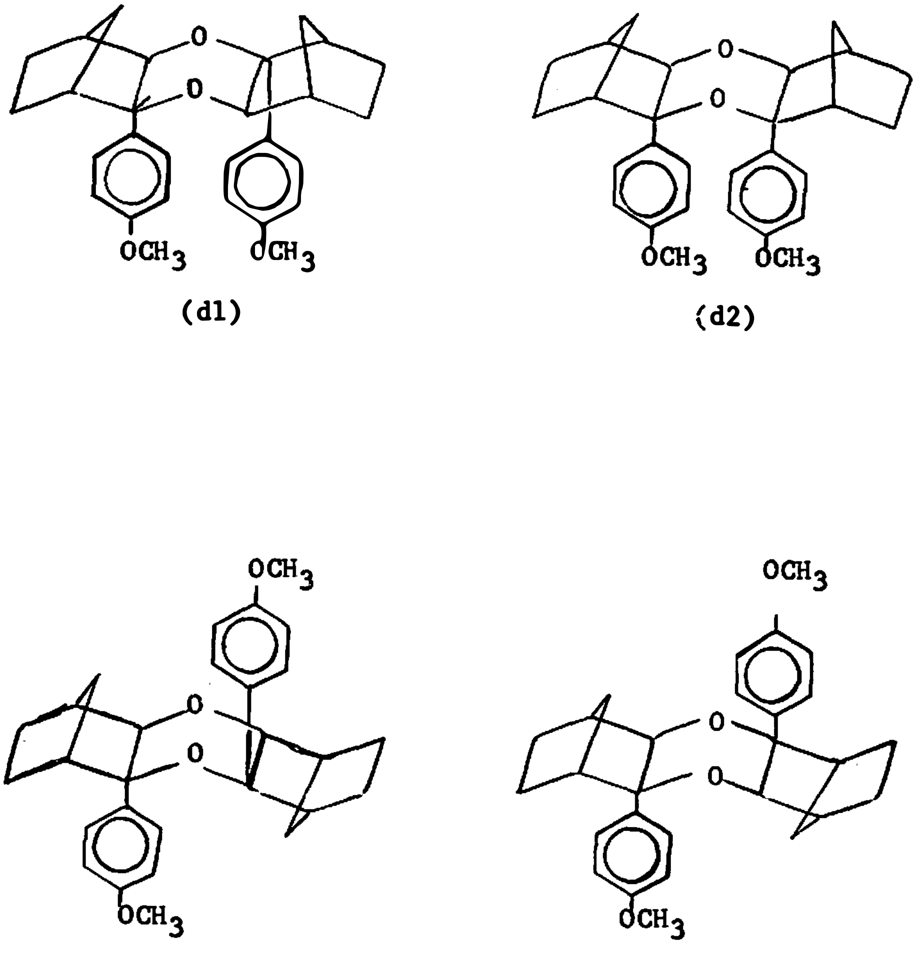
The *p*-anisylcyclohexene oxide was prepared from the olefin by the method of Payne and isolated in moderate purity as a pale yellow liquid. In a manner analogous to that of the 2-phenylnorbornene oxide, (LVII), the arylcyclohexene oxide added methanol across the carbon-oxygen bond.

D. Reassignment of the Structure of (LIV)

In view of the above mentioned anomalies, a reinvestigation of some of the rather fundamental data concerning (LIV) was undertaken. As mentioned in the introduction (p. 67), a molecular weight determination by the Rast method, (F. B. Strauss, Oxford, England), indicated a molecular weight somewhat below 200. In two separate molecular weight determinations by the vapor pressure osmometry method, (Galbraith Laboratories, Knoxville, Tenn.) values of 428 and 419, ($HCCl_3$ and THF solvents, respectively) were obtained.

The mass spectrum was redetermined but this time a scan was performed from m/e 450 down. A small m/e 432 peak was observed as well as m/e 232, 216, and 200. The mass spectral data are listed in Table XIX (p. 114).

