The Acetolysis of *cis*- and *trans*-9-*t*-Butylspiro-[4.5]dec-6-yl *p*-Toluenesulphonate

A THESIS

PRESENTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in the

UNIVERSITY OF ADELAIDE

by

MOSTYN HENRY LAFFER B.Sc. (Hons.)

Department of Organic Chemistry

1971

CONTENTS

SUMMARY

This thesis is presented in two parts.

The first section deals with a kinetic and product study of the acetolysis of cis- and trans-9-t-butylspiro[4.5]-dec-6-yl p-toluenesulphonate. Methods of identification of the products are described and an attempt to rationalize the kinetic results and product distribution has been made. It is suggested that chair and non-chair conformations may be important in the acetolysis of the two esters and that both the conformations of the derived cations and the position of the counter-ions in [redacted] ion pairs are important in the determination of the products. The importance of the configuration of the leaving group in the above rigid systems has been confirmed by the formation of ring-contracted products (ca. 10%) (3-t-butylcyclopentylidene)cyclopentane and (3-t-butylcyclopentyl)cyclopent-1-ene from the trans-ester, in which a suitable trans-anti-planar arrangement of the leaving and migrating group exists. No products of ring contraction were formed in the case of the cis-ester.

The second part of the thesis describes synthetic routes to some 9-t-butylspiro[4.5]dec-6-yl, (3-t-butylcyclo-pentyl)cyclopentyl and 2-t-butyldecalyl systems which were required for the solvolytic study in part one.

The work presented in this thesis represents a detailed study of the acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate and the results differ significantly, in certain aspects, to a recent less detailed report in the literature.

STATEMENT

This thesis contains no material previously submitted for a degree or diploma in any University and to the best of my knowledge and belief contains no material previously published or written by another person, except where due reference is made in the text.

MOSTYN H. LAFFER.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr. G. E. Gream for his guidance and interest during the supervision of this work. I also wish to thank my wife, Margaret, for her untiring encouragement and help.

Grateful acknowledgement is made of the support of a Commonwealth of Australia Postgraduate Award.

INTRODUCTION

I.1.

Since the proposal by Baeyer and Villiger[1,2] that the coloured species, present in solutions of triphenylmethyl derivatives in concentrated sulphuric acid were salt-like in structure, the chemistry of carbonium ions has received detailed attention.[3,4,5,102]

Neighbouring group participation[6] has been used in many instances to explain enhanced rates in solvolytic reactions,[7-13] increased tendency toward rearrangement[14] and to rationalize the stereospecificity of product formation.[15,16b-20] The increase in rate has been explained in terms of anchimeric assistance,[21] a phenomenon which relates to the attainment of the transition state and does not necessarily indicate the intermediacy of a non-classical[22,23] carbonium ion.

Since the classical example of neighbouring group participation, reported by Winstein and Lucas,[16] in the reaction of isomeric 3-bromobutan-2-ols with hydrobromic acid, many other examples of participation by groups possessing lone-pair electrons have been investigated. These include the benzamido[24], acetoxyl[25], carbonyl[26], amino[27], acetal[28], ester[29], thio-ester[30,31], acyl[32] and silyl[33] groups. Extensive work showed that participation was not restricted to compounds containing the above type of functional groups and anchimeric assistance to ionization

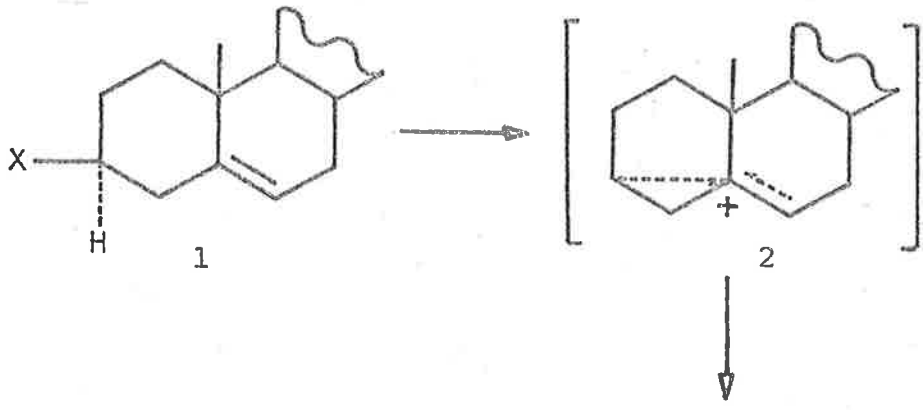
by alkyl groups and olefinic bonds led Winstein[34] to suggest the terms sigma (σ) and pye (π) routes, in order to distinguish between these two solvolytic processes.

The participation of olefinic π-electrons in cationic reactions of allylic[35] and homoallylic[36,37,38] compounds has been recognized for some time. In 1946, Shoppee[39] reported that nucleophilic substitution of cholesteryl chloride (1, X=Cl), under ionic conditions, proceeded with retention of configuration, which he attributed to a homoallylic interaction of the incipient cation and the Δ^5-olefinic bond. After further investigation of the cholesteryl system, Winstein and co-workers[40,41] proposed that participation by the electrons in the olefinic bond gave the bridged non-classical cation (2).* (Scheme I.1.) This was in contrast with the solvolysis of the epicholesteryl derivatives (1 where X is in the a-position) in which participation by the π-electrons was not evident.[42]

An early example of participation by a remote double bond was reported by Le Ny[43] in 1960, when she found that the acetolysis of cyclohept-4-enylmethyl p-bromobenzene-

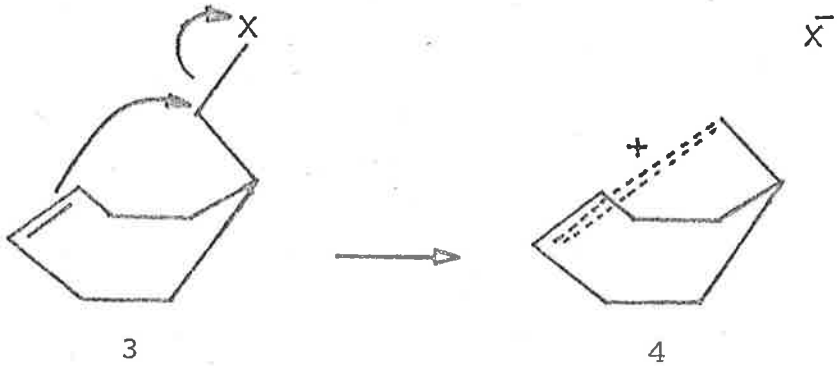
---

* Quantum mechanical calculations indicate that this ion will be stabilized by overlap of the p-orbital of the carbonium ion at carbon-3 and the π-orbitals of the double bond.[37]



Scheme I.1.

sulphonate (3, X=OBs*) proceeded some thirty times faster than the saturated analogue and yielded a single cyclic acetate, endo-bicyclo[3.2.1]octan-2-yl acetate, whose configuration was consistent with the intervention of the bridged cation (4). (Scheme I.2.) A similar intermediate (4)



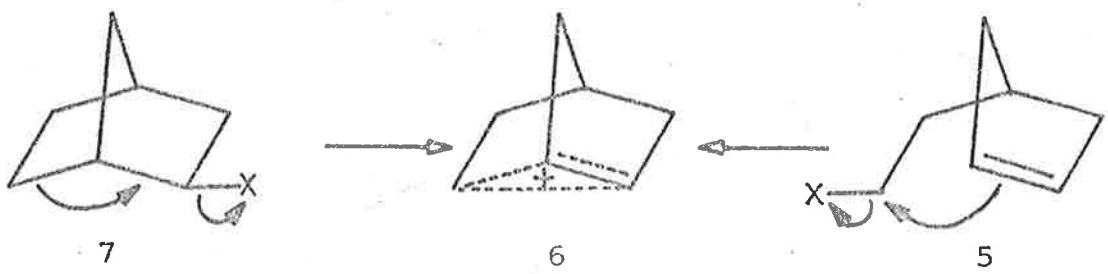
Scheme I.2.

---

* OBs = p-bromobenzenesulphonyloxy

has also been suggested in the ionic reactions of endo-(equatorial)-bicyclo[3.2.1]octan-2-yl derivatives (σ-route).[44]

Great interest was aroused when Lawton[45] and Bartlett[46] both showed that solvolysis of 2-(cyclopent-3-enyl)ethyl derivatives (5, X=OTs[46] and ONs[45])* involved the anchimerically assisted formation of a mesomeric norbornyl cation (6) (ref. 47 and 48) and that the rates of reaction exceeded those of the corresponding saturated analogues (7) by factors ranging from 6 to 1900, depending on the solvent. This was a clear example of the formation of apparently the "same" (or at least a closely related) cation by independent π and σ routes.[34] (Scheme I.3.)



Scheme I.3.

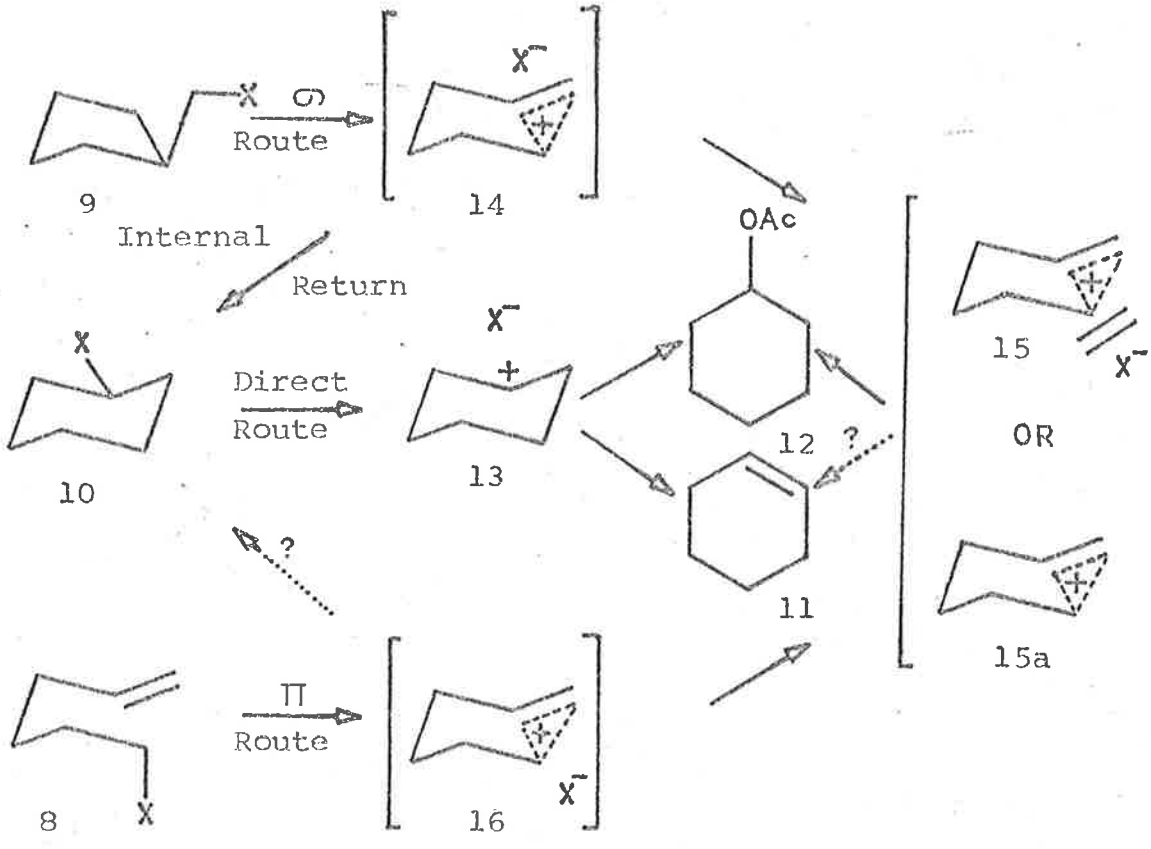
---

* OTs = p-toluenesulphonyloxy

ONs = p-nitrobenzenesulphonyloxy

This gave great impetus to the study of double bond participation in solvolytic reactions[49-53] and consequently many recent investigations have dealt with a comparison of cationic intermediates generated by σ, π and direct routes.[54-59] Two examples of this work will now be examined in more detail.

Bartlett, Closson and Cogdell[60] investigated the acetolysis of hex-5-enyl (8, X=ONs), cyclopentylcarbinyl (9, X=ONs) and cyclohexyl (10, X=ONs) p-nitrobenzene--sulphonates, all of which yield cyclohexyl derivatives by π, σ and direct pathways respectively. (Scheme I.4.)

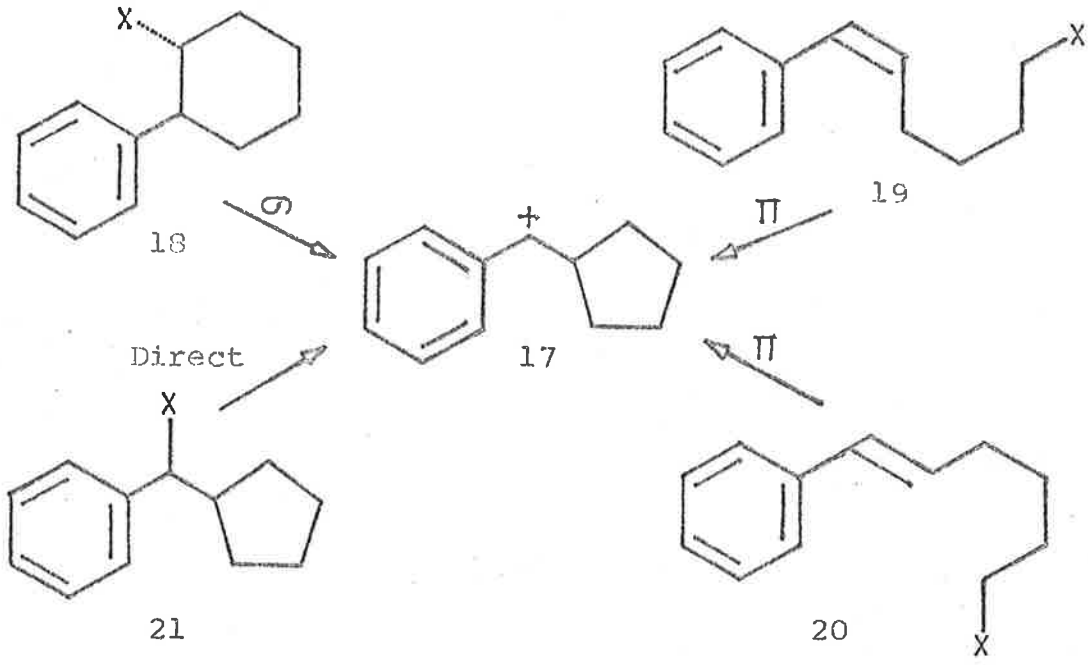


Scheme I.4.

They found that the ratio of cyclohexene (11) to cyclohexyl acetate (12) was 0.40, 3.4 and 6.7 for the esters (8, X=ONs), (9, X=ONs) and (10, X=ONs) respectively and concluded that this was not consistent with the intermediacy of a common cation. An explanation was proposed in terms of the position of the counter-ion in the two species (14) and (16) and the nature of the product-determining intermediates. The authors suggested that the cyclohexyl cation (13) was formed, in a simple heterolytic process from (10, X=ONs) (direct route), and yielded (11) and (12) in the usual manner. In the case of the cation (14) (σ route), the counter-ion is in a suitable position to undergo internal return to (10, X=ONs) or alternatively (14) could give the solvent separated ion pair (15) or the free cation (15a), which, the authors suggest, are not "geometrically favourable precursors for cyclohexene". The position of the counter-ion in the intimate ion-pair (16) is not ideal, however, for internal return to (10) and thus the products should arise mainly from (15) or (15a).

Recently Roman and Closson[61] have compared the σ,π and direct routes to the cyclopentylphenylcarbinyl cation (17) which is generated in the solvolytic reactions of trans-2-phenylcyclohexyl p-toluenesulphonate (18, X=OTs), cis- and trans-6-phenylhex-5-enyl p-bromobenzenesulphonates (19 and 20 where X=OBs, respectively) and cyclopentylphenyl-

carbinyl p-toluenesulphonate (21, X=OTs). (Scheme I.5.)



Scheme I.5.

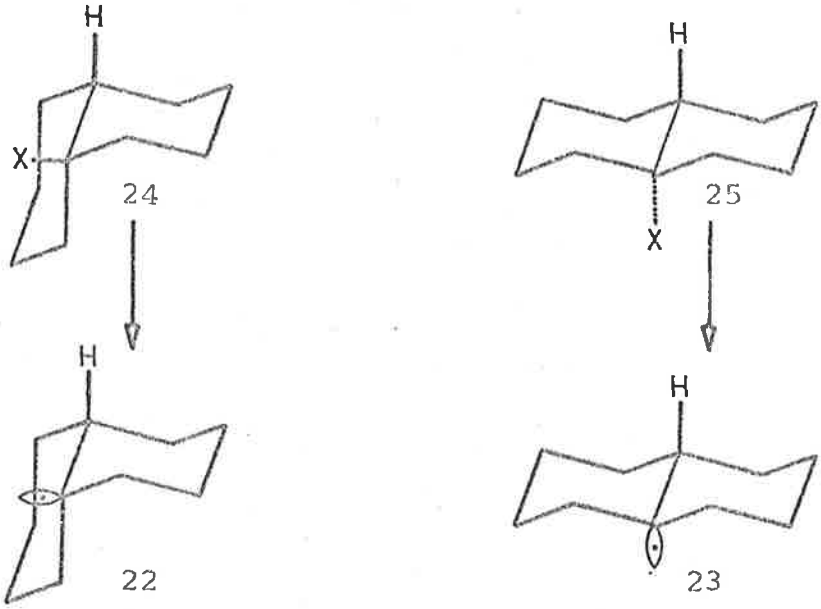
They reported that the benzylic cation (17), which might be expected to be relatively stable, compared to a simple secondary aliphatic ion, retained "a clear memory of its route of formation"; however, contrary to the usual observations,[57,60,62] the π routes (19 and 20 where X=OBs, respectively) yielded a higher proportion of elimination products than the other routes. Furthermore, the deamination of (21, $X=NH_2$) resulted in approximately the same amount of substitution and elimination as from the "cool" σ route (21, X=OTs). These observations were not consistent solely with the involvement of an intimate ion-pair in which the counter-ion behaved as a base in abstracting a proton to

give olefinic material.[63,64]

The authors suggested an explanation in terms of the relative energetics of the Π and σ routes. They considered that the ion formed by the Π route was both classical, as opposed to non-classical, and "hot". This extra energy could be manifested as molecular distortions or in unencumberance[65] of the ion, which could "lead to a lowering of the selectivity of the cation in its subsequent reactions". This postulate was consistent, it was reasoned, with the frequent similarity in the product distribution obtained from solvolytic reactions involving σ-deamination and Π routes;[62] differences between the two were ascribed to minor conformational and solvation effects.

The general interest in the comparison of solvolytic reactions, proceeding by σ, Π and direct routes, has stimulated investigations, both in these laboratories and elsewhere, into the nature and conformational integrity of the 9-decalyl cation (26), generated by these processes.

Further impetus was given to this work when Bartlett et.al.[66] proposed the transient intermediacy of two conformationally distinct tetrahedral[121] 9-decalyl radicals (22 and 23) in order to explain the results of the thermal decomposition of cis- and trans-9-carbo-t-butylperoxydecalin (24 and 25 where X=$CO_3C(CH_3)_3$, respectively). (Scheme I.6.) This conclusion was confirmed in essence by Greene and



Scheme I.6.

Lowry,[67] who reported the radical reactions of cis- and trans-9-decalylcarbinylhypochlorites (24 and 25 where X=CH_2OCl, respectively). In 1968, however, Struble, Beckwith and Gream[68] concluded that (22) and/or (23), formed by the cyclization of the 4-(cyclohex-1-enyl)butyl radical, had reached conformational equilibrium before hydrogen extraction could occur.*

Grob,[69] Gream[70] and Fort[71,72] have all carried out investigations on the nature of the 9-decalyl cation (26) which is analogous, in certain respects, to the radical

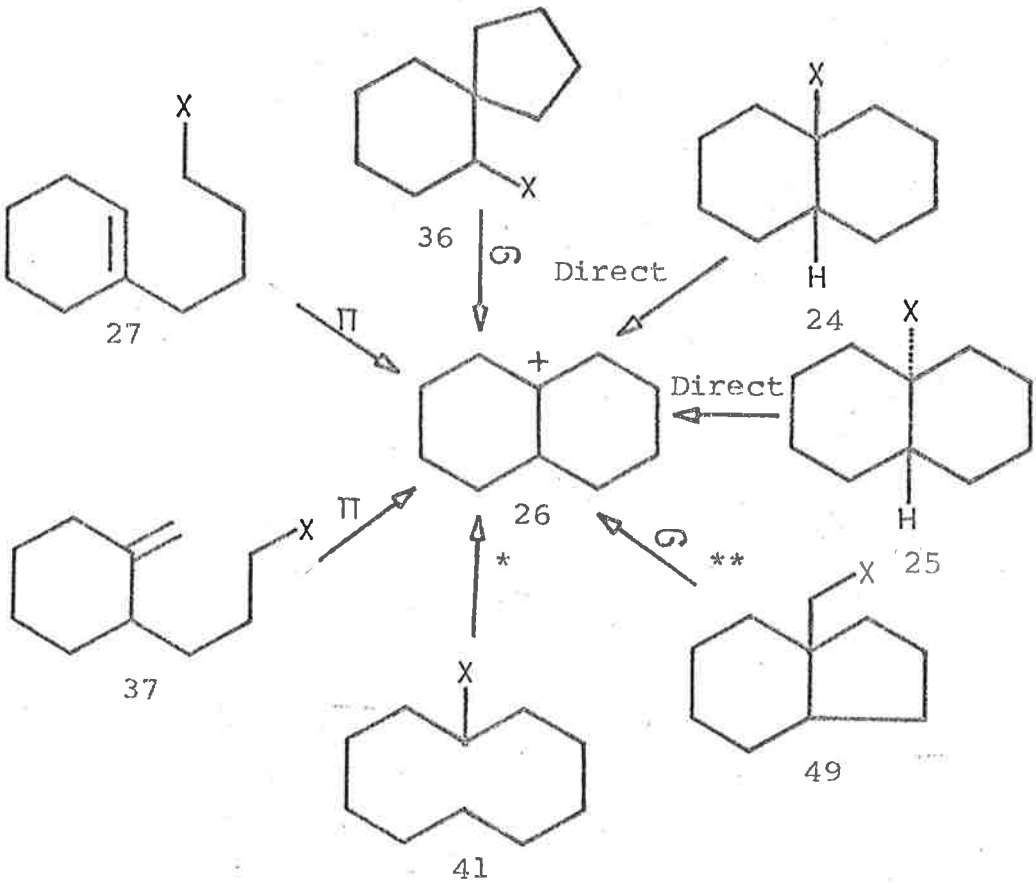
---

* Compare reference 73.

system described above. This work[69,70,72] will be considered in more detail below.