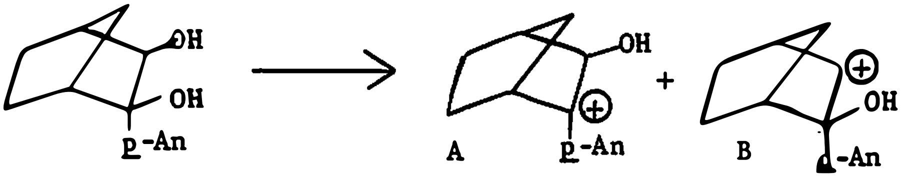
It soon became obvious that structure (LIV) was not the correct assignment for the high melting solid. Rather, the dimer of (LIV), structure (d1), (Figure 23, p. 112), fits all the data. Three other dimeric structures are also theoretically possible, and all four dimeric structures are shown in Figure 23. Structures (LIV)(d2) and (LIV)(d3) were determined indefensible on purely mechanistic grounds. In equation 23 the pathway necessary for the formation of these two isomers is shown. The formation of the secondary carbonium in step (23(B)) is indefensible, since it would be much less stable than the tertiary aryl carbonium ions solely involved in the alternative pathway, (equation 24).



(d1) (d2)

(d3) (d4)

Figure 23. Possible structures for the dimer of LIV.

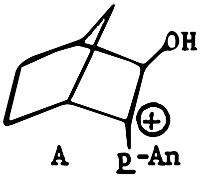


(23)

$$A + B \longrightarrow (LIV)(d2) \text{ or } (LIV)(d3)$$

Formation of isomer LIV(d3) would also require such an intermediate, and hence both structures are discarded as being of any consequence.

Structures LIV(dl) and LIV(d4), however, can be thought to form by pathway 24 depicted below.

2 

⟶ (LIV)(dl) or (LIV)(d4) (24)

Structure LIV(d4) may be excluded on the ground that the aryl rings must be <u>cis</u> with respect to one another, said <u>cis</u> orientation being required to explain the unquestionable evidence of restricted rotation and the extremely upfield absorptions of two of the protons at 6.42 δ and 6.53 δ

The dimeric dioxanate structure, LIV(dl), is compatible with the nmr and mass spectral data, Table XXV, and especially with the nonreactivity of the compound, its high melting point, and insolubility in some common organic solvents.

The probable mass spectral degradation pattern is depicted in Figure 24. The degradation is believed to follow a dual scheme, the

TABLE XXV

MASS SPECTRUM OF *p*-ANISYLNORBORNENE OXIDE DIMER

m/e	% Intensity
432 (P)	0.86
233	0.43
232	0.30
216 (m/2)	0.60
201	5.05
200	73.30
173	14.33
172 (Base)	100.00
157	11.28
135	19.76
128	6.36
121	8.85

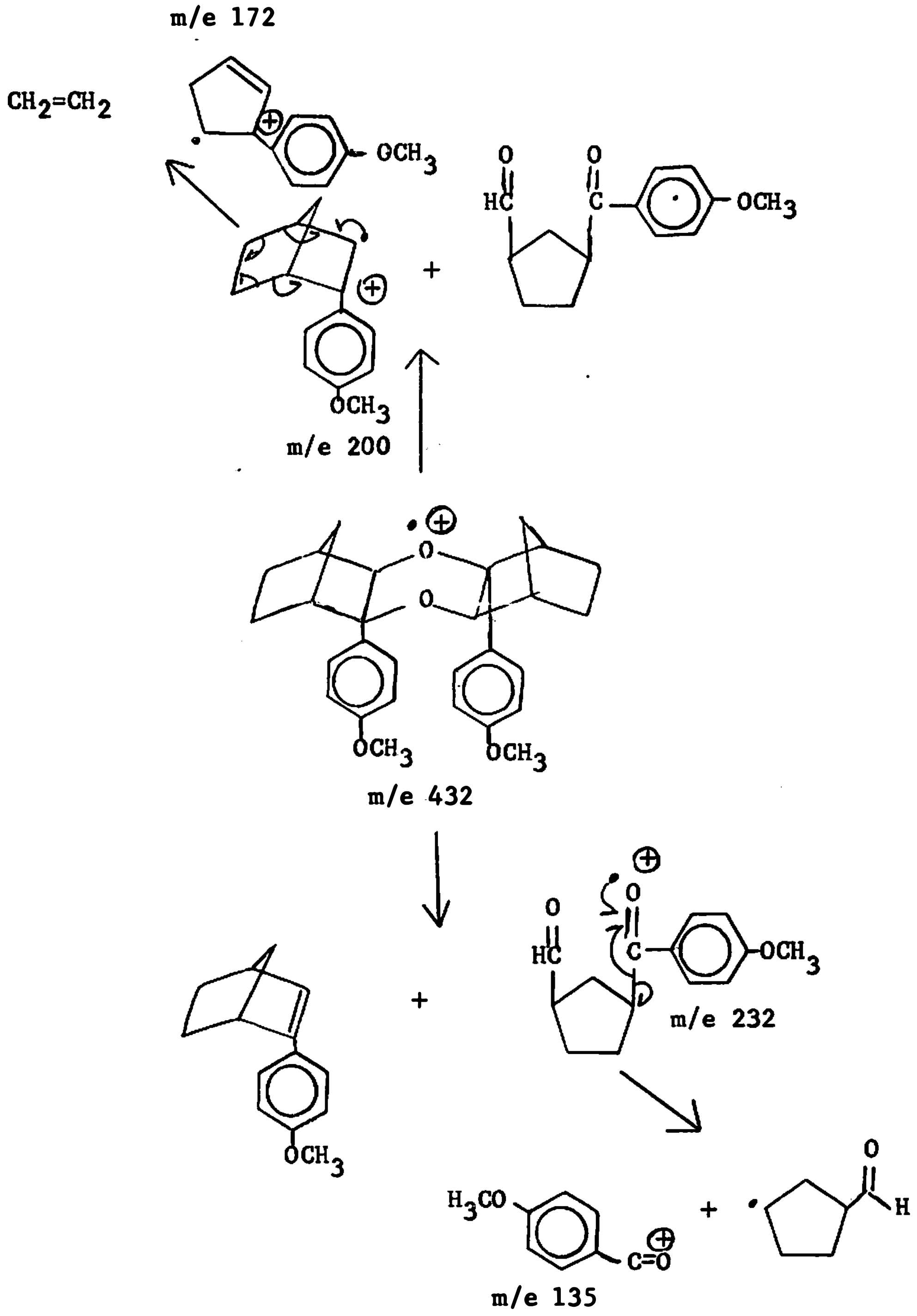


Figure 24. Mass spectral degradation of *p*-anisylnorbornene-2,3-*exo*-oxide dimer.

upper path being analogous to that of 1,4-dioxan itself, the main fragment of which corresponds to ionized ethylene.[31]

E. Note Added in Proof

During manuscript preparation a publication[41] appeared describing much the same conclusions expressed in Section E. Nonetheless, these results and observations were reported herein in view of the more complete nature and thorough analysis of the problem presented here.

CHAPTER III

EXPERIMENTAL

A. Introduction

The same remarks as regard melting points, uv, 60MHz nmr, mass, and ir spectra apply here as in Part A (p. 50).

The ultrahigh nuclear magnetic resonance spectra for the spin decoupling, computer matching, and high temperature experiments were obtained with the use of a Varian HA-100 nmr spectrometer, (University of Tennessee, Knoxville, Mr. Bill Peed, operator, and University of Sydney, Sydney, Australia, Dr. Sever Sternhell and G. C. Brophy, operators).

For the column chromatography, Alcoa "F-20" alumina was used on a 4' column with 1" bore, fitted with a teflon stopcock. Approximately 25 g alumina packing were used for every gram of crude mixture. The column was eluted with low boiling ligroin-ether mixed solvent.

B. Preparation and Reactions of Aryl Substitued Norbornene Oxides and Derivatives

1. <u>Preparation of the Dideuterio Derivative of (LIV) for Quantitative High Temperature Nuclear Magnetic Resonance Experiments</u>

a. Deuteration of anisole. Anisole (17.5 g, 0.162 mole) was treated with 105 ml _n_-butyllithium in cyclohexane solution (ca 0.168 M Foote Mineral Corporation) at reflux temperature under nitrogen for forty-eight hours according to the method of Hendrix.[33] Then, the mixture was cooled and hydrolyzed with 99.5% deuterium oxide (excess). The mixture was stirred for one hour, filtered, the organic phase separated, washed and dried. The solvent was evaporated and the above procedure was repeated exactly. This yielded a good quantity of 2,6-dideuterioanisole, the nmr of which indicates greater than 70% deuterium incorporation.