Although a number of ionic reactions, including the dehydration of 1- and 2-decalols,[74,75] the deamination of 1-aminodecalins[76] and the solvolysis of 1- and 2-decalyl derivatives,[77-79] proceed in part by localization of the positive charge at the 9-position of the decalyl skeleton, only systems whose reaction paths proceed almost exclusively through the 9-decalyl cation (26) are considered here. (Scheme I.7.)

In 1968 Boschung, Geisel and Grob[69] reported the solvolysis (in 80% ethanol containing triethylamine) of cis- and trans-9-chlorodecalin (24 and 25 where X=Cl, respectively) (direct route) and 4-(cyclohex-1-enyl)butyl p-toluenesulphonate (27, X=OTs) (Π route), all of which should yield the structurally identical 9-decalyl cation (26) as the intermediate. (Scheme I.7.) They found a significant variation in the distribution of products from the three substrates and concluded that different intermediates must be involved. An explanation based solely on the position of the counter-ion, X^-, was discounted as this was inconsistent, they reasoned, with the formation of cis- and trans-9-decalol (24 and 25 where X=OH, respectively) from both (24) and (27) (where X=Cl and OTs, respectively).



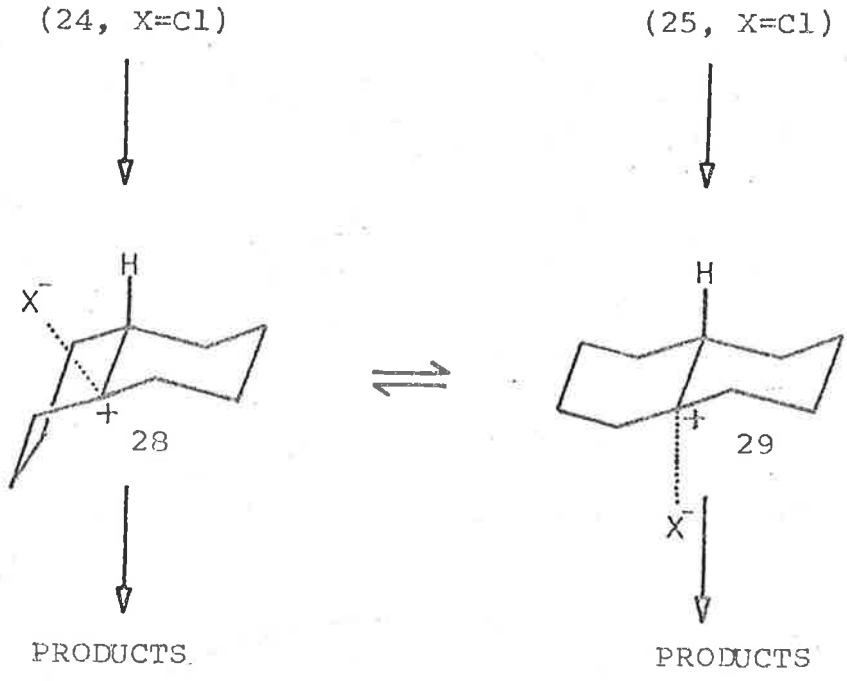
Scheme I.7.

---

* This does not represent a true solvolytic route to (26) but it is significant in the overall consideration of the problem and is discussed later.[80]

** Insufficient data is available to include the routes from the hydrindanyl-carbinyl derivatives (49) in this discussion. Refs. 81,82.

The authors argued plausibly that the cations derived from (24) and (25) (where X=Cl), differed in energy by approximately 1.4 Kcal/mole and that this energy difference was reflected in the formation of the 9-decalyl cation (26) having the conformations (28) and (29) respectively. (Scheme I.8.)



Scheme I.8.

From a consideration of models, Grob[69] concluded that there was a significant barrier to interconversion of (28) and (29) and that product formation occurred faster than equilibration of the two conformers.

The unsaturated ester (27, X=OTs) (Π route) sol-

volysed with participation by the double bond* and the authors reasoned that the intermediate in this reaction was very similar to the intermediate obtained from the cis-chloride (24, X=Cl) as there was a close resemblance in the products obtained from each substrate.

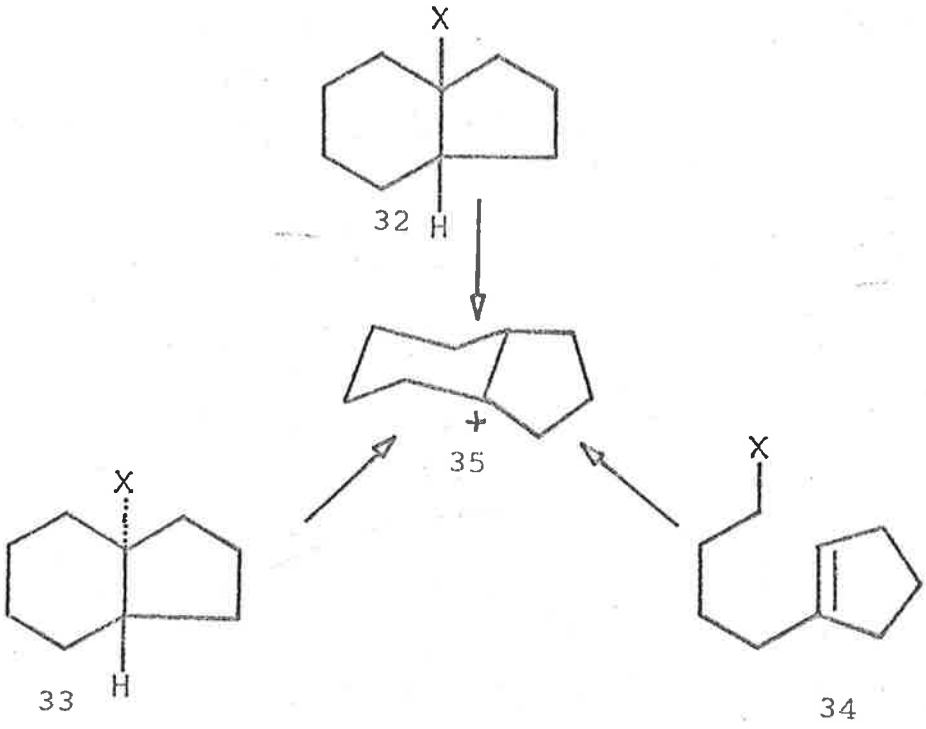
This is a reasonable conclusion when the ratio of $\Delta^{1,9}$- to $\Delta^{9,10}$-octalin (30 and 31, respectively) is considered; however the large differences in the ratios of cis- and trans-9-decalol (24 and 25 where X=OH, respectively), (viz.; 2.23 from (27) (X=OTs), and 0.40 from (24) (X=Cl)), would seem to cast considerable doubt on this hypothesis. Another aspect not discussed by Grob was the fact that the comparison was made between substrates bearing different leaving groups and it has been shown that this factor can markedly alter the nature of the products in solvolytic reactions.[63,64,83-85] Smith and Goon[86] have recently reported the ethanolysis of some cumyl derivatives, (viz. chloride, p-nitrobenzoate and thiobenzoate) and they found that the ratio of elimination to substitution was 0.12, 0.50 and 0.91 respectively, which is a particularly dramatic example of the effect of the

---

* The rate of solvolysis of (26, X=OTs) compared to the saturated analogue, k_{rel}, increased as the nucleophilicity of the solvent decreased: the k_{rel} were 2.16 (80% ethanol), 5.2 (50% acetone) and 40.3 (acetic acid).

leaving group on a solvolytic reaction.

It is of interest, however, that Grob and co-workers[87] considered that the solvolysis of the cis- and trans-8-hydrindanyl chlorides (32 and 33 where X=Cl, respectively) and 4-(cyclopent-1-enyl)butyl p-toluenesulphonate (34, X=OTs) was best envisaged as proceeding through the relatively rigid 8-hydrindanyl cation (35), in which encumberance and the position of the counter-ion were the key factors in determining the nature of the products. (Scheme I.9.)



Scheme I.9.

In 1970 Fort, Hornish and Liang[72] reported the solvolysis of cis- and trans-9-decalyl p-nitrobenzoate (24 and 25 where X=PNB, respectively)[71] (direct route) and

rationalized their results in terms of two conformationally isomeric carbonium ions. They also concluded that ion pairs played only a minor role in the reactions.

It was found that (24) and (25) (where X=PNB, respectively) exhibited "normal" solvolytic behaviour, that is, unaffected by steric factors etc.. The authors concluded that the kinetic results and the product distribution were consistent with the concept of two different intermediate cations.

Fort and co-workers[72] considered three possible explanations for their observations:

(i) the solvolysis was bimolecular (E2),

(ii) the solvolysis involved intimate ion-pairs and the counter-ion was responsible for the product distribution,[63,64]

(iii) unencumbered, conformationally distinct cations were the product determining intermediates.

The first premise, (i), was dismissed on kinetic grounds and because of the failure of a trans-anti-planar arrangement of hydrogen and leaving group to facilitate elimination.[88] The second consideration, (ii), was difficult to discount completely; the authors suggested that the absence of epimerization of (24) or (25) (where X=PNB, respectively) during the solvolysis indicated that intimate

ion-pairs were not significant product-determining intermediates.* They conceded that it was possible that intimate ion-pairs were present with the provision, however, that steric factors[91] restricted the movement of the anion from one side of the molecule to the other.

In order to gain further information on the conformation of the intermediate cation, Fort et.al.[72] treated cis- and trans-9-decalol (24 and 25 where X=OH, respectively) with a solution of trifluoro-acetic acid in methylene chloride and trapped the incipient cation with an organosilane.[92,93] The intervention of an ion-pair intermediate was impossible as the leaving group (H_2O) is a neutral molecule and thus the authors concluded that the variation in the stereochemistry of the products was consistent with the intermediacy of conformationally different cations. (It must be recognized however, that the ionizing conditions used above are completely different to those used initially and this must be kept in mind when comparing the respective intermediate ions).

An important consideration, however, was whether the conformational distinction between the two cations and their ability to give different products was a reasonable proposition in terms of the time scale involved. The authors[72]

---

* Compare ref. 89 and 90.

reasoned that the molecular relaxations required to equilibrate systems of this type had rate constants of the order of 10^{-6} - 10^{-8} sec^{-1} (ref. 94), whereas formation of products is most probably a diffusion controlled process where k is 10^{-9} - 10^{-11} sec^{-1} (ref. 95).

They concluded that the third premise, (iii), was consistent with the experimental observations and that these two direct routes to the decalyl cation gave conformationally distinct ions. Unlike Grob,[69] however, they were not willing to suggest possible "shapes" for the conformers.

A comprehensive investigation by Gream[70] on the nature of the 9-decalyl cation (26), generated by σ, π and direct routes, has shown that the product distribution is markedly dependent on the precursor and, as a consequence, different intermediate species must be involved. He has suggested that this is possibly a result of conformational differences in the incipient cation and that the counter-ion could also play more than a minor role in determining the course of the reaction.

The ratio of $\Delta^{1,9}$-octalin (30) to $\Delta^{9,10}$-octalin (31) was compared for each reaction, as it was considered to be a useful probe to determine the intimate mechanism involved in the solvolyses. (Table I.1.)

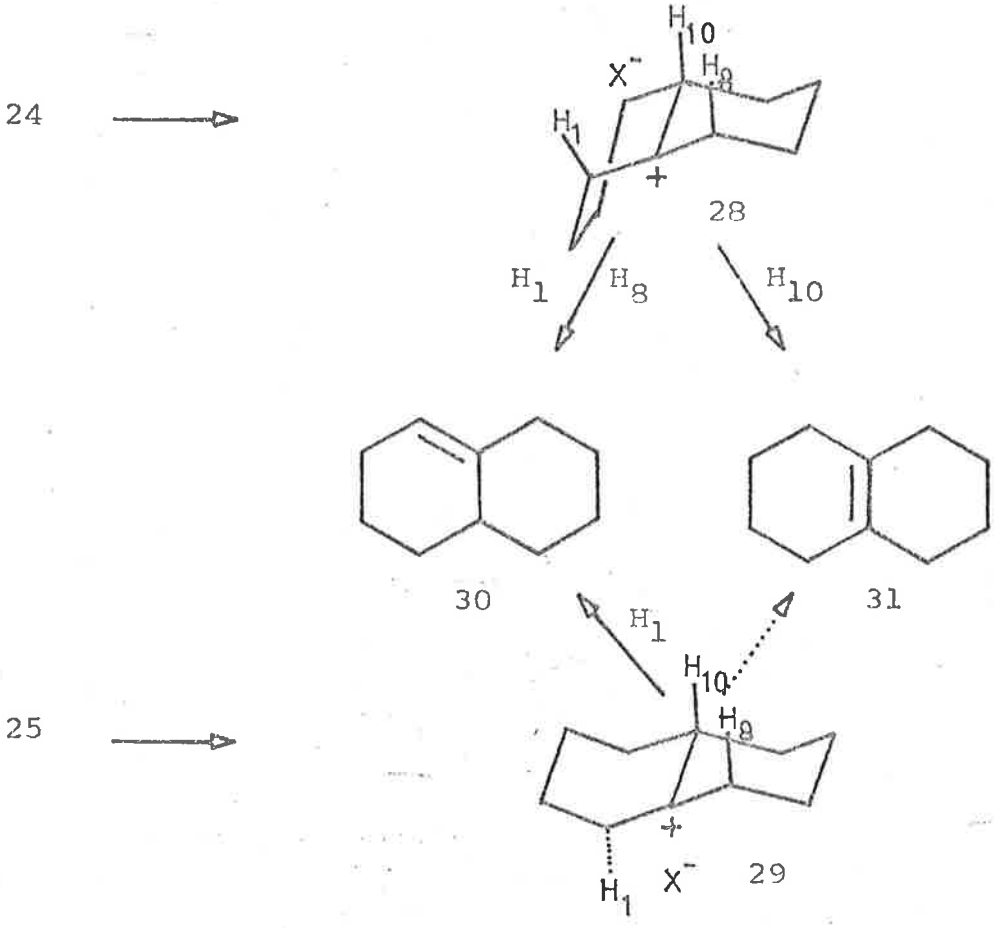
Table I.1.

COMPOUND	SOLVENT	(30)/(31)	Ref.
(24, X=PNB)*	acetic acid/sodium acetate (A)	1.12	70
(24, X=PNB)	60% acetone/sodium acetate	1.07	72
(25, X=PNB)	(A)	7.0	70
(25, X=PNB)	60% acetone/sodium acetate	1.51	72
(24, X=Cl)	(A)	1.09	70
(24, X=Cl)	80% ethanol/triethylamine	1.21	69
(25, X=Cl)	(A)	4.8	70
(25, X=Cl)	80% ethanol/triethylamine	0.28	69
(27, X=ONs)	(A)	2.16	70
(27, X=OTs)	80% ethanol/triethylamine	1.05	69
(27, X=Cl)	(A)	3.35	70
spiro[4.5]dec-6-yl chloride (36, X=Cl)	(A)	0.82	70
(36, X=OTs)	(A)	0.36	70
3-(2-methylenecyclohexyl)propyl p-nitrobenzoate (37, X=PNB)	(A)	1.39	96

* PNB = p-nitrobenzoate.

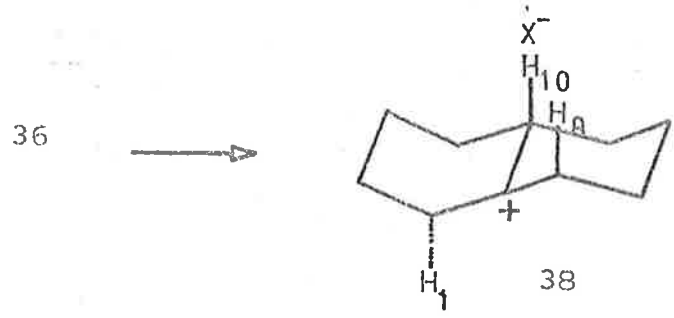
If the cation formed from the trans-9-decalyl derivatives (25 where X=PNB or Cl) is in fact in the conformation (29) (Scheme I.10.), as suggested by Grob,[69] the counter-ion is well situated to act as a base in abstracting the hydrogen at C_1 to give $\Delta^{1,9}$-octalin (30). On the other hand, the counter-ion is on the opposite side of the molecule to the hydrogen at C_{10}, thus restricting its abstraction by the counter-ion. The high ratio of (30) to (31) observed for this system was consistent with this hypothesis. The higher proportion of $\Delta^{9,10}$-octalin produced by the cis-9-decalyl derivatives (24 where X=PNB or Cl) can be rationalized in the same way, as the counter-ion and the hydrogen at C_{10} are on the same side of the molecule. (Scheme I.10).

At first sight, it might be considered that the results of Grob[69] and Fort[72] invalidate this hypothesis. Whittaker[97] however, has shown recently that, although ion-pairs are important in cationic reactions of α- and β-pinene in anhydrous acetic acid, in more nucleophilic solvents, such as those containing water, ion-pairs, if formed at all, are less important in determining the nature of the products. Thus the values of 1.51 and 0.28 (Table I.1.), which were obtained for the trans-9-decalyl derivatives (25 where X=PNB or Cl) in aqueous solvents, were not unexpected.



Scheme I.10.

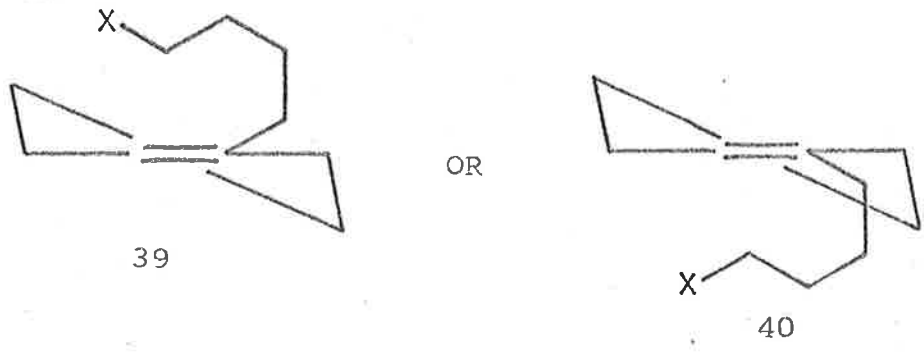
Gream has suggested that if the 9-decalyl cation, generated by the solvolysis of the spiro[4.5]dec-6-yl derivatives (36 where X=Cl or OTs) ($\mathcal{O}$ route), does resemble ion (38), the counter-ion would be well situated to give both (30) and (31) in approximately equal amounts. (Scheme I.11.)



Scheme I.11.

The observed value of 0.82 for (36, X=Cl) approaches this value closely but the ratio 0.36 for (36, X=OTs) is much lower than expected. The author reasoned that this could be a reflection of the nature of the leaving groups.

In the case of the 4-(cyclohex-1-enyl)butyl derivatives (27 where X=Cl or ONs) (Π route), it was apparent that for a particular half-chair conformer, interaction of the Π-bond and the carbon bearing the leaving group could occur either above or below the plane of the ring (39) and (40) and lead to two conformationally different cations. (Scheme I.12.) Gream[70] has pointed out that Grob's[69] conclusion about the similarity of the intermediate cations produced by (27) and (24) (where X=OTs and Cl, respectively) in 80% aqueous ethanol, is difficult to rationalize on the basis of the yields of cis- and trans-9-decalol (24 and 25 where X=OH, respectively), which varied markedly. When the

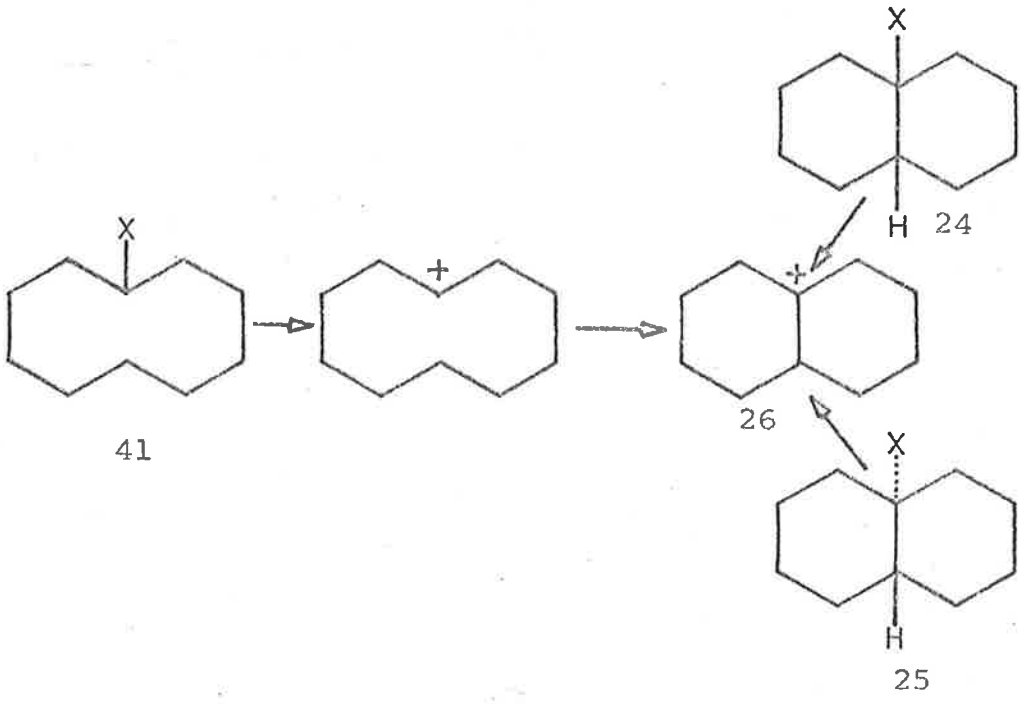


39 40

Scheme I.12.

same leaving group is used,[70] it can be seen (Table I.1.) that the ratio of the two octalins, (30) and (31), is intermediate between those for cis- and trans-9-chlorodecalin (24 and 25 where X=Cl, respectively). The author concluded that the counter-ion is probably not in a good position to abstract a proton and that "the composition of the products does not give any clear indication of the nature of the conformations of the 9-decalyl cation." It may be that a "hot" cation, as suggested by Closson,[61] is involved.