b. Bromination of dideuterioanisole. Some of the above product (5.51 g, 0.0510 mole) was brominated according to the method described by Shirley,[34] utilizing 2.93 ml (8.80 g, 0.0550 mole). A 64.0% (6.12 g) yield of 2,6-dideuterio-4-bromoanisole was obtained.

c. Further steps in the preparation of the deuterio derivative. As described by Dye[28] the bromoanisole was treated with magnesium, this adduct added to norcamphor, and the resulting alcohol dehydrated. The deuterated p-anisylnorbornene was treated with buffered peracetic acid, and the hydroxyacetate was reduced to the diol. The diol was treated in a manner analogous to that described by Kleinfelter and Long,[1] to yield the deuterio analog of (LIV).

2. Reaction of Buffered Peracetic Acid with 2-Phenylnorbornene

The alkene, (25.5 g, 0.150 mole), prepared according to the method of Kleinfelter,[29] was dissolved in 100 ml chloroform and cooled to -10°C. A slurry of 77.8 g (0.404 mole) 40% peracetic acid and 22.9 g anhydrous sodium sulfate was added slowly according to the method of Kleinfelter and Dye.[26,28,29] The solution was allowed to warm up to room temperature and was stirred overnight, and then excess sodium bisulfite was added, and the mixture was poured into water. The resulting aqueous mixture was extracted with chloroform with heavy salting of the aqueous phase. Drying of the organic phase and flash evaporation yielded 30.1 g of yellowish orange oil, the ir of which showed hydroxyl and acetoxyl functions and nmr of which showed it to be 2-*endo*-phenyl-3-*exo*-acetoxy-2-norbornanol. The yield of crude oil product was 82.7%.

Infrared data: 3472, 2900, 1739, 1370, 1234, 1140, 765, and 695 cm^{-1}(CS_2).

Nmr data, (ca 10% (w/v)CCl_4): 7.24 δ (multiplet, aryl), 5.05 δ (doublet, $H_{3\text{-}endo}$), 2.23 δ (H_1,H_4), 1.85 δ (sharp singlet, acetoxy methyl), 0.8-1.5 δ (complex multiplet, H_5, H_6, H_7).

3. Reaction of *meta*-Chloroperbenzoic Acid with 2-Phenylnorbornene

The olefin (5.00 g, 0.0290 mole) was dissolved in 50 ml chloroform in a flask equipped with a dropping funnel, reflux condensor, magnetic stirrer, and a methanol-ice cooling bath. To this solution was added 11.1 g (0.0770 mole) sodium benzoate and the temperature was brought to -10°C. The peracid, (10.5 g, 0.0610 mole) purified by washing with a phosphate buffer of pH 7.5,[35] was added dropwise as a solution in 130 ml chloroform. A gentle temperature rise was noted upon addition, and the mixture stirred in the cold for 1.5 hrs. Next, 100 ml of 20% sodium bisulfite solution was added, followed by solid sodium bicarbonate to effect neutrality, and the mixture was allowed to warm up to room temperature. This mixture was extracted with chloroform, the extracts washed, dried, and the solvent flash evaporated. A yellowish oil was obtained (4.10 g), the ir of which revealed both hydroxyl and ester carbonyl functions to be present. The nmr spectrum indicated a possible mixture of the desired epoxide and 2-*endo*-phenyl-3-*m*-chlorobenzoyloxy-2-norbornanol. No further attempt at characterization was undertaken.

4. Payne Oxidation of 2-Phenylnorbornene

The method of Payne[16] was employed for the epoxidation. In a 500 ml round bottomed flask equipped with a dropping funnel, magnetic stirrer, ice bath, and nitrogen atmosphere was placed 54 ml anhydrous methanol, 90.3 g (9.00 ml, 0.0900 mole) benzonitrile, 1.50 g potassium bicarbonate and 15.0 g (0.0810 mole) 2-phenylnorbornene. The temperature was brought to +10°C and maintained during the addition of 6.12 g (6.00 ml, 0.0900 mole) 50% hydrogen peroxide. Stirring at this temperature under the inert atmosphere was continued for forty-eight hours. The resulting white suspension was poured onto ice, extracted with chloroform, and then ether. The extracts were combined, dried over anhydrous sodium sulfate and flash evaporated. A yellow oil resulted, to which carbon tetrachloride was added to precipitate the by-product, benzamide. After filtration, the filtrate was flash evaporated and the residual oil was vacuum distilled. The yield was 12.6 g (84.0%) of clear colorless oil. bp 100-105°C (0.8 mm). The product was identified as 2-phenylnorbornene-2,3-*exo*-oxide, on the basis of its nmr and ir spectra.