In a recent communication, Olah and co-workers[80] reported that they could not detect conformational isomers of the 9-decalyl cation (26) which had been prepared by dissolution of cyclodecanol (41, X=OH), cis- and trans-9-decalol (24 and 25 where X=OH, respectively) and cis- and trans-decalin (24 and 25 where X=H, respectively)[98] in "super acid" media. (Scheme I.13.)

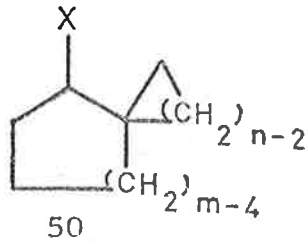


Scheme I.13.

They concluded that if two conformers of the 9-decalyl cation were indeed present initially, they had reached a state of equilibrium before product formation could occur. (See footnote*, page 11.)

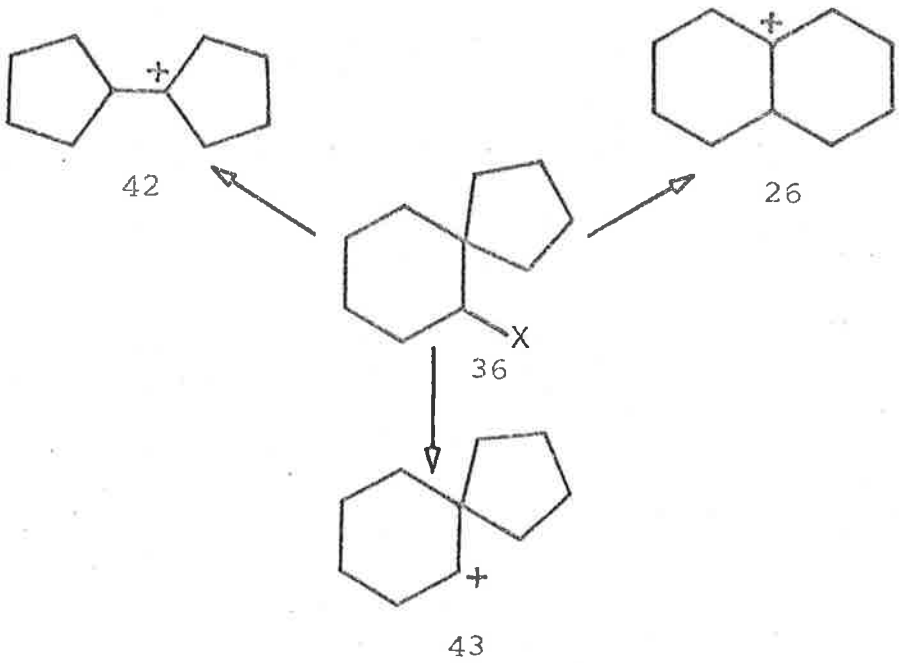
I.2.

The spiro ring system (50 where m=5-8 and n=5-7 and where X is a suitable leaving group) has been the vehicle for the study and assessment of the contribution of ring strain[99-101] and/or anchimeric assistance as a driving force in Wagner-Meerwein type rearrangements, under conditions of deamination,[111,112] dehydration[103,107-110,114] and solvolysis.[104-106,113,115]



50

Of prime importance are the spiro[4.5]dec-6-yl derivatives (36) which, Gream[70] has shown, are suitable substrates to study the σ route to the 9-decalyl cation (26). Until this work[70] however, the main interest was centred on the rearrangements of this system.[103,105,108,111,113,114,116,117] (Scheme I.14.) Products derived, under ionic conditions, from the 9-decalyl cation (26) (ring expansion), the cyclopentylcyclopentyl cation (42) (ring contraction) and the parent spiro cation (43) have been observed,[70,108,111,113] in varying amounts.



Scheme I.14.

I.3.

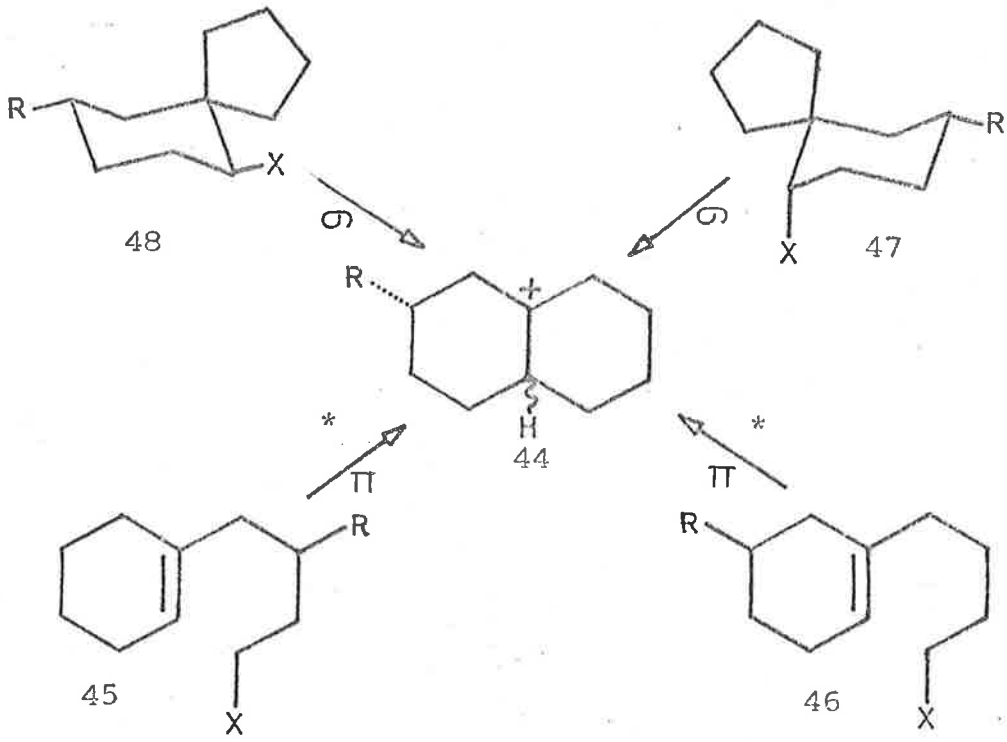
OBJECTS.

As an extension of the work dealing with the 9-decalyl cation (26), it was decided to investigate the σ and π^* routes to the 2-t-butyl-9-decalyl cation (44) which, by virtue of its substitution contains two asymmetric centres. As a consequence, the olefinic products directly derived from the intermediate (44) can be positional isomers with respect to the t-butyl group and each positional isomer can be one of a pair of geometric isomers (see section II.1.). It was hoped that the nature of the isomers would yield further information about the conformation of the intermediate cations (44) and also the role of ion-pairs in the reaction. (Scheme I.15.)

The overall distribution of products could also help to elucidate the precise mechanism of the solvolytic reactions of this system, in which the configuration of the leaving group is fixed.

---

* Time did not permit an investigation of the solvolysis of 3-t-butyl-4-(cyclohex-1-enyl)butyl or 4-(5-t-butylcyclohex-1-enyl)butyl derivatives (45 and 46 where X=Cl or OTs, respectively) (π route) in this work, however Serelis[96] is at present engaged on this problem.



R=$(CH_3)_3C$**

Scheme I.15.

The first part of this thesis deals with the acetolyses of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) and the second part with the synthesis of some of the required compounds.

---

* See footnote on page 26.

** This representation applies to all diagrams in this thesis.

DISCUSSION

II.1.

A study of the acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively).

In the present work, the t-butyl group has been incorporated into the substrates (cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively)) in order to restrict the number of conformations that the two substrates may take up.[118] Winstein and Holness[119] were the first to use the t-butyl group as a conformation "locking" group when they investigated the solvolysis of cis- and trans-4-t-butylcyclohexyl derivatives (51 and 52 where X=OTs, respectively). (Figure II.1.1.) This study was undertaken in order to gain information about "the differences to be expected simply from the equatorial or axial disposition of the reactive group on the chair form of the cyclohexane ring."

The reason for the t-butyl group being used for the above purpose was based on the fact that the group has a distinct preference (>5.5Kcal/mole) for occupying an equatorial rather than an axial position.[120,121,143]

Although Winstein at the time considered that cis- and trans-4-t-butylcyclohexyl derivatives (51 and 52) represented pure species (in ground states and also transition states), evidence has since accumulated suggesting

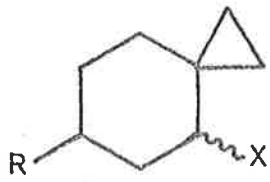
that non-chair and chair conformers may be important in the solvolytic reactions of these derivatives.[122]

Figure II.1.1.

In 1965, Shiner and Jewett suggested, from an evaluation of deuterium isotope effects, that trans-4-t-butylcyclohexyl p-bromobenzenesulphonate (52, X=OBs) underwent solvolysis through a non-chair transition state[123] and that the cis-epimer (51, X=OBs) reacted via a skewed chair conformer.[124] It should be noted however that Okamoto et.al.,[125] in recent reports on the solvolytic isomerization and rearrangement of cis-4-t-butylcyclohexyl p-toluenesulphonate (51, X=OTs), have cast some doubt on the conclusions drawn by Shiner and Jewett.[123,124]

On the other hand Whiting and co-workers[79] have argued plausibly in support of the findings of Shiner and Jewett[123,124] on the basis of a careful analysis of the products formed in the acetolysis of the cis- and trans-esters (51 and 52 where X=OTs, respectively).

Recently an informative example of the t-butyl group failing to lock cyclohexyl rings in pure chair conformations in the solvolysis of cis- and trans-6-t-butylspiro[2.5]oct-4-yl p-nitrobenzoate (137) was reported by Schleyer.[126]



137

In the absence of clear-cut evidence favouring either chair or non-chair conformers,[127,128,133] the results presented in this thesis are discussed in terms of both possibilities.

The chair (47(c) and 48(c), respectively) and the non-chair (47(n) and 48(n), respectively) conformers of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) are represented by Newman projections shown in Figure II.1.2.

The kinetic results for the acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) are presented in Table II.1.1.

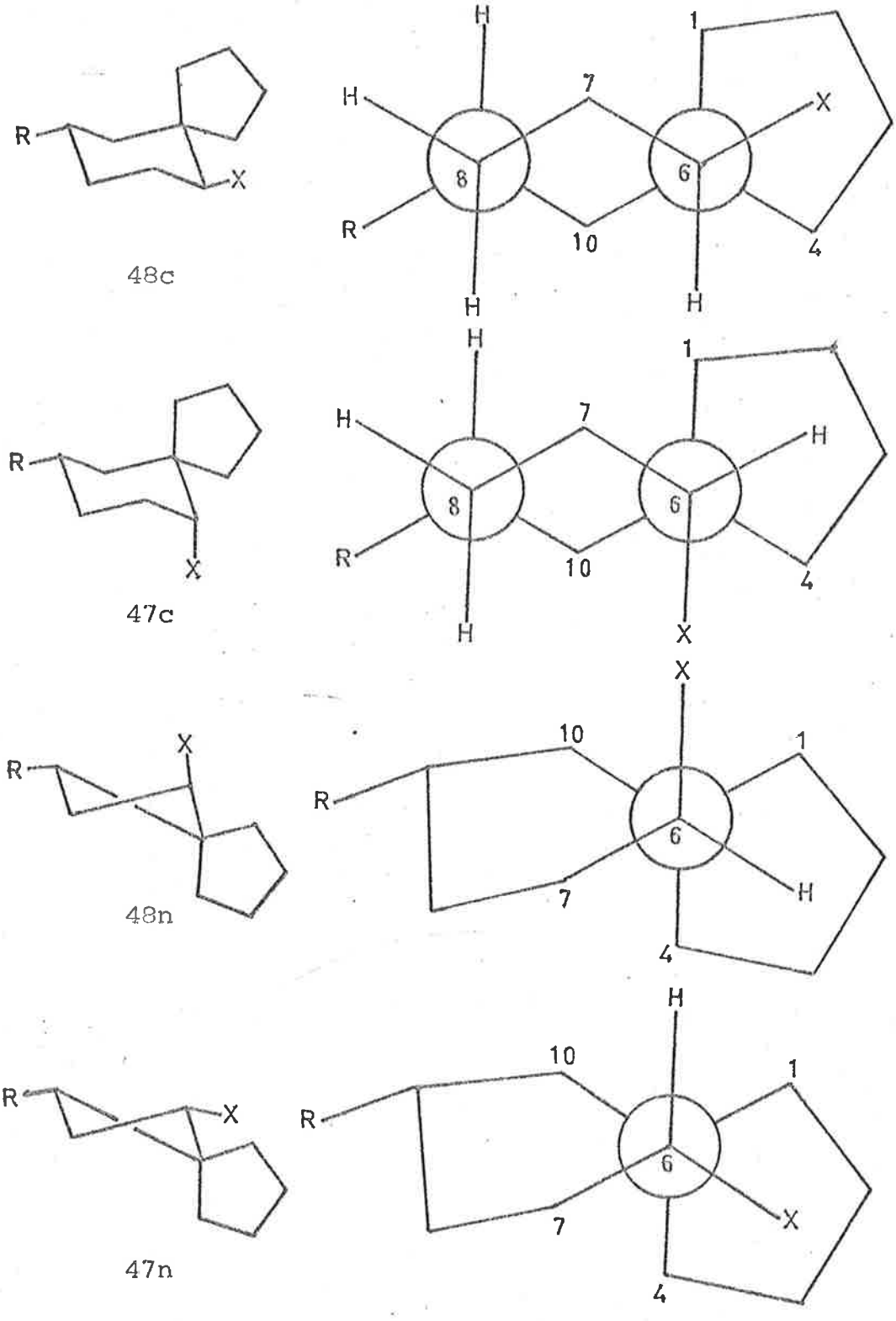


Figure II.1.2.

Table II.1.1.

Rates of Acetolysis[a] of the spiro esters (47 and 48 where X=OTs, respectively).

COMPOUND	TEMP. °C	$10^{-5}k$ sec^{-1}	k_{rel}	$\Delta G^{\ddagger}$ kcal/ mole	$\Delta H^{\ddagger}$ kcal/ mole	$\Delta S^{\ddagger}$ e.u.
(47 where X=OTs)	27.3	7.31				
		7.52				
	33.4	13.78				
		14.42				
	40.3	34.17				
	45.1	54.99				
		55.42				
	25[b]	5.4	25.7	23.4	21.9	-4.7
	25[c]	5.1				
(48 where X=OTs)	45.3	3.66				
		3.48				
	52.2	8.50				
		8.86				
	60.4	23.94				
		24.34				
	25[b]	0.21	1	25.2	25.6	+1.3
	25[c]	0.22				

a. The solutions were initially ca. 0.01M in ester and ca. 0.02M in sodium acetate.

b. Extrapolated from data at other temperatures.

c. ref. 115.

The significance of these results becomes clearer by a comparison with other similar systems. (Table II.1.2.)

Table II.1.2.

Relative rates[a] of acetolysis of some p-toluenesulphonate derivatives at 25°.

COMPOUND (p-toluenesulphonate, where X=OTs)	k_{rel}	reference
cyclohexyl (10)	1.0	129
2,2-dimethylcyclohexyl (53)	3.0	113,105
2,2-dimethyl-3-butyl (54)	3.8	130
cis-4-t-butylcyclohexyl (51)	1.8	131
cis-4-t-butyl-2,2-dimethyl-cyclohexyl (55)	3.0	132
cis-9-t-butylspiro[4.5]dec-6-yl (47)	1080.0	115
cis-10-t-butylspiro[5.5]undec-7-yl (57)	8.4	115
spiro[4.5]dec-6-yl (36)	434.0	115,105
trans-4-t-butylcyclohexyl (52)	0.9	131,119
trans-4-t-butyl-2,2-dimethyl-cyclohexyl (56)	1.8	132
trans-9-t-butylspiro[4.5]dec-6-yl (48)	44.0	115
trans-10-t-butylspiro[5.5]undec-7-yl (58)	22.0	115
spiro[5.5]undec-7-yl (59)	28.6	115

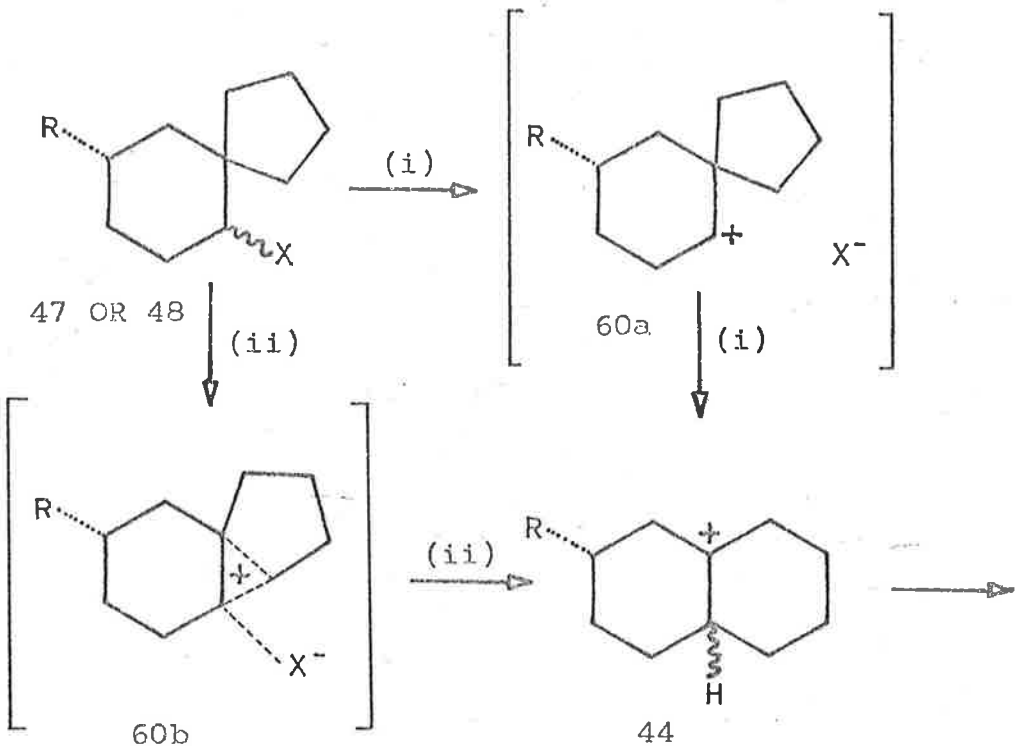
a. Where the rates of solvolysis were not available at 25°, the values have been extrapolated from data available in the literature.

In particular a comparison of the rates of acetolysis of cis-4-t-butylcyclohexyl (51, X=OTs), cis-4-t-butyl-2,2-dimethylcyclohexyl (55, X=OTs) and cis-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47, X=OTs) (1.8, 3.0 and 1080, respectively) indicates that the five-membered ring participates and consequently provides a considerable driving force[134,135,105] in the heterolysis of the cis-ester (47, X=OTs). The magnitude of this driving force can be fully appreciated in the relatively small rate increase in the acetolysis of cis-10-t-butylspiro[5.5]undec-7-yl p-toluenesulphonate (57, X=OTs) when compared to cis-4-t-butyl-2,2-dimethylcyclohexyl p-toluenesulphonate (55, X=OTs) (2.8:1, respectively). In the former compound (57, X=OTs), the five-membered ring, present in the ester (47, X=OTs) has been replaced by an adjacent six-membered ring.

A similar consideration of trans-4-t-butylcyclohexyl (52, X=OTs), trans-4-t-butyl-2,2-dimethylcyclohexyl (56, X=OTs) and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs) reveals a variation of 0.9, 1.8 and 44, respectively, in the relative rate of acetolysis. This observation is consistent with participation by the adjacent cyclopentyl ring in the trans-ester (48, X=OTs). If the participation is absent, the rate of acetolysis of the two trans-esters (56 and 48 where X=OTs) should vary only slightly because in both cases the environment of the leaving group

is quite similar.

In other words, the ring expansion does not proceed by path (i) (transition state 60a) (Scheme II.1.1.), but is described by path (ii) which leads to the intermediate cation (44) via the transition state (60b).



Scheme II.1.1.

Gream[70] has observed the presence of both cis- and trans-9-decalyl acetates (24 and 25 where X=$OCOCH_3$, respectively) in the products from the acetolysis of spiro[4.5]dec-6-yl p-toluenesulphonate (36, X=OTs). As the formation of these acetates (24 and 25 where X=$OCOCH_3$) is not consistent with the intermediacy of a non-classical cation;[23] by analogy, it seems likely that the proposed

intermediate (44) in the acetolysis of both the cis- and trans-esters (47 and 48 where X=OTs, respectively) is a classical tertiary cation. (see also ref. 136)

In order that neighbouring group participation can occur it is generally considered necessary to have a trans-anti-planar arrangement of migrating and leaving groups.[11, 137,139] This condition is satisfied by the chair conformer of cis-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 (c)) (Figure II.1.2.) in which the C_1-C_5 bond can participate in the heterolysis with accompanying expansion of the five-membered ring. Participation by a trans-anti-planar bond, which will lead to the 2-t-butyldecalyl cation (44) can only occur in a non-chair conformer of trans-9-t-butylspiro[4.5]dec-6-yl (48, X=OTs). (Figure II.1.2.) A release of energy of approximately 6-10kcal/mole has been estimated for this ring opening process due to the loss of strain (Baeyer, Pitzer and non-bonded interactions).[99,101,138] However this estimation will vary according to the progress of ring expansion in the transition state.*

---

* That is, the amount of strain release will presumably increase as the ring opening of the five-membered ring proceeds towards the attainment of the 2-t-butyl-9-decalyl cation (44).

In order to develop the concept of the role of chair and non-chair conformers more fully, it is possible to divide the rate of acetolysis of both cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) into component parts using the generalized Winstein-Holness equation[119] (equation 1) -

$$k_{overall} = k_e N_e + k_a N_a + k_n N_n \qquad \text{Eq. 1.}$$

where the subscripts e, a and n, refer to the equatorial and axial chair conformers and the non-chair conformers, respectively; N and k represent the population and the rate of solvolysis, respectively, of each conformer.

The cis- and trans-isomers (47 and 48 where X=OTs) are now considered in terms of this equation as follows:

(i) The expression for the cis-ester (47, X=OTs) is probably of the form, (equation 2),

$$k_{overall(cis)} = k_a N_a = 5.4 \times 10^{-5} sec^{-1} \qquad \text{Eq. 2.}$$

as it is generally accepted that cis-4-t-butylcyclohexyl derivatives undergo solvolysis exclusively in the chair conformer[79] (axial leaving group). Consequently, $N_a = 1$ and $k_{overall(cis)}$ will be $5.4 \times 10^{-5} sec^{-1}$.