Infrared data: 2941, 1307, 1268, 1136, 1125, 1086, 1069, 1028, 982, 962, 943, 922, 895, 863, 829, 797, 770, 757, 750, 736, 692, and 667 cm^{-1} (CS_2).

Nmr data: See Table XVII (p. 89).

Uv data: See Table XVIII (p. 91).

5. Payne Oxidation of 2-*p*-Chlorophenylnorbornene

The 2-*p*-chlorophenylnorbornene (mp 50-51 C) was prepared by D. C. Kleinfelter in a manner analogous to that of the 2-phenylnorbornene.

A procedure identical to that of the 2-phenylnorbornene was utilized to prepare the epoxide using 5.51 g (0.0300 mole) olefin, 3.01 g (3.00 ml, 0.0300 mole) benzonitrile, 2.04 g (2.00 ml, 0.0300 mole) 50% hydrogen peroxide, 18 ml methanol and 0.50 g potassium bicarbonate. The mixture was stirred at 0° C for sixty hours under an atmosphere of nitrogen. The solution was then poured onto ice and a white gummy solid was obtained which eventually crystallized. Upon filtration, 2.83 g crude product was obtained. This material was recrystallized from ligroin to yield white needles, mp 44-45° C. Nmr and ir analyses were very similar to those of the phenylnorbornene oxide. The yield was 48.0%.

Infrared data: 2935, 1093, 1011, 983, 957, 942, 916, 895, 862, 846, 810, 768, and 722 cm^{-1} (CS_2).

Nmr data: See Table XVII (p. 89).

Anal. Calcd. for $C_{13}H_{13}OCl$: C, 70.75; H, 5.90; Cl, 16.10. Found: C, 70.48; H, 5.83; Cl, 16.11.

6. Lithium Aluminum Hydride Reduction of 2-Phenylnorbornene-2,3-*exo*-Oxide

To a slurry of 0.80 g (0.013 mole) lithium aluminum hydride and 10 ml dry ether in a round-bottomed flask equipped with a magnetic stirrer and condensor was added dropwise a solution of 0.98 g (0.0053 mole) of the epoxide in 20 ml ether. The mixture was heated to reflux by the heat of the magnetic stirrer and stirred overnight. The resultant mixture was cooled and poured onto 150 ml crushed ice. Excess ether was added and the mixture filtered. The organic phase of the filtrate was isolated, washed, and dried. Flash evaporation of the solvent yielded 0.76 g of white oil which crystallized upon cooling. Recrystallization from ligroin gave a white solid, mp 50.5-52° C. The ir and nmr spectra were identical to those reported[29] for 3-endo-phenyl-2-exo-norbornanol (lit mp 52-53°C).[29] A total yield of 0.60 g (60%) of the phenylnorbornanol was realized.

7. Reaction of Phenylmagnesium Bromide with 2-Phenylnorbornene-2,3-exo-Oxide

The Grignard reagent was prepared from 9.42 g (6.30 ml, 0.0600 mole) bromobenzene and 1.92 g (0.0800 mole) magnesium in dry ether as described in the experimental section of Part A (p. 52). The organometallic reagent solution was refluxed for 2.5 hours and then cooled. To the cold solution was added an ethereal solution of 5.00 g (0.0270 mole) of the phenyl-substituted norbornene oxide. Adduct formation was noticeably exothermic, the solution changed color from black to light brown, and a copious precipitate was noted. This mixture was refluxed for eighteen hours, then cooled and hydrolyzed with cold water. The mixture separated into two layers, a white aqueous phase, and a yellow, upper, organic layer. The phases were separated, the aqueous phase extracted twice with ether and the organic extracts combined with the original organic phase. This solution was washed twice with water, then dried. Filtration and flash evaporation of filtrate yielded a yellow oil. Nmr analysis of this crude oil product indicated it to be 2,3-diphenyl-2-exo-norbornanol. The crude oil was purified by column chromatography whereby the hydrocarbon by-products (i.e. biphenyl) were removed with ligroin. Subsequent elution with pure ether yielded the pure diphenylnorbornanol as a white oil, (5.00 g, 70.4%). A portion of this was crystallized from ether. Two further recrystallizations from ether gave a white crystalline solid, mp 77.5-77°C. Only a bonded hydroxyl vibration was seen in the O-H stretching vibrational region of the ir, centered at 3586 cm^{-1}.

Infrared data: 3586 (±2 cm^{-1}, CCl$_4$), 1599, 1299, 1230, 1130, 1072, 1042, 1010, 879, 765, 757, 744, 734, 718, 704, 696, 674, and 653 cm^{-1} (CS$_2$).

Nmr data (ca 15% (w/v)CCl$_4$): 7.12 δ (multiplet, aryl protons), 4.43 δ (H$_{2\text{-}\underline{endo}}$), 3.07 δ (H$_1$), 1.98 δ and 2.20 δ (AB doublet, H$_4$, H$_{7\text{-}\underline{syn}}$), 0.8 - 1.6 δ (H$_5$, H$_6$, H$_{7\text{-}\underline{anti}}$).

Anal. Calcd. for C$_{19}$H$_{20}$O: C, 86.32; H, 7.63. Found: C, 86.08; H, 7.66.

8. Reaction of Acetic Acid with 2-Phenylnorbornene-2,3-*exo*-Oxide

The epoxide, (0.60 gm, 0.0032 mole), was dissolved in 30 ml glacial acetic acid and this solution was stirred at room temperature for six hours by means of a magnetic stirrer. Then, the mixture was poured onto 400 ml ice and this aqueous suspension was extracted with ether. The organic layer was washed with water, neutralized with sodium bicarbonate solution, washed again with water, and dried. Flash evaporation of the solvent yielded 0.82 g (94%) of pale yellow oil. The ir and nmr spectra of this oil were identical to those of 2-*endo*-phenyl-3-*exo*-acetoxy-2-norbornanol, (p.119).

9. Methanolysis of 2-Phenylnorbornene-2,3-exo-Oxide

The epoxide, (5.0 g, 0.027 mole), was dissolved in 40 ml absolute methanol and stirred for forty-eight hours. At the end of this time the solution was poured into ice water. This aqueous suspension was extracted with ether, the organic layer separated, washed with water, and dried. Flash evaporation of the solvent yielded 6.2 g crude yellow oil which was vacuum distilled, yielding 5.7 g clear, colorless oil (bp 108-110°C, 0.6 mm). Nmr and ir analyses proved the structure to be that of 3-*endo*-phenyl-3-*exo*-methoxy-2-*exo*-norbornanol.

Infrared data: 3516 (±2 cm^{-1}), (CCl_4), 2940, 1389, 1285, 1258, 1128, 1086, 1009, 994, 950, 919, 902, 768, 756, 733, and 702 cm^{-1}, (CS_2).

Nmr data, (ca 20% (w/v) CCl_4): 7.41 δ (multiplet, aryl), 3.98 δ (doublet of doublets, $H_{2\text{-}\underline{endo}}$), 2.93 δ (singlet, OCH_3), 2.83 δ (H_1, (?)), 2.08 δ (H_4, $H_{7\text{-}\underline{syn}}$ (?)), 0.9-1.7 δ (complex multiplet, H_5, H_6, $H_{7\text{-}\underline{anti}}$).

A tosylate was prepared, and recrystallized three times from ether, yielding a white, crystalline material, mp 135-137°C.

Anal. Calcd. for 2-*exo*-tosyloxy-3-*endo*-phenyl-3-*exo*-methoxy-norbornane, $C_{21}H_{24}SO_4$: C, 67.47; H, 6.45. Found: C, 67.71; H, 6.43.