(ii) The rate of acetolysis of the trans-ester (48, X=OTs) on the other hand is better described by equation 3, in which the contribution of $k_e N_e$ has been confirmed by

$$k_{overall(trans)} = k_e N_e + k_n N_n = 0.21 \times 10^{-5} sec^{-1} \quad \text{Eq. 3.}$$

the detection of ring contracted products, (3-t-butylcyclopentylidene)cyclopentane (69) and (3-t-butylcyclopentyl)--cyclopent-1-ene (68), in the product mixture. These are produced by the rearrangement of the chair conformer (48(c)) in a stereo-electronically favourable process, involving the C_5-C_{10} bond. (Figure II.1.2.)

Whiting[79] has argued plausibly that k_e is small and possibly very small and consequently $k_e N_e < k_n N_n$, although $N_e > 0.99$ and $N_n < 0.01$; as a result the major contribution to $k_{overall(trans)}$ arises from the contribution of the non-chair conformer (48(n)). (Figure II.1.2.)

It should be noted that Dauben[134] has concluded from an investigation of the solvolysis of a series of bicyclo[m.n.o]alkane-1-methyl derivatives that "the orientation of the leaving group in relation to the migrating bond is secondary to strain release in determining rate and products." This conclusion requires the addition of a third term $k_e' N_e$ in the expression for $k_{overall(trans)}$ (equation 4).

$$k_{overall(trans)} = k_e N_e + k_e' N_e + k_n N_n \quad \text{Eq. 4.}$$

In this context $k_e' N_e$ refers to the rate of the ring expansion process which occurs in the trans-chair conformer (48(c)). (Figure II.1.2.) Intrinsically, this process is however

stereo-electronically unfavourable.

Consequently it is impossible, on the basis of the kinetic results alone, to resolve whether participation is occurring in the non-chair conformer (48(n)) or in the alternative chair conformer (48(c)). (Figure II.1.2.) Of the two, the non-chair conformer contains a trans-anti-planar arrangement of the leaving and migrating groups.

Evidence will be presented, which supports the concept of stereo-electronically favourable processes occurring in the acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively). This evidence is based on the composition of the product mixture from the acetolysis of the two esters (47 and 48 where X=OTs).

An inspection of the thermodynamic parameters of the cis- and trans-esters (47 and 48 where X=OTs, respectively) reveals that the difference in the values of the free energy of activation, $\Delta G^{\ddagger}$ (23.4 and 25.2kcal/mole respectively) arise mainly from the enthalpy of activation, $\Delta H^{\ddagger}$ (21.9 and 25.6kcal/mole, respectively) rather than the entropy of activation, $\Delta S^{\ddagger}$ (-4.7 and +1.3e.u., respectively). This probably indicates that bond rupture and formation ($\Delta H^{\ddagger}$) are the controlling factors which determine the relative rates of acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-

6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively). The fact that the values of ($\Delta S^{\ddagger}$) obtained for the two esters (47 and 48 where X=OTs) differ only slightly indicates that the shape of the transition state is similar.

This is in contrast to the solvolytic reactions of some 3-steroidal p-toluenesulphonate esters, reported by Baker, Hudec and Rabone.[141] They found that the greater rate of solvolysis of the axial epimers arose from differences in entropy rather than enthalpy of activation.

The activation parameters found in this work conform to the trends observed by Winstein*[119] in the acetolysis of cis- and trans-4-t-butylcyclohexyl p-toluenesulphonate (51 and 52 where X=OTs, respectively). (Table II.1.3.)

Table II.1.3.

p-Toluenesulphonate ester	$\Delta H^{\ddagger}$ kcal/mole	$\Delta S^{\ddagger}$ e.u.
51*	26.7	-0.5
52*	28.1	+1.7
47	21.9	-4.7
48	25.2	+1.3

An energy profile can be constructed with the experimentally determined values of the free energy of activation, $\Delta G^{\ddagger}$, and the free energy difference of the ground state ΔG^{o} of cis- and trans-9-t-butylspiro[4.5]dec-

6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively).

Two independent values of ΔG^{o} were obtained by different methods.

The first method consisted of equilibration of either cis- or trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, respectively) in refluxing isopropyl alcohol in the presence of Raney nickel catalyst.[142] (Figure II.1.3.)

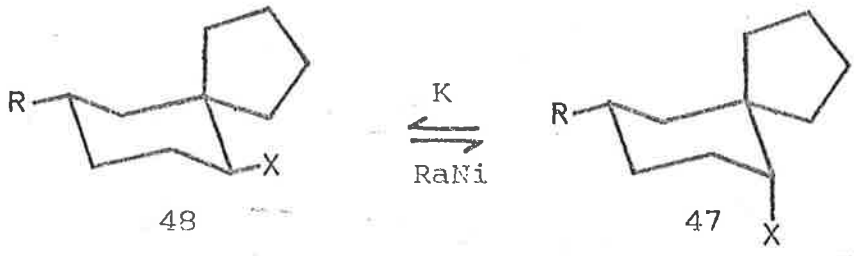


Figure II.1.3.

Gas liquid chromatographic analysis of the equilibrium mixture revealed the presence of the cis-alcohol (47, X=OH, ca. 37%) and the trans-alcohol (48, X=OH, ca. 63%). Substitution of the derived equilibrium constant, $K = \frac{63}{37}$ in the expression

$$\Delta G^{o} = -RT\ln K$$ (R is the universal gas constant and T is the temperature)[144]

gave a value of 0.4kcal/mole for the ground state free

energy difference* in favour of the trans-isomer (48, X=OTs).

The second method utilized the Winstein-Holness relationship[119,145]

$$K = \frac{k_a - k}{k - k_e}$$

where K is the conformational equilibrium constant at 25° for cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluene--sulphonate (47 and 48 where X=OTs, respectively) k_a ($5.4 \times 10^{-5} sec^{-1}$) and k_e ($0.2 \times 10^{-5} sec^{-1}$) are the rate constants for the conformationally pure** cis- and trans-esters (47 and 48 where X=OTs, respectively). k ($2.1 \times 10^{-5} sec^{-1}$) is the rate constant for the acetolysis of spiro[4.5]dec-6-yl p-toluenesulphonate (36, X=OTs).[115] This calculation yielded a similar, though less reliable** value of 0.2kcal/mole for ΔG^{o}.

Having established that the ground state free energy difference between the cis- and trans-esters (47 and 48 where X=OTs, respectively) is 0.2-0.4kcal/mole, an energy diagram

---

* The reasonable assumption has been made that the ground state free energy difference between equatorial and axial hydroxy[146] and p-toluenesulphonyloxy substituents[147] is very similar.

** This assumption, although not necessarily valid, forms the basis of this calculation.

(described in Figure II.1.4.) can be constructed for the acetolysis of these compounds.

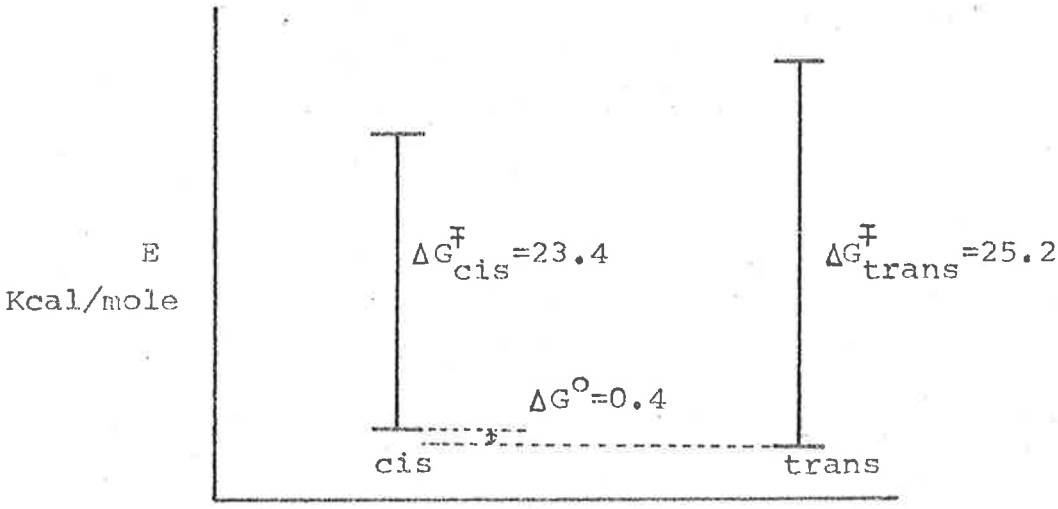


Figure II.1.4.

If non-chair conformers are involved in the acetolysis of the trans-ester it is reasonable to assume that a fast equilibrium exists between the chair and non-chair conformers and reaction then occurs from the higher energy non-chair species.

As was mentioned earlier, the population of the chair and non-chair conformers of the trans-ester (48, X=OTs) are described by N_e and N_n, respectively. (Eq. 1.) Owing to the enthalpy difference (>5.5kcal/mole) between chair and non-chair conformers of cyclohexyl derivatives,[100,140] the concentration of non-chair conformers, N_n, is very

small in the ground state and as a result is not reflected in the value of ΔG^{o} obtained by the first method.

The second method presupposes conformationally pure chair cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) and consequently the value of ΔG^{o} once again reflects the ground state free energy difference between the chair conformer (48(c)) and (47(c)). (Figure II.1.2.)

The above situation can be described by an energy diagram (Figure II.1.5.) in which the value of ΔG^{o} is >5.5kcal/mole.

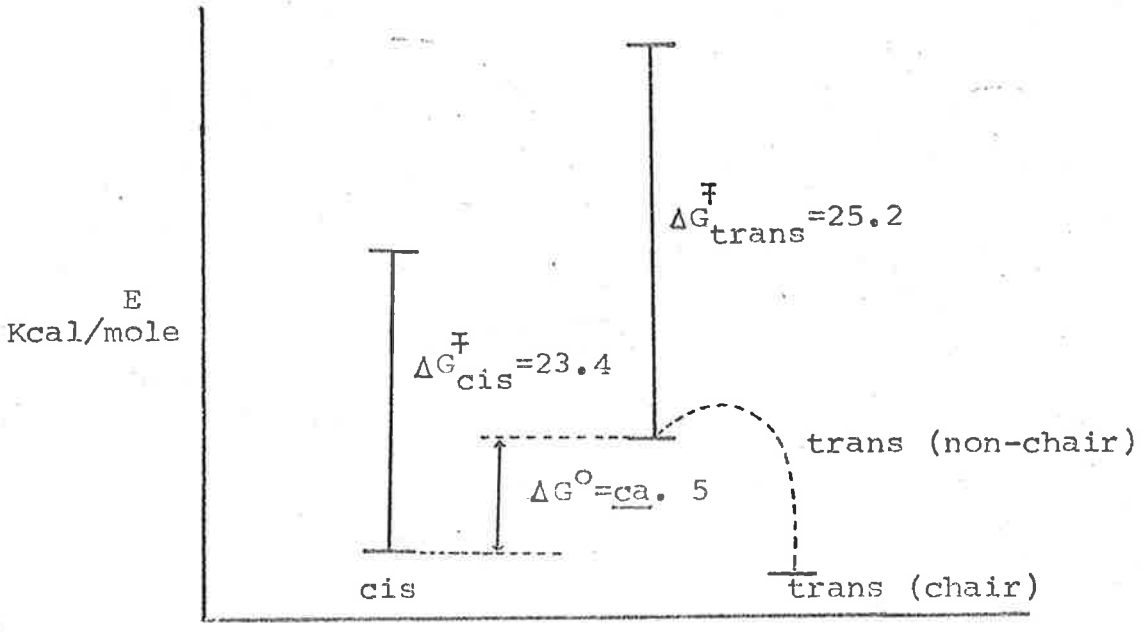
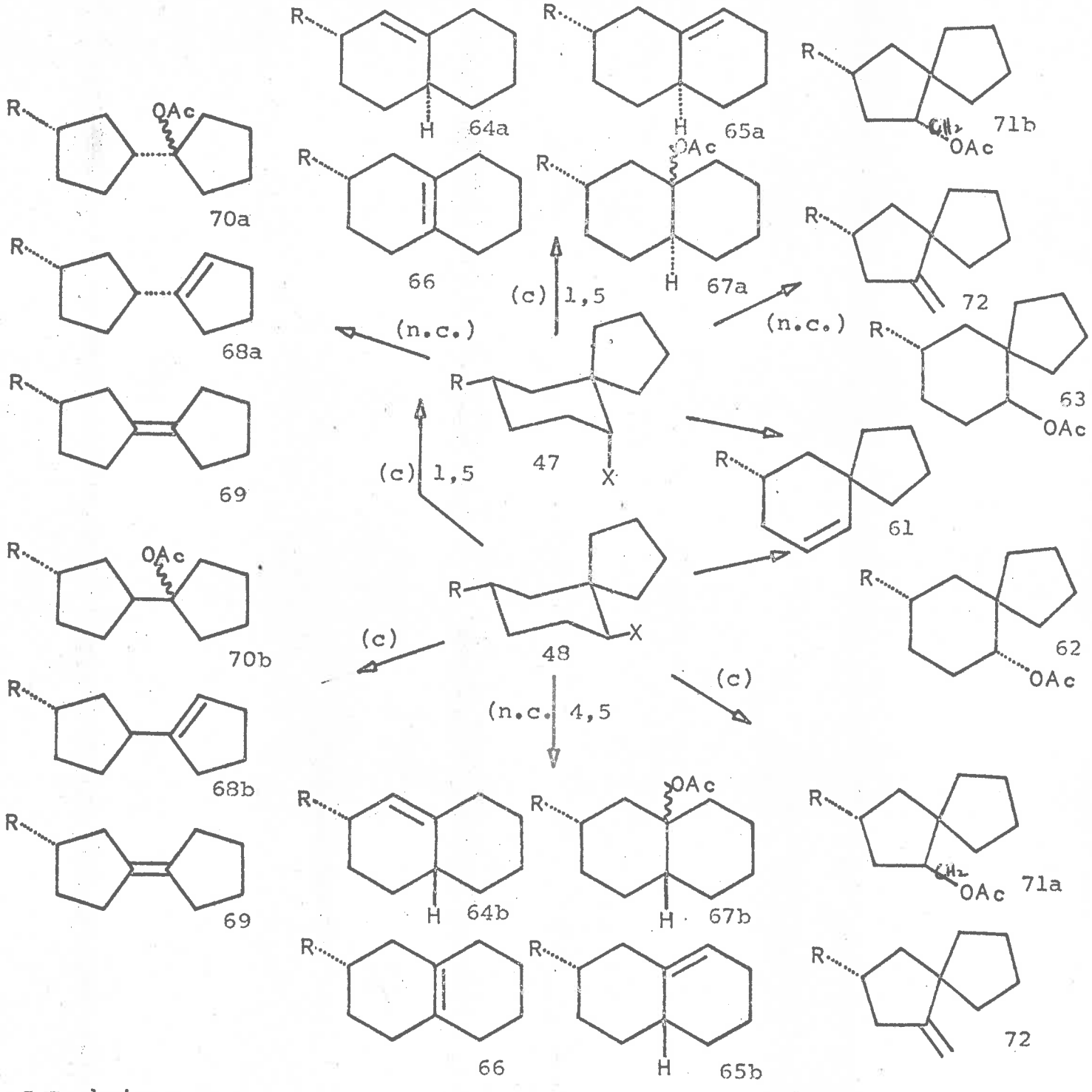


Figure II.1.5.

Strong evidence in favour of non-chair conformers is presented in the following discussion of the product distribution in the acetolysis of the two esters (47 and 48 where X=OTs). This evidence is consistent with the diagram (Figure II.1.5.), which possibly represents the energy levels of ground and transition states in the solvolytic reactions of these two esters.

The nature of the products formed in the acetolysis of 9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) has provided significant information concerning the mechanism of the reaction. In Scheme II.1.2. the possible products and their possible modes of formation are outlined.


R
OAc
70a
68a
69
70b
68b
69
64a
65a
71b
66
67a
72
(c) 1,5
(n.c.)
(n.c.)
63
47
X
61
48
62
(c)
(c)
(n.c.) 4,5
64b
67b
71a
66
65b
72
c = chair
n.c. = non-chair

Scheme II.1.2.

From a consideration of Scheme II.1.2. it appears that the products may depend on the conformation of the parent ester (47 and 48 where X=OTs). An analysis of these theoretical possibilities is presented below for the chair and non-chair conformations of cis- and trans-9-t-butyl--spiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively).

1. (a) The chair conformer of the cis-isomer (47, X=OTs) has the C_1-C_5 bond and the leaving group in a trans-anti-planar arrangement* to one another. Consequently the participation of the electrons in the C_1-C_5 bond in this conformation would give -

(i) trans-2-t-butyl-$\Delta^{1,9}$-octalin (64a)

(ii) trans-7-t-butyl-$\Delta^{1,9}$-octalin (65a)

(iii) 2-t-butyl-$\Delta^{9,10}$-octalin (66)

(iv) cis- and trans-trans-2-t-butyl-9-decalyl acetate (67a).

(b) The chair conformer of the cis-isomer (47, X=OTs) also would give rise to the formation of -

(i) 9-t-butylspiro[4.5]dec-6-ene (61)

(ii) cis- and trans-9-t-butylspiro[4.5]dec-6-yl acetate (62 and 63, respectively)

---

* This is generally considered to be the stereo-electronically most favourable orientation in which rearrangement can occur.[11]

through the intermediacy of the 9-t-butylspiro[4.5]dec-6-yl cation formed without any participation.

2. (a) In the case of the non-chair conformer of the cis-isomer (47, X=OTs) the C_1-C_5 bond and the leaving group can attain a trans-anti-planar arrangement. In this conformation however, the t-butyl group is placed in an energetically unfavourable pseudo-axial position,[122] and consequently the formation of products by the stereo-electronically favourable process is unlikely.

(b) The non-chair conformer of the cis-isomer (47, X=OTs) also gives rise to the formation of -

(i) cis-(3-t-butylcyclopentyl)cyclopent-1-ene (68a)

(ii) (3-t-butylcyclopentylidene)cyclopentane (69)

(iii) cis-(3-t-butylcyclopentyl)cyclopentyl acetate (70a)

in a concerted process. This process involves the participation of the C_1-C_{10} bond and the leaving group in a trans-anti-planar arrangement to one another.

(c) In addition, the non-chair conformer of the cis-isomer, described in 2.(a), has a trans-anti-planar arrangement of the C_7-C_8 bond and the leaving group. This conformation could give rise to -

(i) cis-8-t-butylspiro[4.4]nonane-6-methyl acetate (71b)

(ii) 8-t-butyl-6-methylenespiro[4.4]nonane (72)

but this process is considered unlikely on the following two grounds -

(i) it represents the conversion of a secondary to a primary cation, and

(ii) the process requires a conformation in which the t-butyl group is placed in an energetically unfavourable pseudo-axial position.

3. (a) The chair conformer of the trans-isomer (48, X=OTs) has the C_5-C_{10} bond and the leaving group in a trans-anti-planar arrangement to one another. Consequently this participation would give -

(i) trans-(3-t-butylcyclopentyl)cyclopent-1-ene (68b)

(ii) (3-t-butylcyclopentylidene)cyclopentane (69)

(iii) trans-(3-t-butylcyclopentyl)cyclopentyl acetate (70b).

(b) The chair conformer of the trans-isomer (48, X=OTs) also could give rise to the formation of -

(i) trans-8-t-butylspiro[4.4]nonane-6-methyl acetate (71a)

(ii) 8-t-butyl-6-methylenespiro[4.4]nonane (72)

by virtue of the trans-anti-planar arrangement of the C_7-C_8 bond and the leaving group. As mentioned in 2.(c), this process is considered unlikely because it represents the conversion of a secondary to a primary cation.

(c) In addition the chair conformer of the trans-isomer (48, X=OTs) may lead to the formation of the following products -

(i) trans-2-t-butyl-$\Delta^{1,9}$-octalin (64a)

(ii) trans-7-t-butyl-$\Delta^{1,9}$-octalin (65a)

(iii) 2-t-butyl-$\Delta^{9,10}$-octalin (66)

(iv) cis- and trans-trans-2-t-butyldecal-9-yl acetate (67a).

This process would involve migration of the C_1-C_5 bond. Although the electrons in this bond are not in a stereo-electronically favourable trans-anti-planar arrangement with the leaving group, this mechanism must be considered as a result of Dauben's conclusions. (See page 38)

(d) Finally the chair (or non-chair) conformer of the trans-ester (48, X=OTs) also gives rise to the formation of -

(i) 9-t-butylspiro[4.5]dec-6-ene (61)

(ii) cis- and trans-9-t-butylspiro[4.5]dec-6-yl acetate (62 and 63, respectively).

4. In the case of the non-chair conformer of the trans-isomer (48, X=OTs), the C_4-C_5 bond and the leaving group can attain a trans-anti-planar arrangement. This conformation gives rise to -

(i) cis-2-t-butyl-$\Delta^{1,9}$-octalin (64b)

(ii) cis-7-t-butyl-$\Delta^{1,9}$-octalin (65b)

(iii) 2-t-butyl-$\Delta^{9,10}$-octalin (66)

(iv) cis- and trans-cis-2-t-butyl-9-decalyl acetate (67b).

The likelihood of the occurrence of the various processes outlined in 1,2,3 and 4 above for the acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluene--sulphonate (47 and 48 where X=OTs, respectively) is now discussed in the light of the products that were actually formed.

The results of the product study of the acetolysis of the two spiro esters (47 and 48 where X=OTs, respectively) are listed in Table II.1.4.

Table II.1.4. (PART A)

Products from the solvolysis of *cis*- and *trans*-9-*t*-butylspiro[4.5]dec-6-yl *p*-toluenesulphonate (47 and 48 where X=OTs, respectively) in acetic acid containing sodium acetate.

Substrate	Temp °C	Time h.	Conc.M sodium acetate	Conc.M lithium perchlorate	PRODUCTS (%)[a] 61	68a 68b	69	64a 64b	65a 65b	66	unidentified olefin[c]	unidentified acetate[c,d]
48,X=OTs	52.6	10	0.019	-	0.7	4.4	4	23.0	0.9	67.1	0.5	-
(*ca.*	"	"	0.031	-	1.2	3.5	5[b]	23.8	1.4	63.3	0.6	-
0.01M)	"	"	0.039	-	1.2	4.5	6[b]	23.6	1.2	62.9	0.7	-
	"	"	0.023	0.036	1.1	3.9	6[b]	19.6	1.0	67.4	0.6	-
47,X=OTs	52.6	1.7	0.019	-	0.4	-	-	3.3	13.1	77.6	-	5.3
(*ca.*	"	"	0.031	-	0.2	-	-	2.9	13.4	79.9	-	3.9
0.01M)	"	"	0.039	-	0.3	-	-	3.4	13.8	78.9	-	3.9
	"	"	0.023	0.036	0.3	-	-	2.8	10.6	81.7	-	4.6

a. The yields have been normalized to 100%.

b. Limited accuracy (see Section II.2.)

c. Indicated by the g.l.c. retention times.

d. The acetates (62) and (63) were not present.