C. Preparation and Methanolysis of p-Anisylcyclohexene

1. Reaction of Buffered Peracetic Acid with p-Anisylcyclohexene

To 10.0 g (0.0540 mole) *p*-anisylcyclohexene, mp 50-51 C, generously supplied by Dr. M. Watsky, (prepared by the $KHSO_4$ dehydration of 1-*p*-anisylcyclohexanol) dissolved in 20 ml chloroform was added a slurry of 12.5 ml peracetic acid (40%), (0.0660 mole), and 2.5 g powdered anhydrous sodium acetate according to the procedure of Dye.[28] The temperature was maintained at 0°C during addition and then continued at 10°C for sixteen hours. Excess sodium bisulfite and sodium bicarbonate were then added and the mixture was extracted with chloroform. The organic layer was washed, dried, and the solvent flash evaporated. This yielded 11.5 g of yellowish white oil, which solidified into a hard mass on standing for a few minutes. This material was recrystallized from ligroin (bp 60-80°C), giving 8.24 g fluffy white crystals, mp 194-196°C.

The infrared spectrum of this compound showed both hydroxyl and acetoxyl moities to be present. The nmr suggested that the compound had a tertiary hydroxyl and secondary acetoxyl group due to the absorption at 5.27 δ. The corresponding proton of cyclohexanol absorbs at 3.51 δ,[36] while that of the acetate absorbs at 4.58 δ.[36] Such a downfield absorption would probably be due to the proton adjacent to an acetoxyl group rather than a hydroxyl group. The yield was 58%.

<u>Infrared data</u>: 3505, 2920, 1738, 1568, 1335, 1268, 1218, 1147, 1076, 1040, 993, 972, 948, 868, 852, 826, 803, and 795 cm^{-1} (CS_2).

<u>Nmr data</u> (ca 5% (w/v) CCl_4): 7.10 δ (AA'BB' quartet, aryl), 5.27 δ (H_2), 3.81 δ (OCH_3), 1.78 δ (acetoxy-CH_3), 1.5-2.1 δ (ring protons).

<u>Anal</u>. Calcd for $C_{15}H_{17}O_4$: C, 68.16; H, 7.63. Found: C, 67.90; H, 7.26.

2. Saponification of 1-p-Anisyl-2-acetoxy-cyclohexanol

The saponification procedure of Kleinfelter and Schleyer was employed.[37] The hydroxyacetate (6.6 g, 0.025 mole) was added to a solution of 2.1 g (0.038 mole) potassium hydroxide in 15 ml of water and 96 ml 95% ethanol. The solution was contained in a round-bottomed flask equipped with a condensor and heating mantle and was brought to reflux. Refluxing was maintained for 2.5 hrs and then the ethanol was evaporated on the steam cone. The resulting concentrate was poured onto 500 ml ice and the resultant mixture filtered. The mass of yellowish crystals obtained was taken up in chloroform and ligroin was added to the saturation point. In this manner, 4.25 g (75%) white, solid diol, mp 100-102°C (lit. value 106-107°C)[39] were obtained. No carbonyl absorption could be observed in the ir.

Infrared data: 3505, 2938, 1615, 1511, 1469, 1450, 1306, 1248, 1212, 1178, 1111, 1070, 1058, 1037, 1000, 972, 869, 832, and 807 cm^{-1} ($HCCl_3$).

Anal. calcd. for $C_{13}H_{17}O_3$; C, 70.24; H, 8.16. Found: C, 70.49; H, 8.23.

3. Reaction of 1-p-Anisylcyclohexane Diol with HCl/THF

The diol, 1.5 g,(0.0070 mole) was dissolved in 10 ml THF. To this was added 5 ml conc hydrochloric acid, and a color change to yellow and a temperature rise were noted. The solution was heated with steam for 10 minutes during which time the color changed to green. More water was added (10 ml), and heating was continued until a brown oil settled from the solution. The solution was cooled in an ice bath, water added, and a yellow, crystalline product was obtained, which was filtered and recrystallized from ligroin bp 60-80°C. The infrared spectrum showed a strong carbonyl absorption and no hydroxyl stretch was observed. The compound was assumed to be the pinacol rearrangement product, 2-p-anisylcyclohexanone. A second recrystallization gave pale yellow crystals, (0.70 g, 50%), of mp 87-88°C, (lit. value 89.5-90°C).[40]

Infrared data: 2935, 1719, 1610, 1250, 1182, 1126, 1045, 834, 824, 817, and 807 cm^{-1} (CS_2).

Anal. Calcd. for $C_{13}H_{15}O_2$: C, 76.44; H, 7.90. Found: C, 76.45; H, 7.74.