Table II.1.4. (PART B)

Products from the solvolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) in acetic acid containing sodium acetate.

Substrate	Temp °C	Time h.	Conc.M sodium acetate	Conc.M lithium perchlorate	PRODUCT RATIO 64/65	64+65/66	64/66	65/66
48, X=OTs	52.6	10	0.019	-	25.6	0.36	0.34	0.013
(ca.0.01M)	"	"	0.031	-	17.0	0.40	0.38	0.022
	"	"	0.039	-	19.7	0.39	0.38	0.019
	"	"	0.023	0.036	19.6	0.30	0.29	0.015
47, X=OTs	52.6	1.7	0.019	-	0.25	0.21	0.04	0.17
(ca.0.01M)	"	"	0.031	-	0.22	0.20	0.04	0.17
	"	"	0.039	-	0.25	0.22	0.04	0.17
	"	"	0.023	0.036	0.26	0.16	0.03	0.13

During this investigation Christol, Krapcho, Peters and Arnal[115] reported a less detailed study of the acetolysis of the two epimers (47 and 48 where X=OTs, respectively). The results of their product study are shown in Table II.1.5.

Table II.1.5.

Substrate	Temp °C	PRODUCTS (%)[a]			
		61	64 and 65	66	acetates
48, X=OTs	60	1	25	74	5
47, X=OTs	60	1	4	95	5

a. No recognition of the possibility of geometric isomers was made.

An evaluation of experimental results in the light of the theoretical discussions (pages 47-51) enable the following conclusions to be drawn.

Firstly, the presence of 1-(3-t-butylcyclopentyl)--cyclopentyl derivatives (68a,* 68b* and 69) in the product mixture from the trans-ester (48, X=OTs) is strongly indicative of reaction via a chair conformation (Figure II.1.2.)

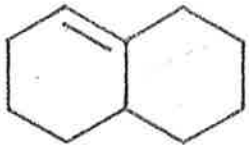
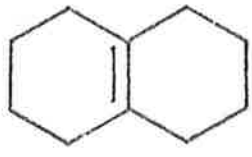
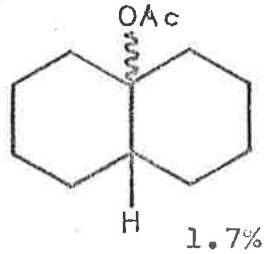
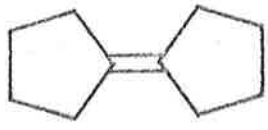
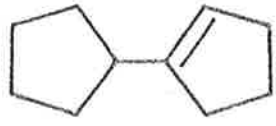
* Both the cis- and trans-olefins (68a and 68b, respectively) were synthesized. The two isomers could not however be distinguished by gas liquid chromatographic or by spectral techniques.

in which the participation by the trans-anti-planar bond provides sufficient energy for the ring contraction process to occur. On the other hand, the absence of these products (68a, 68b and 69) in the acetolysis of the cis-isomer (47, X=OTs) is in accord with reaction proceeding exclusively via a chair conformer (Figure II.1.2.) in which stereo-electronic considerations make the formation of ring contract-ed products improbable.

In the acetolysis of spiro[4.5]dec-6-yl p-toluene--sulphonate (36, X=OTs) only 0.4% of products corresponding to ring contraction were found.[70] (Table II.1.6.)

Table II.1.6.

Products from the solvolysis of spiro[4.5]dec-6-yl p-toluenesulphonate (36).

Substrate	PRODUCTS			
36, X=OTs	 24.3%	 68.4%		1.7% cis 4.1% trans
	 0.2%	 0.2%	 0.2%	

This is in marked contrast to the approximate 10% formed from the trans-ester (48, X=OTs) and is obviously a function of the flexibility of the six-membered ring in the unsubstituted spiro ester (36, X=OTs). Without the t-butyl group, the ester (36, X=OTs) can react preferentially in a chair conformation that places the leaving group in a suitable position to undergo ring expansion. This process is both stereo-electronically favourable and involves the energetically favourable participation of the adjacent five-membered ring. Consequently ring contraction is not a major product forming process. (Figure II.1.6.)

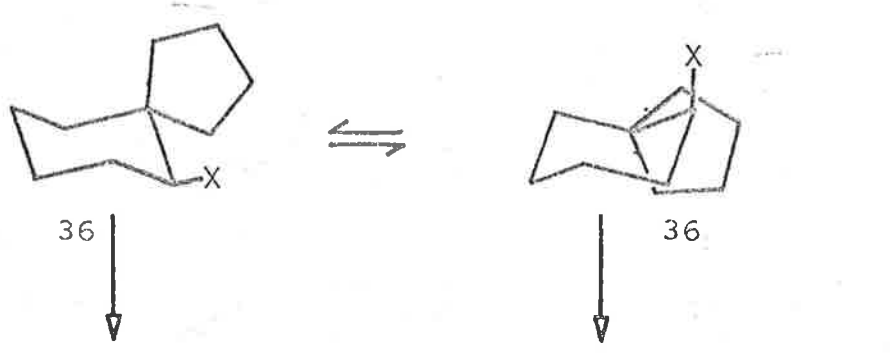


Figure II.1.6.

Since the position of the counter-ion in ion-pairs is believed to play an important role in the determination of products in acetolysis reactions[84,64,70,60] the subsequent discussion will centre around the influence of the counter-ion on the formation of the ring expanded products

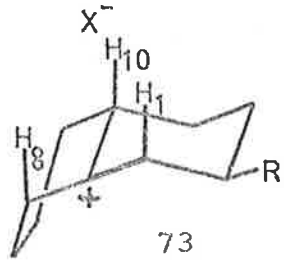
(cis- and trans-2-t-butyl-$\Delta^{1,9}$-octalin (64b and 64a, respectively), cis- and trans-7-t-butyl-$\Delta^{1,9}$-octalin (65b and 65a, respectively) and 2-t-butyl-$\Delta^{9,10}$-octalin (66)). The formation of these products is considered in terms of the theoretical discussion earlier.

As was mentioned in the introduction, the ratio of $\Delta^{1,9}$-octalin (30) to $\Delta^{9,10}$-octalin (31) has proved useful in the investigation of the mechanism of the ionic reactions which involve the intermediacy of the 9-decalyl cation (25).[70] In the present study, the ratios of the octalins (64)/(65), (64)+(65)/(66), (64)/(66) and (65)/(66) have been used as a basis for gaining information about the mechanism of the solvolysis of the two esters (47) and (48) (where X=OTs) in terms of both the conformation of the intermediate 2-t-butyl-9-decalyl cation (44) and the position of the counter-ion.

Although it is not disputed that the acetate anion is a stronger base than the p-toluenesulphonate anion the possibility can occur that the latter may be ideally situated to abstract a proton from the position β to the incipient cation. It is important that the hydrogen which is removed by the base in this process is in a stereo-electronically favourable position.[148] In effect, this process requires the vacant p-orbital of the incipient cation to be in the same plane as the orbital of the C-H bond in question.

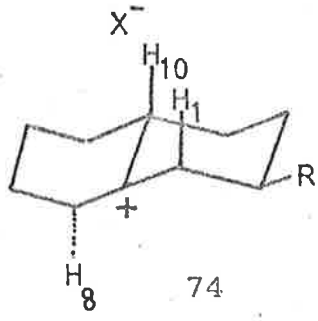
The importance of counter-ions in the slightly nucleophilic solvent, acetic acid, has been known for some time. Skell and Hall[64] have shown that E-1 elimination from erythro and threo-3-deuterio-2-butyl p-toluene--sulphonates gives cis- and trans-2-butenes as the result of almost exclusive cis-elimination of p-toluenesulphonic acid in acetic acid or nitrobenzene. In the more nucleophilic solvents, such as 80% ethanol-water, trans-elimination predominates. An explanation was advanced in which the departing anion could act as a base to remove the nearest proton immediately after the ionization in the less nucleophilic solvents.

Acetolysis of the cis-ester (47, X=OTs) (chair conformation) will yield an intermediate cation, the conformation of which could be either cis-like (73) or trans-like (74). (Figure II.1.7.) (Grob et.al.[69] suggested that these conformers, in which one ring takes a boat form, are not readily interconvertible. This premise is based solely on an examination of models.) The counter-ion in both conformers (73) and (74) will be initially very close to H_{10} (hydrogen on C_{10}) and could act as a base to remove it as a proton to give 2-t-butyl-$\Delta^{9,10}$-octalin (66). A value of 0.21 for the ratio ((64)+(65)/(66)) is compatible with this elimination process.



73

(47, X=OTs) ⟶ OR



74

Figure II.1.7.

The formation of the two octalins (64) and (65) can be visualized as proceeding by elimination of H_1 and H_8, respectively, by the counter-ion.

Although by a small movement the counter-ion, X^-, is able to get into a position where it can abstract H_1 and H_8 in the cis-like conformer (73), it can only abstract H_1 in the trans-like conformer (74). (H_8, being on the opposite side of the molecule in (74), is not in an accessible position to be removed by the counter-ion). The observed value of 0.25 for the ratio (64)/(65) is consistent only with the cis-like conformer (73).

That the olefin did not arise mainly by abstraction of H_8 by acetate ion, present in the reaction medium, is consistent with the observation that the ratio (64)/(65) was unaltered by an increase in the concentration of this ion. (Table II.1.4.) It is thus concluded that the cis-like conformer (73) provides the best model for the intermediate cation involved in the solvolysis of cis-9-t-butylspiro[4.5]--dec-6-yl p-toluenesulphonate (47, X=OTs). It is to be noted that this result is in contrast to the conclusion of Gream,[70] who suggested the possibility of a trans-like conformer in the transition state of the acetolysis of spiro[4.5]dec-6-yl p-toluenesulphonate (36, X=OTs). Of particular interest is the fact that the ratio of the octalins ((64)+(65)/(66)) (that is, 0.36) observed in the present study closely resembles the ratio of $\Delta^{1,9}$-octalin (30) to $\Delta^{9,10}$-octalin (31) (that is, 0.39) recorded by Gream.[70] This may indicate that both reactions proceed by way of intermediate conformers having similar shapes.

As was previously mentioned, an initial non-chair conformer of the trans-ester (48, X=OTs) will lead to a number of cis*-2-t-butyl-9-decalyl cations (77-81) each

---

* This refers to a cis-relationship of the hydrogens at the 2 and the 10 positions.

having a different conformation. Conversely a chair conformer of the trans-ester (48, X=OTs) should yield the isomeric trans*-cations (75 and 76). (Scheme II.1.3.)

It can be seen that the cations (75) and (76) are very similar to cations (73) and (74), (obtained in the solvolysis of the cis-ester (47, X=OTs)), respectively. The two sets differ significantly in that the counter-ion, X^-, should be further removed from H_{10} and H_1 in (75) and (76) than in (73) and (74). This is a consequence of the orientation of the leaving group in the chair conformation of the parent esters (47 and 48 where X=OTs). Thus, the counter-ion should be in a much better position to abstract H_8 in preference to H_1 and the value of the ratio (64)/(65) will consequently be very small; the found value (25.6) is not compatible with this process and a chair conformer of the trans-ester (48, X=OTs) can be considered as an unlikely intermediate in the ring-expansion process.

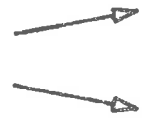
As previously mentioned, Dauben et.al.[134] suggested that stereo-electronic factors are secondary to the release of ring strain in determining the rate and product distribution in the solvolysis of some bicyclo[m.n.o]alkane-1-methyl derivatives. However the results shown above are not

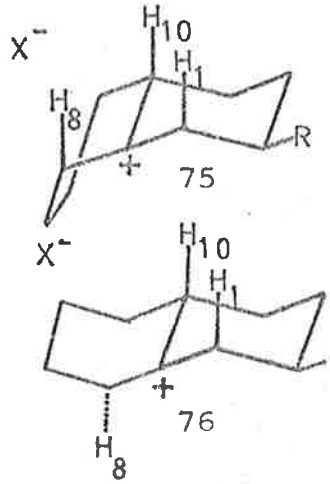
---

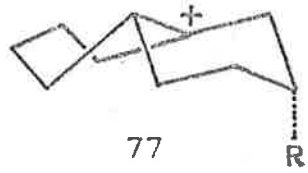
* This refers to a trans-relationship of the hydrogens at the 2 and the 10 positions.

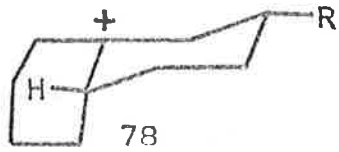
(48, X=OTs)

(CHAIR)



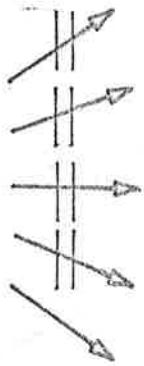


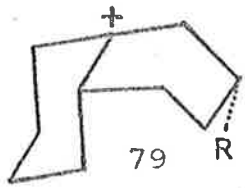


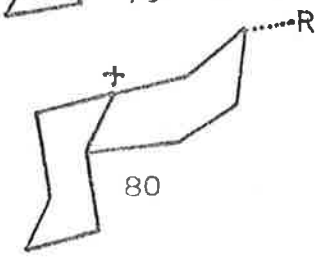


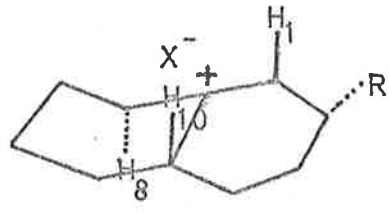
(48, X=OTs)

(NON-CHAIR)









Scheme II.1.3.

consistent with their suggestion when applied to this spiro system (47 and 48, where X=OTs).

The possible intermediate cations (77-81) arising from a non-chair conformer of the trans-ester (48, X=OTs) are depicted in Scheme II.1.3. After a thorough investigation of Dreiding models it seemed reasonable to disregard four, (77), (79) and (80) (for steric reasons) and (78) (for torsional reasons) of the conformers of the cis-2-t-butyl-9-decalyl cation.

In the flexible cation (81), the t-butyl group occupies a pseudo-equatorial position on a twist-boat ring while the unsubstituted ring is in a true boat conformation. The cation can exist in a number of different conformations as a result of this flexibility. The one depicted in Scheme II.1.3. is the only energetically favourable conformer which adequately satisfies the requirements of an explanation of the nature of the products based on the position of the counter-ion. The counter-ion, X^-, is in a good position to act as a base in abstracting H_{10} and H_1 but not H_8, which is now on the opposite side of the molecule. Consequently 2-t-butyl-$\Delta^{9,10}$-octalin (66) and cis-2-t-butyl-$\Delta^{1,9}$-octalin (64b) should be formed at the expense of cis-7-t-butyl-$\Delta^{1,9}$-octalin (65b). The observed values of 25.6, 0.34 and 0.013 for the ratios (64)/(65), (64)/(66) and (65)/(66), respectively, are consistent with this interpretation.

The presence of 9-t-butylspiro[4.5]dec-6-ene (61, ca. 0.5%) in the product mixture from acetolysis of both cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluene--sulphonate (47 and 48 where X=OTs, respectively) can be attributed to the stereo-electronically favourable E-1 elimination of the β-hydrogen in the 9-t-butylspiro[4.5]dec-6-yl cation.

Once again, the effect of increasing the concentration of acetate ion did not have a significant effect on the product distribution and it can be concluded that this species does not play an important role in the formation of the products.

The addition of lithium perchlorate, an efficient disruptor of intimate ion-pairs,[149] resulted in a marginal effect on the product distribution. It is fundamental to this discussion, however, that the intermediate ion-pairs generated from the epimeric esters (47 and 48 where X=OTs) are probably not intimate ion-pairs[150] because of the distance between the centre of positive charge and the anion X^-.

The observations made provide reasonable but not conclusive evidence to substantiate the stated arguments that chair and non-chair conformers are involved in the acetolysis of the cis- and trans-esters (47 and 48 where X=OTs, respectively) respectively.

II.2.

Determination of the Compositions of the Acetolysis Products.

The results of Christol and co-workers[115] on the acetolysis of cis- and trans-9-t-butylxpiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively) are outlined in Table II.1.5.

The present study shows these results to be incomplete. Firstly, Christol and co-workers failed to detect the presence of ring contracted products -

(i) cis- and trans-(3-t-butylcyclopentyl)cyclopent-1-ene (68a and 68b, respectively)

(ii) (3-t-butylcyclopentylidene)cyclopentane (69)

and secondly they did not differentiate between the positional and geometric isomers -

(i) cis- and trans-2-t-butyl-$\Delta^{1,9}$-octalin (64b and 64a, respectively)

(ii) cis- and trans-7-t-butyl-$\Delta^{1,9}$-octalin (65b and 65a, respectively).

The detection and characterization of the ring-contracted products (68)* and (69) have been successfully

---

* The olefin (68) represents the mixture of geometric isomers (68a and 68b). These were synthesized and were indistinguishable under all conditions of g.l.c. analysis and from their spectral properties.

carried out and are outlined in the following discussion. In addition the structures of the positional isomers, 2-t-butyl-$\Delta^{1,9}$-octalin (64) and 7-t-butyl-$\Delta^{1,9}$-octalin (65) have been established. (see page 73)

The trace from the g.l.c. column (12' x $\frac{1}{8}$" glass 5% Apiezon) that gave the best separation of the products formed by the acetolysis of the cis- and trans-esters (47 and 48, respectively) is reproduced in Figure II.2.1.

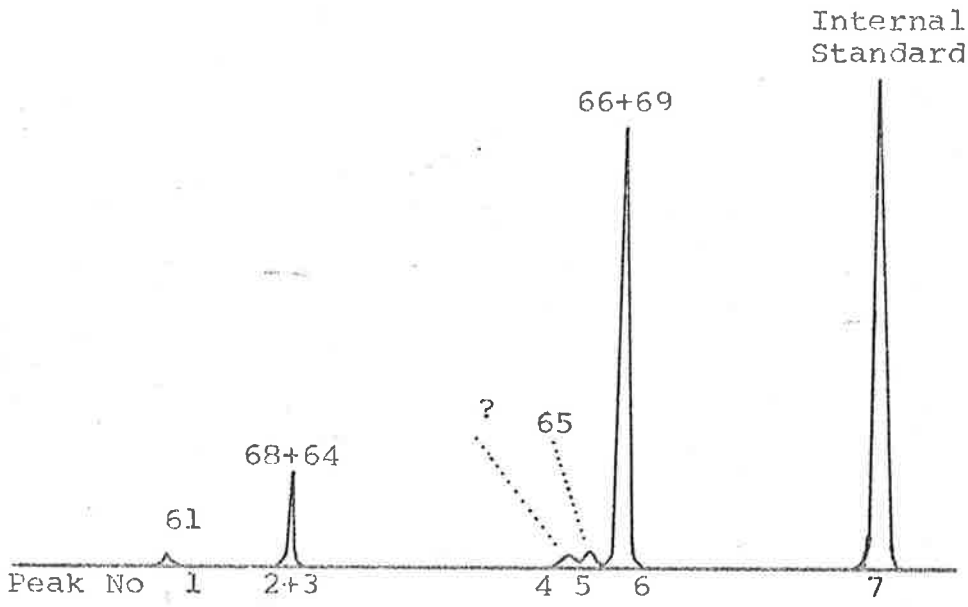


Figure II.2.1.

Detection and Quantitative determination of (3-t-butylcyclopentyl)cyclopent-1-ene (68).

The cis- and trans-olefins (68a and 68b, respectively) were synthesized and found to be inseparable under all conditions of gas liquid chromatographic analysis.

It was also found that only one column (150' x 0.02" Apiezon, Golay) could partially resolve the olefins (68) and (64).* This was particularly interesting as separation was obtained at temperatures in excess of 170°, while, at lower temperatures, peaks (2) and (3) (Figure II.2.1.) coalesced to a single symmetrical peak. The amount of the olefin (68) present (ca. 17%) (expressed as a fraction of peaks (2) and (3)) was estimated by measurement of the peak heights.

A quantitative estimate, as well as confirmation of identity, of (3-t-butylcyclopentyl)cyclopent-1-ene (68) was obtained by three other methods. In each of these a fraction, presumed to contain the olefins (68) and (64), was isolated from the product mixture. This mixture was obtained by acetolysis of the trans-ester (48, X=OTs), separated by preparative g.l.c. and treated in the following ways -

(i) Gas-liquid chromatographic analysis of the mixture, after it had been hydrogenated (5% palladium on carbon in acetic acid), indicated the presence of (3-t-butylcyclopentyl)cyclopentane (82, ca. 14%), trans-trans- and cis-cis-2-t-butyldecalin (84 and 83, ca. 60%

---

* The olefin (64) was possibly a mixture of geometric isomers.

and 20%, respectively) and an unidentified product* (ca. 6%). (Scheme II.2.1.)

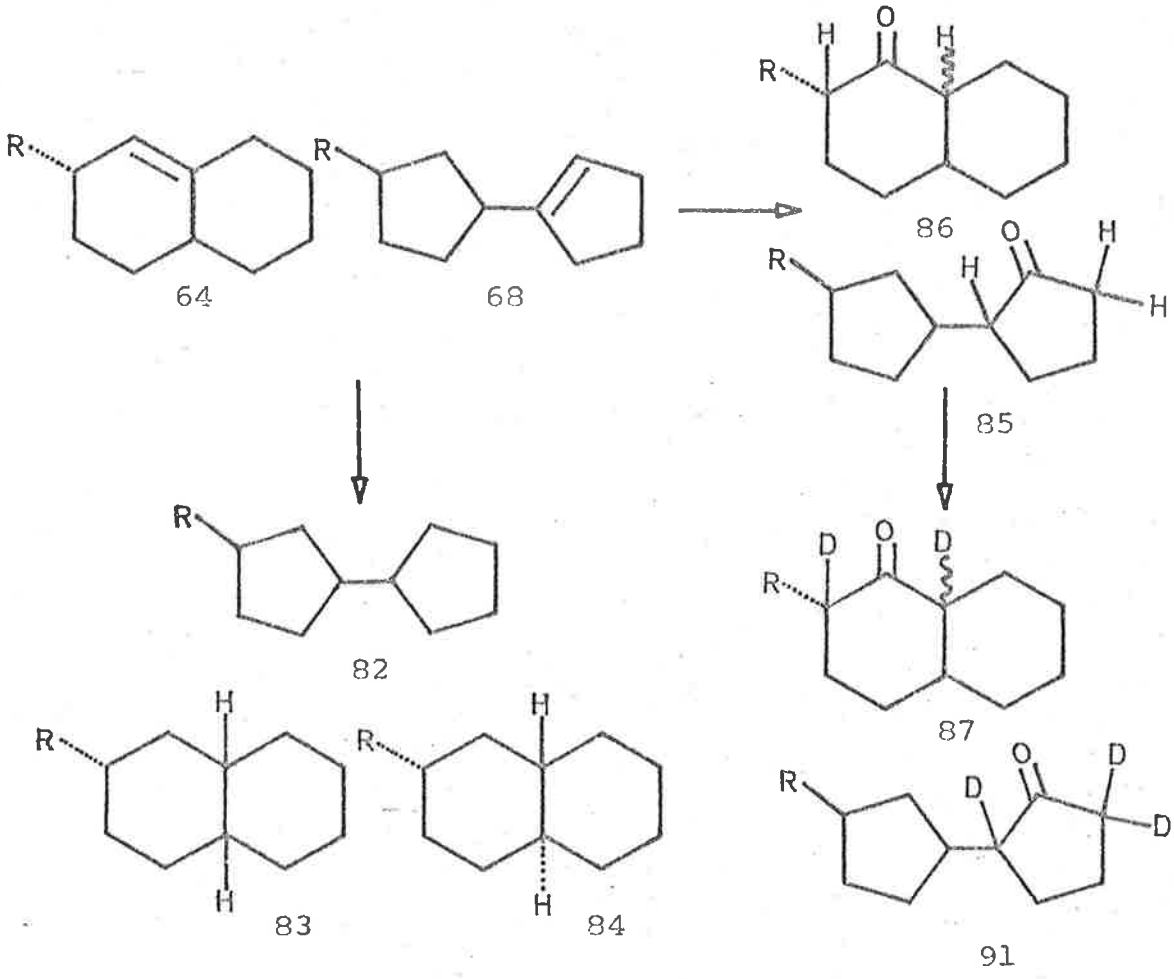
(ii) Hydroboration, followed by oxidation to the corresponding ketones yielded a mixture of ketones containing 2-(3-t-butylcyclopentyl)cyclopentanone (85, ca. 19%) and 2-t-butyldecal-1-one (86, ca. 81%) (possibly a mixture of geometric isomers). (Scheme II.2.1.)

(iii) The mixture of ketones from part (ii) above was dissolved in o-deuterio-ethanol containing a catalytic amount of sodium ethoxide. The mass spectrum** of the product contained peaks at m/e 211 and 210 in the approximate ratio 14/86. This was consistent with the presence of 2-(3-t-butylcyclopentyl)-2,5,5-tri-deuteriocyclopent--anone (91, ca. 14%) and 2-t-butyl-2,9-dideuteriodecal-1-one (87, ca. 86%).

---

* This product was also present in the hydrogenation of a mixture of (3-t-butylcyclopentylidene)cyclopentane (69) and 2-t-butyl-$\Delta^{9,10}$-octalin. It may be an isomeric 2-t-butyldecalin.

** See appendix.



Scheme II.2.1.

The results correspond to an overall yield of ca. 4.4% for the olefin (68) produced in the acetolysis of the trans-ester (48, X=OTs).

Detection and Quantitative determination of (3-t-butyl-cyclopentylidene)cyclopentane (69).

The mixture, presumed to contain the olefins (69) and (66), was separated from the product mixture (obtained by acetolysis of the trans-ester (48, X=OTs)) by preparative g.l.c. and treated in the following manner -

(i) Hydrogenation of the mixture followed by g.l.c. analysis, revealed the presence of (3-t-butylcyclo-pentyl)cyclopentane (82, ca. 5%), trans-trans-2-t-butyl-decalin (84, ca. 75%), cis-cis-2-t-butyldecalin (83, ca. 11%) and an unidentified product* (ca. 9%). (Scheme II.2.2.)

(ii) The second method was used initially as a qualitative procedure to detect the presence of (3-t-butyl-cyclopentylidene)cyclopentane (69) in a mixture which was assumed to contain this olefin (69) and 2-t-butyl-$\Delta^{9,10}$-octalin (66). It was later developed to provide a quantitative measure of (69) in the same mixture.

An accurately weighed sample of (3-t-butylcyclo-pentylidene)cyclopentane (69) (obtained by independent synthesis) was subjected to ozonolysis under standard conditions (see section IV) and the resulting ozonide was reduced to give 3-t-butylcyclopentanone (88) and cyclopentanone. The absolute yield (56 ± 5%) of the ketone (88)

---

* see footnote on page 68.

was determined by g.l.c. analysis (naphthalene was used as an internal standard) of the products.

The ozonolysis was repeated, using the same conditions, with an accurately weighed sample of the mixture of olefins* (66 and 69) (obtained by preparative g.l.c.) and the weight of the ketone (88) was again calculated. A simple mathematical manipulation (Eq.1.) yielded the weight of (3-t-butylcyclopentylidene)cyclopentane (69) in the original mixture of olefins (69 and 66).

$$\text{weight of olefin (69)} = \frac{\text{Molecular weight (69)}}{\text{Molecular weight (88)}} \times \text{weight of (88)} \times \frac{100}{56} \qquad \text{Eq.1.}$$

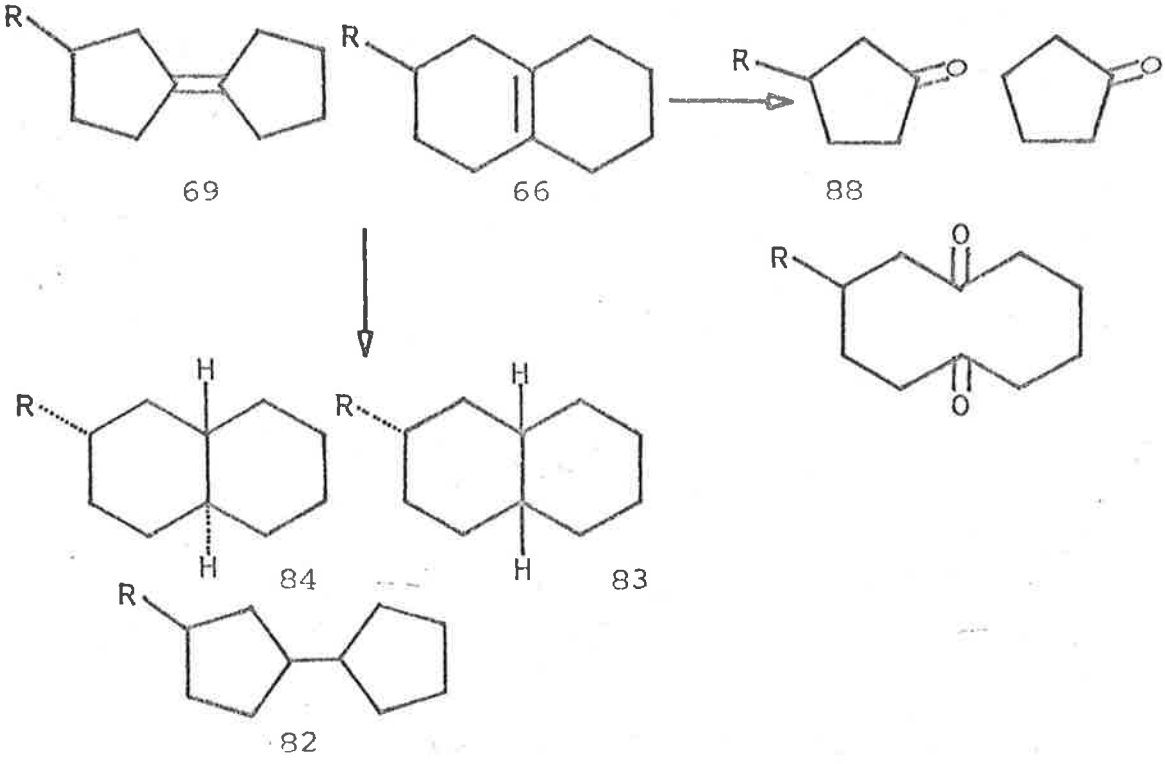
This gave a value of 6 ± 1% for the yield of the olefin (69) which is in good agreement with the value obtained by procedure (i).

From the two procedures (i) and (ii), it was possible to determine the yield of (3-t-butylcyclopentylidene)-

---

* A similar procedure was used on the total product mixture (obtained from the acetolysis of the trans-ester (48, X=OTs)) but g.l.c. analysis of the ketone (88) was complicated by the presence of compounds with similar retention times.

-cyclopentane* (69, ca. 4%) in the total product mixture from the acetolysis of the trans-ester (48, X=OTs).



Scheme II.2.2.

---

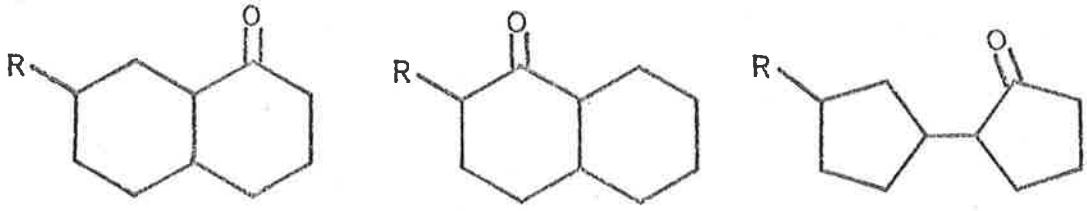
* This procedure was carried out on the fraction (peak 6) isolated from the acetolysis of the cis-ester (47, X=OTs) but g.l.c. analysis showed that no 3-t-butylcyclopentanone (88) was present.

Identification of 2-t-butyl-$\Delta^{1,9}$-octalin (64) and 7-t-butyl-$\Delta^{1,9}$-octalin (65).

7-t-Butyl-$\Delta^{1,9}$-octalin (65) was synthesized by an unambiguous route (section IV) and was shown to correspond to peak 5. (Figure II.2.1.) Unfortunately the isomeric octalin (64) was not synthesized and consequently several methods were used in an attempt to uniquely determine it in the product mixture from the acetolysis of the cis- and trans-ester (47 and 48, respectively).

Considerable difficulty was encountered in the separation, by preparative g.l.c., of the olefin (65) from the solvolysis products, because of the similar retention times of 2-t-butyl-$\Delta^{9,10}$-octalin (66) and the supposed olefin (65). Consequently the sample of the olefin, presumably 7-t-butyl-$\Delta^{1,9}$-octalin (65) contained 2-t-butyl-$\Delta^{9,10}$-octalin (66) as an impurity.

The octalin (65) was then hydroborated and oxidized to the corresponding ketone (89). (Figure II.2.2.)



89 86 85

Figure II.2.2.

At the same time a sample of the olefin presumed to be 2-t-butyl-$\Delta^{1,9}$-octalin (64), was separated from the mixture of olefinic products obtained from the acetolysis of trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs). This was contaminated (previously determined) with (3-t-butylcyclopentyl)cyclopent-1-ene (68, ca. 15%).

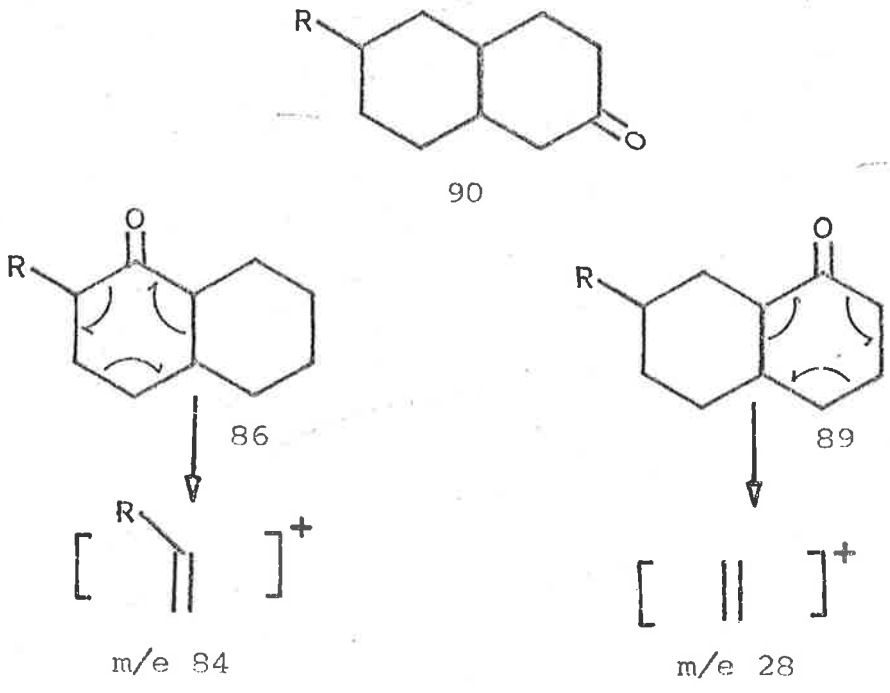
Hydroboration and subsequent oxidation of this sample gave a mixture of ketones. The identity of 2-(3-t-butylcyclopentyl)cyclopentan-1-one (85) in the mixture was confirmed by comparison (g.l.c.) with an authentic sample. The other products were presumed to be isomeric 2-t-butyl--decal-1-ones (86).

The mass spectra of these ketones provide strong evidence in favour of the structures assigned in Figure II. 2.2.

Initially it was envisaged that the McLafferty rearrangement[151] would distinguish between the ketones (86) and (89); the former (86) would be expected to undergo the rearrangement, whereas the latter (89) does not have the required arrangement of the carbonyl and adjacent t-butyl groups.[152] It was found however that the presence of a strong peak at m/e 152 which was expected to be characteristic of the McLafferty rearrangement had no diagnostic value as all the isomeric t-butyldecalones (86, 89 and 90) (Scheme II.2.3.) gave a strong peak at m/e 152.

Eventually it was found that a Retro-Diels-Alder fragmentation[153] was particularly valuable as a diagnostic test in determining the position of the carbonyl function in the ketones under discussion, that is (86) and (89).

An inspection of the mass spectra of the two ketones revealed that the ketone presumed to be (86) exhibited a base peak at m/e 84. On the other hand, the ketone presumed to be (89) exhibited only a negligible peak at m/e 84 (10). The origin of this fragment, m/e 84, is outlined in Scheme II.2.3.



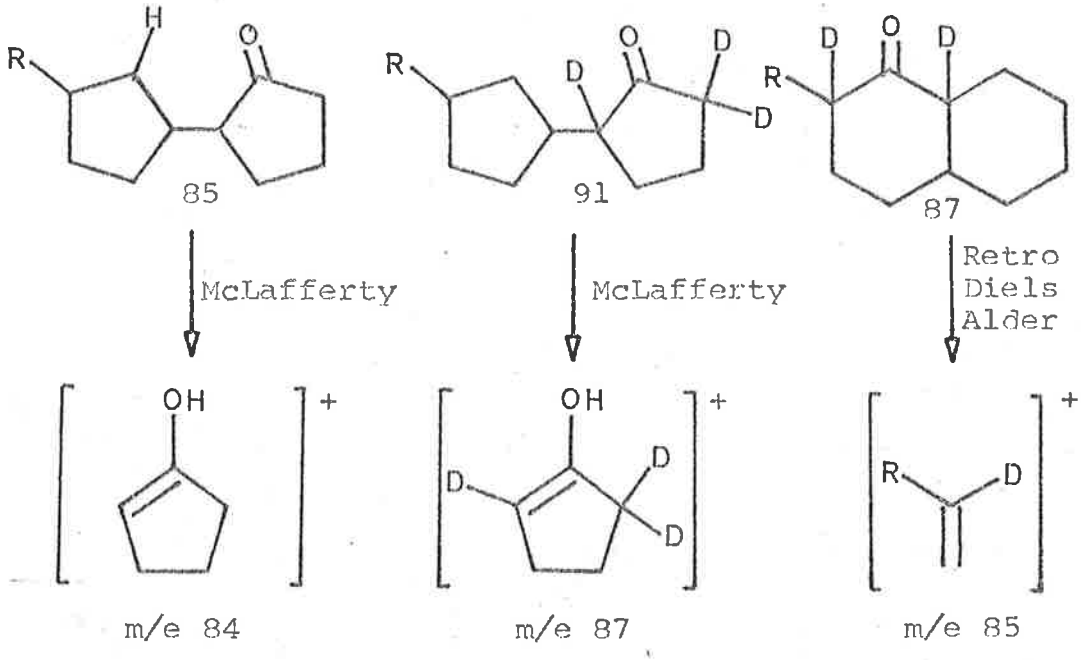
Scheme II.2.3.

This result appears to indicate that the structures assigned to the ketones (86) and (89) are correct. The logical conclusion to be drawn from this result is that the structure assigned to the olefin (64) is correct.

After this investigation had been completed, an authentic sample of 2-(3-t-butylcyclopentyl)cyclopentan-1-one (85) was prepared and the mass spectrum of this sample was subsequently found to exhibit a base peak at m/e 84. (McLafferty rearrangement) (Scheme II.2.4.) The presence of this ketone(85) had been established in the sample that supposedly contained 2-t-butyldecal-1-one (86). Consequently some doubt was cast on the conclusion concerning the structures assigned to the ketones and the associated olefins (64 and 65).

In order to clarify this situation, the original sample, which contained the ketones (85) and presumably (86), was dissolved in o-deuterio-ethanol containing a catalytic amount of sodium ethoxide and the mass spectrum of the product was recorded. This contained a strong peak at m/e 85 (49) and a minor peak at m/e 87 (7). It is reasonable to assign the former to the Retro-Diels-Alder fragmentation of the ketone presumed to be 2-t-butyl-2,9-dideuteriodecal-one (87), whilst the latter arises from the McLafferty rearrangement of 2-(3-t-butylcyclopentyl)-2,5,5-trideuterio-

-cyclopentan-1-one (91).* (Scheme II.2.4.)



Scheme II.2.4.

It appears that although there is a contribution from the ketone (85) to the base peak, m/e 84, in the mass spectrum of the original sample (containing the ketones (85) and presumably (86)), the Retro-Diels-Alder fragmentation of the ketone presumed to be (86) is the major contributor.

Additional evidence for the structural assignment to the ketone assumed to be (86) was provided by an exam-

---

* The strength of this line of reasoning is limited by the fact that an authentic sample of the deuterated ketone (91) was not prepared.

ination of the mass spectra of -

(i) The product obtained by dissolution of the original sample, containing the ketones (85) and presumably (86), in deuterio-ethanol with a catalytic amount of sodium ethoxide.

(ii) The product obtained by dissolution of an authentic sample of 7-t-butyldecal-1-one (89) in deuterio-ethanol containing a catalytic amount of sodium ethoxide.

The former sample (i) produced a molecular ion at m/e 210 (13) and a peak at m/e 154 (100), which were characteristic of a dideuterated-t-butyldecalone while the latter sample (ii) exhibited a molecular ion at m/e 211 (13) and a peak at m/e 155 (58), which were characteristic of a trideuterated-t-butyldecalone. (The mass spectra are collected in the appendix)

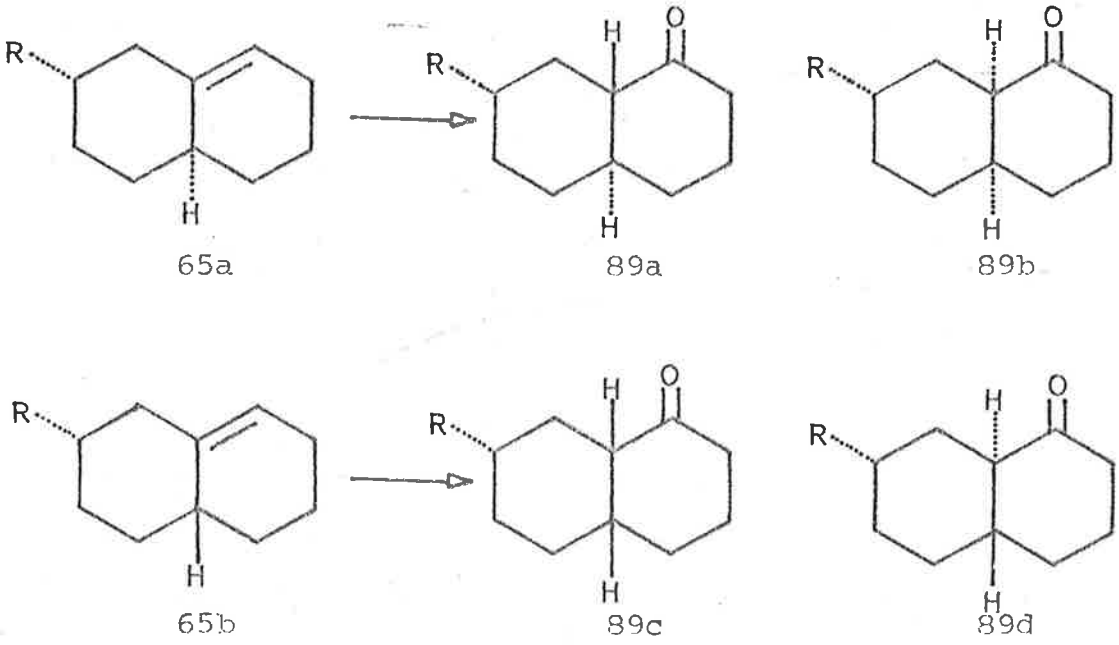
Attempted Detection of the Geometric Isomers of 7-t-Butyl-$\Delta^{1,9}$-octalin (65a and 65b) in the product mixture from the acetolysis of cis-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47, X=OTs).

Although the olefin, trans-7-t-butyl-$\Delta^{1,9}$-octalin (65a) obtained by synthesis was shown to have exactly the same g.l.c. behaviour (on seven different columns) as the compound(s) giving rise to the single peak 5 (Figure II.2.1.), it was considered possible that peak 5 was in fact produced by the two isomeric cis- and trans-7-t-butyl-$\Delta^{1,9}$-

octalins (65b and 65a, respectively).

In order to explore this possibility, the fraction of products from the acetolysis of the cis-ester (47, X=OTs) corresponding to peak 5 (Figure II.2.1.) was separated by preparative g.l.c.. It was not possible however, to separate this fraction without contamination from peak 6 which contained 2-t-butyl-$\Delta^{9,10}$-octalin (66).

Hydroboration of this fraction, followed by oxidation to the ketones was anticipated to yield a mixture of up to four geometrical isomers of 7-t-butyldecal-1-one (89a, 89b, 89c and 89d). (Scheme II.2.3.)



Scheme II.2.3.

The stereochemistry at the C_{10} position of these ketones should be identical to that of the parent olefin(s). House[154] indicated that a cis-relationship between the hydrogens at C_7 and C_9 would be more stable than a trans-arrangement. Consequently, equilibration of this mixture of ketones (89a - 89d) should result in a mixture which contains predominantly the two thermodynamically most stable ketones, trans-trans-7-t-butyldecal-1-one (89a) and cis-cis-7-t-butyldecal-1-one (89c). The former ketone is characteristic of the trans-olefin (65a) and the latter ketone is characteristic of the cis-olefin (65b).