4. Payne Oxidation of p-Anisylcyclohexene

A mixture of 10.0 g (0.0530 mole) of the olefin, 4.90 g (5.10 ml), (0.0530 mole), benzonitrile, 1.02 g potassium bicarbonate, and 40 ml absolute methanol were placed in a round-bottomed flask equipped as in the case of 2-phenylnorbornene, p. 120. Through the dropping funnel were added 3.82 g (4.00 ml, 0.0530 mole) 50% hydrogen peroxide. This mixture was stirred at room temperature for twelve days, at the end of which time it was poured onto ice. This aqueous suspension was extracted with ether and the organic layer dried. Flash evaporation of the solvent gave a yellow oil. The nmr spectrum of the oil gave evidence of the epoxide by virtue of the broad singlet centered at 3.10 δ due to the oxirane CH (analogous proton in cyclohexene oxide, 3.05 δ).[38] A small amount of olefinic impurity was present as evidenced by a small absorption at 5.95 δ (olefinic proton of p-anisylcyclohexene). The oil was taken up in low boiling ligroin, charcoaled, and the solution cooled in a dry ice-acetone bath. An impure, low melting solid was obtained, which was recrystallized, giving 3.0 g white crystalline material which melted at room temperature. The nmr spectrum of this oil indicated the pure epoxide due to the absence of olefinic absorption. The yield was 28.0 %.

Infrared data: 2900, 1637, 1315, 1180, 1041, 993, 972, 889, 847, 829, 802, and 789 (CS_2).

Nmr data (ca 15% (w/v) CCl_4): 7.17 δ (AA'BB' quartet, aryl protons), 3.82 δ (sharp singlet, OCH_3), 3.10 δ (triplet, H_2), 1.33-2.62 δ (cyclohexyl protons).

4. Methanolysis of p-Anisylcyclohexene Oxide

The oxide, 1.0 g,(0.0049 mole), was dissolved in 10 ml absolute methanol and stirred at room temperature by means of a magnetic stirrer for four days. The solution was poured into water and the organic compound was extracted with ether. The ether layer was washed with water and dried. The solvent was flash evaporated yielding 0.73 g yellow oil. The infrared spectrum showed a strong hydroxyl peak. The nmr spectrum was poorly resolved but showed no oxirane hydrogen absorption. Two alkyl methoxyl peaks were observed in an approximate 3:1 ratio. A diffuse hydroxyl peak was detected by exchange with deuterium oxide. This suggests the oxirane ring of this compound can be opened with methanol as with the 2-phenylnorbornene oxide. No further attempt at characterization was made.

Infrared data: 3510, 2938, 1609, 1304, 1252, 1210, 1181, 1111, 1085, 1045, 995, 916, 874, 823, 805, and 795 cm^{-1} (CS_2).

Nmr data (ca 15% (w/v) CCl_4): 7.08 δ (overlapped AA'BB' quartets, aryl protons), 3.68 δ (sharp singlet, aryl OCH_3), 2.83 δ, 2.92 δ (sharp singlets, alkyl OCH_3's), 1.0-2.1 δ (complex multiplet, cyclohexyl protons).

D. Attempted Preparations of 2-p-Anisylnorbornene-2,3-exo-Oxide

1. Reaction of m-Chloroperbenzoic Acid with 2-p-Anisylnorbornene.[28]

A procedure analogous to that with 2-phenylnorbornene, p. 119, was employed utilizing 5.4 g (0.027 mole) 2-p-anisylnorbornene, 98 ml chloroform, 5.6 g sodium benzoate, and 5.3 g, (0.031 mole), purified m-chloroperbenzoic acid. The reaction time was one hour and upon usual workup 5.0 g of white oil was obtained, the nmr and ir spectra of which indicated a hydroxy-m-chlorobenzoate.

2. Payne Oxidation[16] of 2-p-Anisylnorbornene

An anologous procedure to that used for 2-phenylnorbornene (p. 120) was followed utilizing 5.0 g, (0.025 mole of the olefin, 2.7 g, (0.027 mole), benzonitrile, 0.43 g potassium bicarbonate, and 1.8 g, (0.027 mole, 1.9 ml), 50% H_2O, and 18 ml MeOH. The temperature was maintained at 0°C for sixty hours. Workup in the usual manner yielded an oil, the spectrum of which indicated at least three components, i.e., three distinct aryl methoxyl peaks . No further attempt at characterization of the mixture was undertaken.

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