Unfortunately, owing to the fact that an uncontaminated sample of peak 5 was unattainable, the ultimate aim of this work could not be realized. Examination of the ketonic fraction, following the hydroboration and oxidation of this sample, revealed the presence of at least seven compounds. It is conceivable that these probably arose by migration of the boron, during the hydroboration procedure. There is ample precedent* to support the migration of the boron atom from a tertiary bridge-head position to a secondary carbon atom and it follows that this would produce the isomeric ketones (86, 89, 94 and 95). (Figure II.2.3.)

---

* Gream has observed similar migratory tendencies in the hydroboration of $\Delta^{9,10}$-octalin. (see also ref. 155)

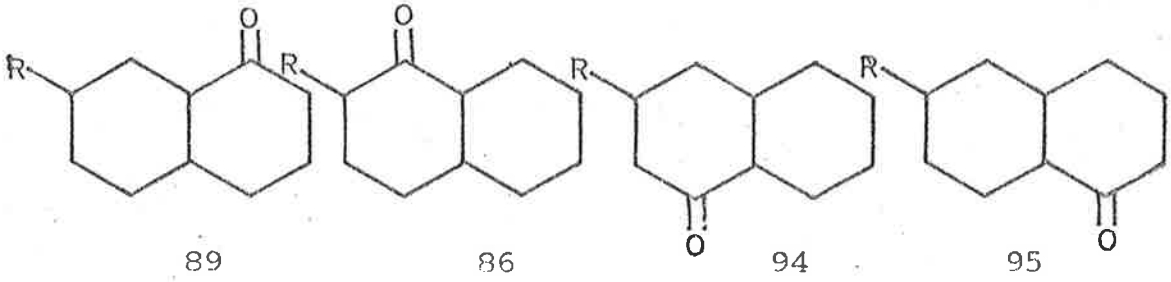


Figure II.2.3.

At this stage, in the absence of an authentic sample of cis-7-t-butyl-$\Delta^{1,9}$-octalin (65b), no information could be obtained about the presence or absence of the isomeric 7-t-butyl-$\Delta^{1,9}$-octalins (65a and 65b).

III.1.

Synthesis of some of the compounds required in the study of the acetolysis of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively).

Synthesis of cis- and trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, respectively) and the corresponding p-toluenesulphonate esters.

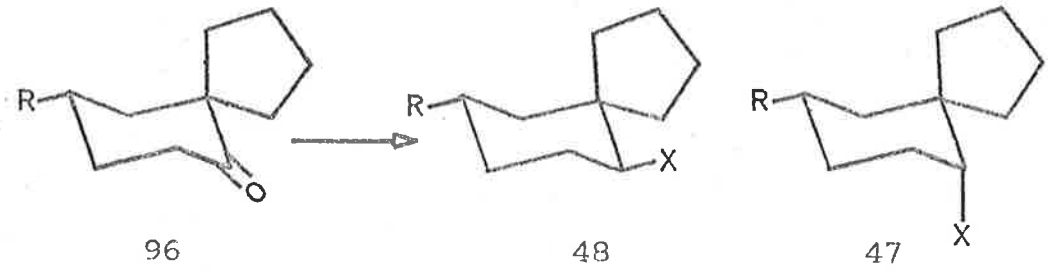
Initially it was considered desirable to devise syntheses which would yield the two alcohols cis- and trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, respectively) with a high degree of stereoselectivity.

9-t-Butylspiro[4.5]decan-6-one (96), an obvious precursor to the two alcohols (47 and 48 where X=OH) was prepared, in 69, 55 and 58% yield, by treating 4-t-butyl--cyclohexanone (97) with 1,4-dibromobutane and potassium t-butoxide in benzene, toluene and t-butyl alcohol, respectively.

An inspection of models of the ketone (96) indicated that both "product developement control" and "steric approach control"* would favour the formation of the

* It has been suggested recently that "steric approach control" is the significant factor in these reductions.[157]

equatorial alcohol (48, X=OH) when the ketone (96) was treated with complex metal hydrides.[156] (Scheme III.1.).



96 48 47

Scheme III.1.

Lithium tri-t-butoxyaluminium hydride, lithium aluminium hydride and sodium borohydride gave the trans-alcohol (48, X=OH) contaminated with 7, 9 and 10%, respectively, of the cis-epimer (47, X=OH) (Table II.1.).

Careful recrystallization from aqueous methanol gave the trans-alcohol (48, X=OH) which appeared to be pure when examined by g.l.c. and t.l.c.. Surprisingly however, it was not possible to obtain satisfactory microanalytical data for the compound although such data was readily obtained from its acetyl and p-toluenesulphonyl derivatives.

An attempt to obtain the acetyl derivative and from it thus the cis-alcohol (47, X=OH) by inversion of the configuration at C_6 of trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs) by treatment of the ester (48,

X=OTs) with potassium acetate in dimethylformamide[158] was unsuccessful. At 5° unchanged starting material (48, X=OTs) was recovered while at reflux temperature a mixture of olefins was obtained. Similar behaviour has been encountered with trans-4-t-butyl-2,2-dimethylcyclohexyl p-toluenesulphonate (56) which undergoes elimination rather than SN2 substitution when treated with tetramethylammonium acetate in N-methylpyrrolidone.[132]

Reduction of the ketone (96) in the presence of Adam's catalyst and acetic acid yielded the trans-alcohol (48, X=OH) contaminated with 22% of the epimer (47, X=OH). This is consistent with the preferential approach of the catalyst surface to the less hindered, a-face of the molecule (Table III.1.).[159]

Eliel[160] and Henbest[161] have demonstrated the usefulness of soluble iridium-phosphite catalysts in the presence of mineral acids to convert cyclohexanone derivatives to axial alcohols. Although 4-t-butylcyclohexanone (97) gave essentially pure cis-(axial)-alcohol,* 9-t-butylspiro-[4.5]decan-6-one (96) was unaffected even under prolonged and vigorous conditions. The conclusion that the carbonyl

---

* The reduction of the ketone (97) has been reported by Eliel[160] but was repeated in this work with an identical result.

group is too hindered in (96) for reaction to occur with the iridium complex is in harmony with a recent report that 2,2-dimethylcyclohexanone gave the corresponding alcohol in low yield after prolonged reaction while 2,2,6-trimethyl--cyclohexanone was recovered unchanged.[162] (Table III.1.)

Table III.1.

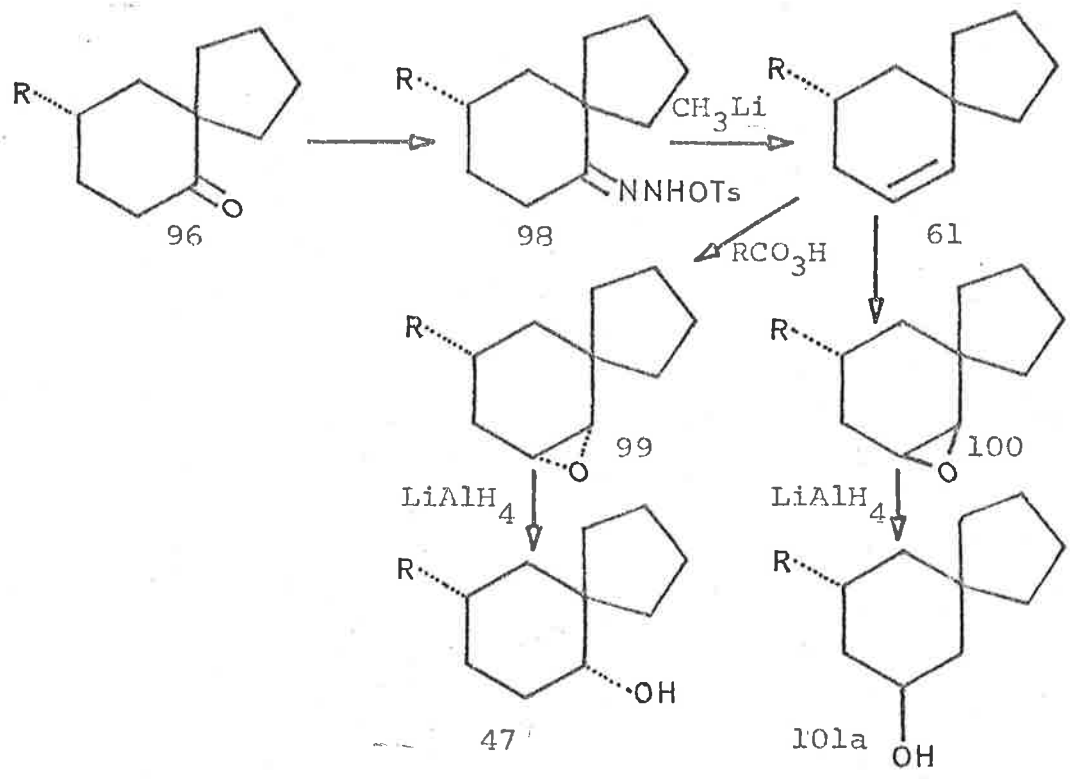
Results of the Reduction of 9-t-Butylspiro[4.5]decan-6-one (96)

Reaction Conditions	cis-alcohol (47) %[a]	trans-alcohol (48) %[a]
1) Iridiumtetrachloride/hydrochloric acid/trimethylphosphite/water/propan-2-ol	0	0
2) Lithium tri-t-butoxyaluminium hydride/tetrahydrofuran	7	93
3) Sodium borohydride/methanol	10	90
4) Lithium aluminium hydride/ether	9	91
5) Adam's catalyst/acetic acid/hydrogen	22	78
6) Aluminium isopropoxide/propan-2-ol	37	63

a. The alcohols (47 and 48 where X=OH, respectively) were analysed by g.l.c. (R, 167°) and exhibited retention times of 35min 20s and 38min 16s, respectively.

A successful, though for preparative purposes not entirely satisfactory, stereoselective route to the cis-

alcohol (47, X=OH) is outlined in Scheme III.2.



Scheme III.2.

The readily prepared p-toluenesulphonylhydrazone derivative (98) was converted quantitatively into 9-t-butylspiro[4.5]dec-6-ene (61) by treatment with methyl lithium in ether.

Although Winstein[119] stressed the danger of inferring ground state conformations from the product distribution, Rickborn[163] has pointed out, that in epoxidation reactions, conformational effects in the ground state are quantitatively reflected in the transition state. From a consideration of models of the olefin, it was evident that the β-face of the olefin (61) (Figure III.1.), in the most stable con-

formation, was more hindered as a result of the pseudo-axial methylene group than the α-face. The predominant product from the epoxidation should then be cis-9-t-butyl-cis-6,7-epoxyspiro[4.5]decane (99).

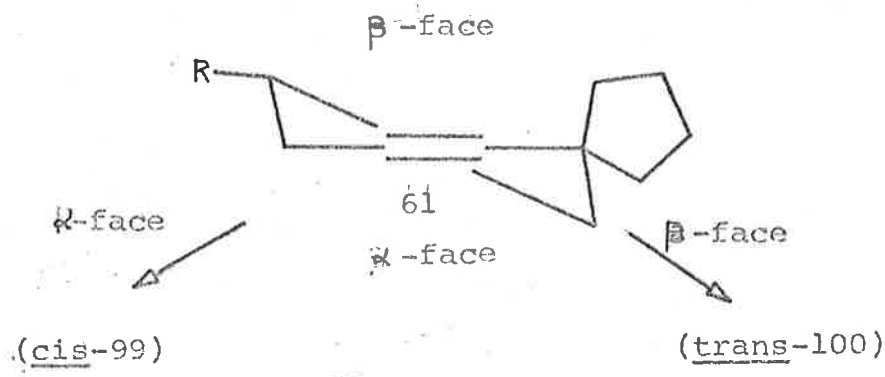


Figure III.1.

When the olefin (61) was treated with m-chloro--perbenzoic, perphthalic or percamphoric acids, a mixture (ca. 3:1) of the two epoxides (99) and (100), respectively, was obtained. Apparently the steric bulk of the epoxidizing agent is not a controlling factor in this reaction. This is not altogether surprising when considered in the light of the mechanism of the epoxidation reaction in which presumably only the oxygen of the peracid is in the immediate vicinity of the olefinic bond.[163]

A pure sample of the cis-epoxide (99) was obtained by preparative gas-liquid chromatography. As a consequence of the well documented trans-diaxial opening of oxirane

rings[164] by reagents such as lithium aluminium hydride and lithium in ethylamine, the epoxide (99) should give cis-9-t-butylspiro[4.5]decan-6-ol (47, X=OH). Indeed, it was found that treatment of the epoxide (99) with lithium aluminium hydride gave a single alcohol* (m.p. 86.5-88.5°) whose properties were clearly different from those of the trans-alcohol (48, X=OH) (m.p. 78.5-79°).

Oxidation of the new alcohol with Jones reagent yielded 9-t-butylspiro[4.5]decan-6-one (96) and thus it must be the required cis-alcohol (47, X=OH).

Confirmatory evidence for this assignment of configuration was available from the n.m.r. and mass spectral properties of the two compounds. Lemieux[166] observed that the half-width of the n.m.r. signal for the carbinol hydrogen of cis- and trans-4-t-butylcyclohexanol (51 and 52 where X=OH, respectively) was approximately 7 and 22c/s, respectively. The generally accepted diagnostic observation[167] is in good agreement with the values of approximately 7 and 20c/s recorded for the corresponding signal in the n.m.r. spectra of the cis- and trans-alcohols (47 and 48),

---

* The alcohol was recrystallized before the analysis was carried out and this would effectively remove any isomeric alcohols produced by rearrangement of the epoxide.

respectively.

The elimination of the elements of water in the mass spectra of the epimeric 4-t-butylcyclohexanols (51 and 52 where X=OH, respectively) has been related to the stereochemistry of the parent alcohol.[168] Dolejs[169] found that the ratio $\left[M - H_2O\right]^+/\left[M\right]^+$ was 60 and 0.12 for trans- and cis-4-t-butyl-2,2-dimethylcyclohexanol (56 and 55 where X=OH, respectively), respectively. The values of 0.44 and 23 found for the cis- and trans-spiro alcohols (47 and 48) respectively, are consistent with the configuration assigned to these two alcohols.

This clearly establishes that the major component of the mixture of epoxides, formed by the epoxidation of the olefin (61) is cis-9-t-butyl-cis-6,7-epoxyspiro$\left[4.5\right]$--decane (99) while the minor component must be the epimeric compound (100).

The following transformations, which were carried out before the mixture of epoxides (99 and 100) had been successfully separated,* are in accord with this assignment.

---

* The difficulty encountered in the g.l.c. separation of these two epoxides (99 and 100) prohibited the isolation of a pure sample of the minor component, trans-9-t-butyl-cis-6,7-epoxyspiro$\left[4.5\right]$decane (100). As a consequence no investigation of this isomer was carried out.

Reduction of the initial mixture (3:1) of the epoxides with lithium aluminium hydride or lithium in ethylamine gave a mixture of four alcohols (see later) which was oxidized with Jones reagent to a mixture of 9-t-butylspiro[4.5]decan-6-one (96) and 9-t-butylspiro[4.5]-decan-7-one (102). (Table III.2.)

Table III.2.

EPOXIDIZING AGENT	9-t-butylspiro-[4.5]decan-6-one (96) %[a]	9-t-butylspiro-[4.5]decan-7-one (102) %[a]
Perphthalic acid	75.5	24.5
Percamphoric acid	69.1	30.9
Chloroperbenzoic acid	68.1	31.9
HYDROBORATING AGENT		
Diborane	43.0	57.0

a. The yields are not corrected for detector response of (96) or (102).

An independent synthesis of the ketone (102) was achieved by successive hydroboration and oxidation of 9-t-butylspiro[4.5]dec-6-ene (61) followed by further oxidation of the derived mixture of alcohols (see later) with Jones reagent. The resulting mixture of the two ketones (96 and 102) (Table III.2.) was separated by preparative gas-liquid chromatography.

Having established that the pure epoxide (99) can

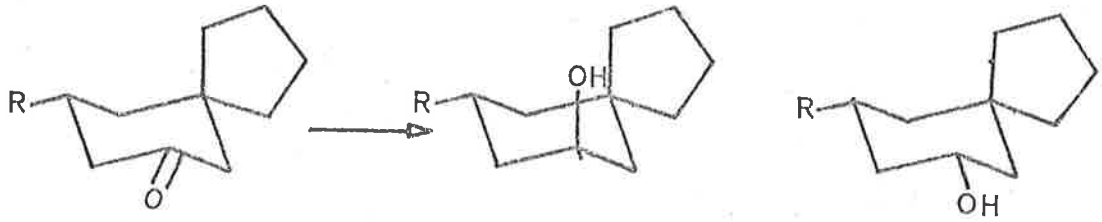
be transformed into 9-t-butylspiro[4.5]decan-6-one (96), the presence of 9-t-butylspiro[4.5]decan-7-one (102) in the mixture of ketones (96 and 102) (Table III.2.) must be derived from the minor component in the mixture of epoxides (99 and 100).* This is consistent with the minor component being trans-9-t-butyl-cis-6,7-epoxyspiro[4.5]decane (100). As a result of stereo-electronic control,[164,170] reduction of the epoxide (100) with lithium aluminium hydride will give trans-9-t-butylspiro[4.5]decan-7-ol (101a) which will form 9-t-butylspiro[4.5]decan-7-one (102) on oxidation.

Reduction of the ketone (102) on a small scale (0.042g) with sodium borohydride gave a mixture of two alcohols (14% and 86%). The configuration of the two epimeric alcohols was tentatively assigned on the basis that reduction of the ketone (102) would lead mainly to the product of "steric approach control",[157] trans-9-t-butyl--spiro[4.5]decan-7-ol (101a). As might be expected this axial alcohol (101a) exhibited a shorter g.l.c. retention

---

* It should be noted that a small fraction of the amount of the ketone (102) present in the mixture could arise from cis-9-t-butylspiro[4.5]decan-7-ol (101b). This alcohol (101b) is probably formed in a rearrangement process during the reductive ring opening of the epoxide mixture (99 and 100). (see following discussion)

time (on a 20' x $\frac{1}{8}$" 5% FFAP column) than the minor component in the mixture of alcohols. Consequently the minor product was assumed to be the epimeric cis-alcohol (101b). (Scheme III.3.)



102 101a 101b

Scheme III.3.

The results of -

(i) the metal hydride reduction of the mixture (3:1) of the epoxides (99 and 100, respectively)

(ii) the hydroboration/oxidation of the olefin (61)

(iii) the reduction of the two ketones (96 and 102)

are outlined in Table III.3.

Table III.3.

	cis-6 alcohol (47) %	trans-6 alcohol (48) %	trans-7 alcohol (101a) %	cis-7 alcohol (101b) %
Reductive opening of the mixture (3:1) of the epoxides (99) and (100)	70[a]	5-10[a]	20[a]	5[a]
Hydroboration/oxidation of the olefin (61)	14[a]	32[a]	24[a]	30[a]
Sodium borohydride reduction of the ketone (102)	-	-	86	14
Sodium borohydride reduction of the ketone (96)	10	90	-	-

a. The ratios recorded here are very approximate as only fair resolution by g.l.c. was possible and the values have been calculated from relative peak heights.

The distribution of the spiro alcohols (47, 48, 101a and 101b) was in accord with the previous stereochemical assignments. Rearrangement of the epoxides (99 and 100) during the metal hydride reduction, rather than the failure of the trans-diaxial opening of the oxirane ring, probably gives rise to the small amounts of the alcohols (48 and 101b) present in the product mixture.

Rickborn[171] has shown that the reduction of trans-4-t-butyl-cis-1,2-epoxycyclohexane with lithium aluminium hydride leads to the formation of trans-3-t-butylcyclo--hexanol (ca. 90%) and cis-3-t-butylcyclohexanol (ca. 10%). The latter alcohol was formed by reduction of 3-t-butyl--cyclohexanone, produced by rearrangement of the trans-epoxide. Other examples of this competitive rearrangement process have been reported.[172,173]

The above preparation of cis-9-t-butylspiro[4.5]--decan-6-ol (47, X=OH) was, however, rather unsatisfactory since the separation of the epoxides (99 and 100) by gas-liquid chromatography was a laborious and lengthy procedure. The most satisfactory source of the cis-alcohol (47, X=OH) was the one used by Christol and co-workers.[115] Reduction of 9-t-butylspiro[4.5]decan-6-one (96) with aluminium iso-propoxide in isopropyl alcohol gave a mixture (2:3) of cis- and trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, respectively) respectively (Table III.1.). Pure cis-

alcohol (47, X=OH) was obtained by careful chromatography of the mixture on neutral alumina (activity 1).*

cis- and trans-9-t-Butylspiro[4.5]dec-6-yl p-toluene--sulphonate (47 and 48 where X=OTs, respectively) were formed by treating the respective alcohols with three equivalents of p-toluenesulphonyl chloride in pyridine at 0° for 48h.

Expected products from the acetolysis of cis- and trans-9-t-butylspiro|4.5|dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively).

In order to be able to study the acetolysis of the two esters (47 and 48 where X=OTs, respectively) most effectively, it was desirable to synthesize as many as possible of the compounds which could conceivably be formed in the solvolyses so that -

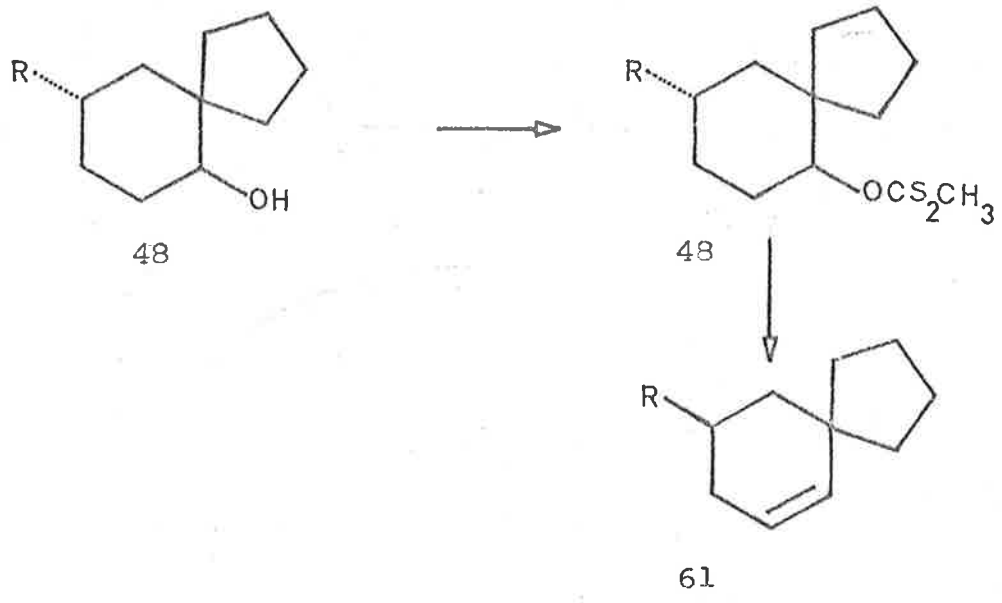
(i) gas-liquid chromatographic procedures could be devised to analyse the product mixtures and

---

* This method was not used earlier as a previous worker in this department had been unsuccessful in separating the two alcohols (47 and 48 where X=OH) by chromatography on neutral alumina.

(ii) the stability of the compounds toward the solvolytic conditions could be determined. The possible products which could be expected from these solvolytic reactions have already been outlined (Scheme II.1.2.). It should be emphasized that products arising from hydride ion shifts in the various carbonium ions have not been considered.

The preparation of 9-t-butylspiro[4.5]dec-6-ene (61) has already been described. A less satisfactory synthesis of (61) involved the thermal decomposition of the methyl--xanthate ester of trans-9-t-butylspiro[4.5]decan-6-ol (48, X=CH_3SCSO). (Scheme III.4.)



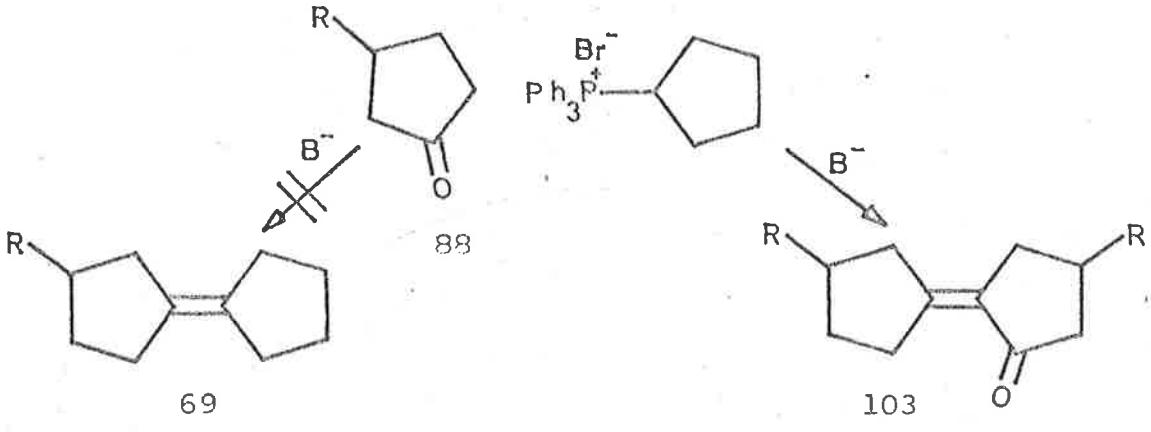
Scheme III.4.

The product from this reaction had an unpleasant

"sulphurous" smell and was distilled from sodium metal in order to purify it.[174] The resultant loss of material limited the synthetic utility of this method.

cis- and trans-9-t-Butylspiro[4.5]dec-6-yl acetate (47 and 48 where X=$OCOCH_3$, respectively) were formed without difficulty from the parent alcohols by the action of acetic anhydride in pyridine.

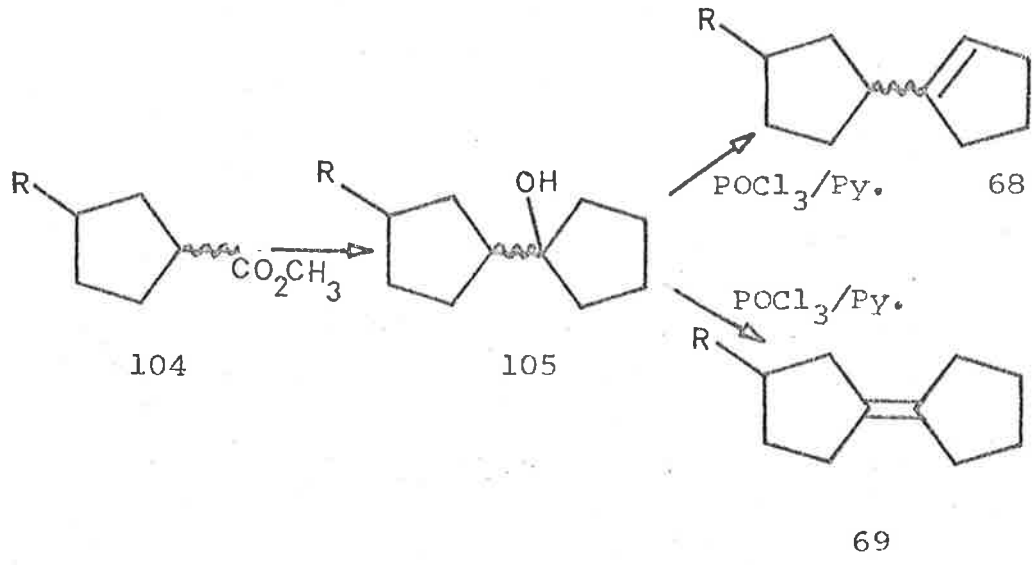
Attempts to prepare (3-t-butylcyclopentylidene)cyclo--pentane (69) by a Wittig[176] reaction between 3-t-butyl--cyclopentanone (88) and triphenylcyclopentylphosphonium bromide resulted in the formation of (3-t-butylcyclo--pentylidene)-4-t-butylcyclopentan-2-one (103) as the major product[175] and none of the desired compound. (Scheme III.5.)



Scheme III.5.

Alternative routes to the olefin (69) involved the use of methyl 3-t-butylcyclopentanecarboxylate (104) as an intermediate. (Scheme III.6.) These routes had the

advantage that (3-t-butylcyclopentyl)cyclopent-1-ene (68) and (3-t-butylcyclopentyl)cyclopentan-1-ol (105) could also be obtained.



Scheme III.6.

When this approach to the synthesis of these compounds (105, 69 and 68) was initiated, syntheses to pure cis- and trans-methylcyclopentanecarboxylate (104a and 104b) were not available.

The first attempt to form the ester (104) involved a Favorskii[177] reaction of cis-2-bromo-4-t-butylcyclohexanone (106a). Treatment of the bromoketone (106a) with sodium methoxide in either methanol (homogeneous conditions) or diethyl ether (heterogeneous conditions) however gave none of the desired compound (104). The only product which could be isolated was the dimer (107) of 4-t-butyl-2-hydroxycyclo-

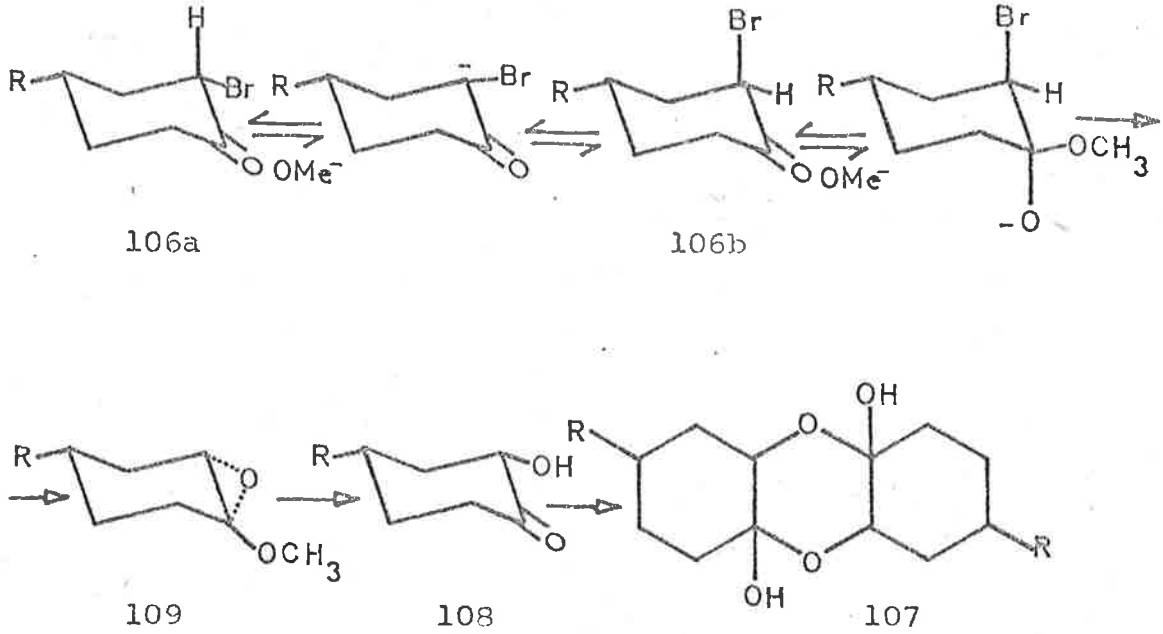
hexanone (108). (Scheme III.7.) The structure of the dimer (107) was assigned on the basis of -

(i) the infrared spectrum (Sharp band at 3400cm^{-1}) (4-t-butyl-2-hydroxycyclohexanone (108), obtained by distillation of the dimer, exhibited absorption at 3600-3100cm^{-1} and 1725cm^{-1})

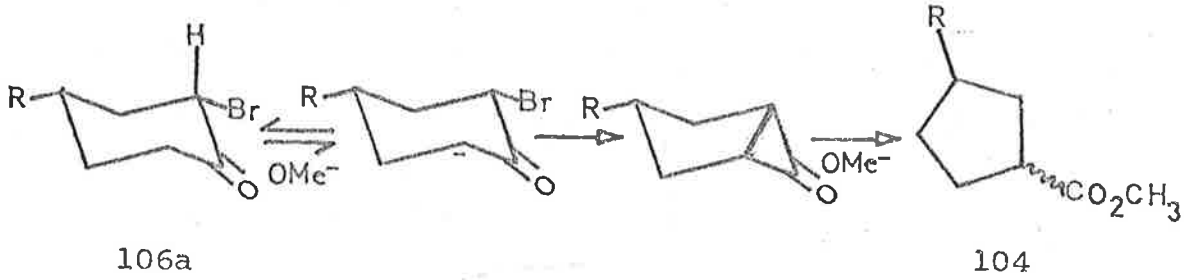
(ii) the mass spectral (base peak at m/e 170) and the microanalytical data which were in accord with the proposed structure. It should be noted that the monomer readily reverts to its dimeric form on standing.

It may be that based catalysed epimerization of the cis-bromide (106a) to the trans-bromide (106b) with consequent conversion of the latter to the epoxy-ether (109) (which undergoes ring opening of the oxirane ring to yield the acyloin (108)[177] during the working-up procedure) (Scheme III.7a.) occurs much faster than the process required for the Favorskii rearrangement. (Scheme III.7b.)

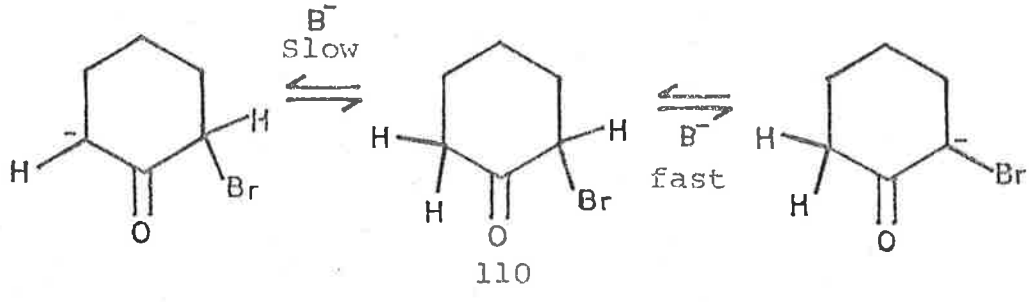
Support for this postulate comes from the works of Bordwell[178] who found that, under basic conditions, the deuterium exchange at the 2 position is much faster than at the 6 position of 2-bromocyclohexanone (110) (Scheme III.8.). He also observed that the "normal" Favorskii product was obtained in good yield by treatment of 2-bromo-4,4-diphenyl--cyclohexanone with base. The success of this reaction is probably a result of the steric bulk of the axial 4-phenyl



Scheme III.7a.



Scheme III.7b.

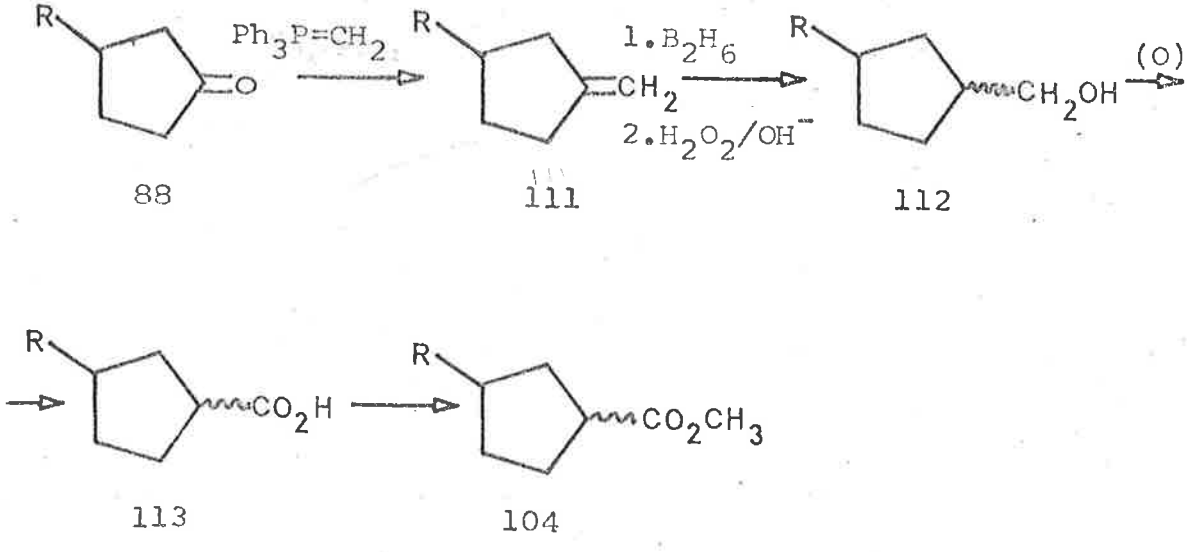


Scheme III.8.

group which constrains the 2-bromo substituent to the equatorial position. No similar structural feature is present in the bromoketone (106a).

An alternative explanation arises from the work of Allinger[179] who proposed that cis-2-bromo-4-t-butylcyclo--hexanone (106a) consists of a mixture of chair and non-chair conformers. The latter conformer contains the bromine in a suitable orientation to allow epoxide formation to take place. This may be a fast reaction and the normal Favorskii rearrangement is unable to compete with it.

A successful though not stereospecific synthesis of methyl 3-t-butylcyclopentylcarboxylate (104) was achieved by the route outlined in Scheme III.9.



88 111 112

113 104

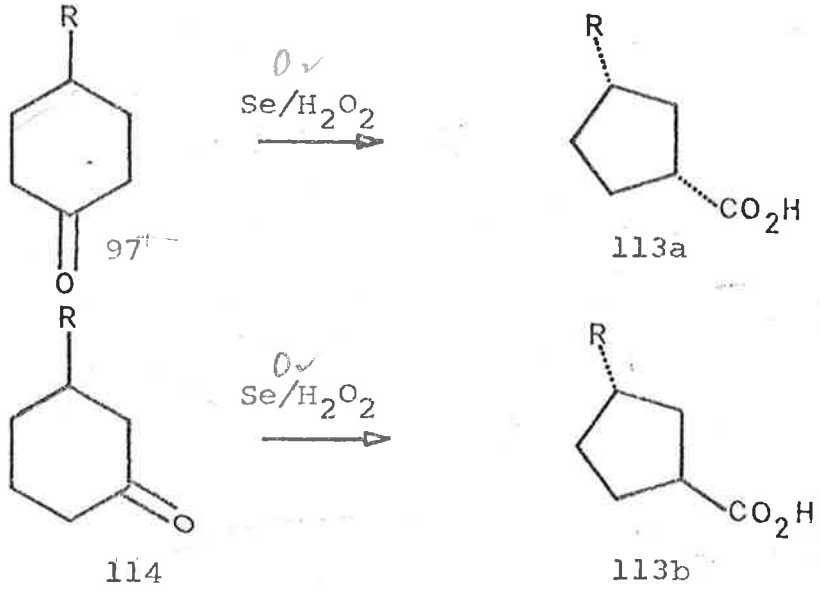
Scheme III.9.

3-t-Butyl-1-methylenecyclopentane (111) was obtained by treatment of the ketone (88) with methylene--triphenylphosphine in ether. Subsequently hydroboration and oxidation of this olefin (111) yielded the alcohol (112) (ir, OH str., 3600-3200cm^{-1}) and Jones oxidation of this alcohol (112) gave 3-t-butylcyclopentanecarboxylic acid (113) (ir, OH str., 3400-2400cm^{-1}, C=O str. 1699cm^{-1}). The ester (104), obtained by methylation of the acid (113), was successfully converted to the alcohol (105) (Scheme III.6.) by means of a di-Grignard reaction and the two olefins (68 and 69) were subsequently obtained by dehydration of the parent alcohol (105) with phosphorous oxychloride in pyridine. The mixture of olefins (68 and 69) was separated by preparative gas-liquid chromatography and the individual components were identified by their spectral properties. (3-t-Butylcyclopentyl)cyclopent-1-ene (68) exhibited a signal characteristic of an olefinic hydrogen (τ4.82-4.50) in its n.m.r. spectrum. On the other hand however (3-t-butylcyclopentylidene)cyclopentane (69) failed to exhibit any signal indicative of an olefinic hydrogen.

Although analytical g.l.c. and the spectral properties of the alcohol (112), the ester (104), the cyclo--pentylcyclopentyl alcohol (105) and the olefin (68) indicated that they were all homogeneous, (compare ref. 180) it seems likely, however, that each of the compounds is a

mixture of geometrical isomers, when the method of preparation is considered.

It has been reported recently that cis- and trans-3-t-butylcyclopentanecarboxylic acid (113a and 113b, respectively) can be prepared stereospecifically from 4-t-butylcyclohexanone (97) and 3-t-butylcyclohexanone (114) respectively, by treatment of the ketones with hydrogen peroxide and selenium dioxide[180] (Payne-Smith reaction[181]). (Scheme III.10.)



Scheme III.10.

When the methyl esters of cis- and trans-3-t-butyl--cyclopentanecarboxylate (113a and 113b, respectively) were separately subjected to the reactions outlined in Scheme III.6. (dehydration of the alcohols was carried out with phosphorous oxychloride in pyridine) the cis- and trans-

isomers of the alcohol (105a and 105b, respectively) and the olefin (68a and 68b, respectively) were obtained. The geometric isomers of the three compounds, however could not be distinguished by spectral or gas-liquid chromatographic techniques. Inability to distinguish the geometric isomers of these three compounds emphasizes the possibility of the presence of the same geometric isomers in the compounds formed by the route outlined in Scheme III.9.

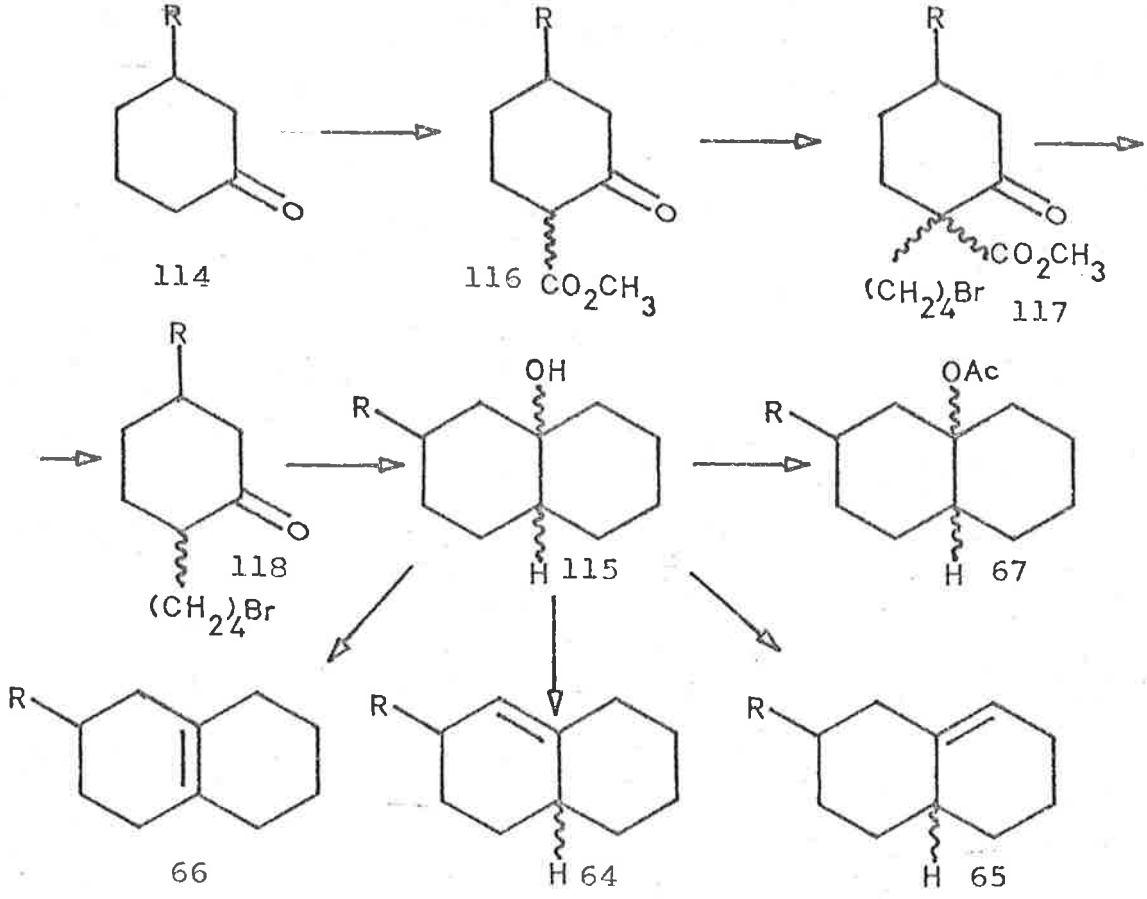
Although the synthesis of (3-t-butylcyclopentyl)--cyclopent-1-yl acetate (70) was desirable, treatment of the alcohol (105) with -

(i) acetylchloride and dimethylaniline

(ii) sodium hydride in tetrahydrofuran followed by acetylchloride

yielded none of the desired acetate (70). This behaviour of (3-t-butylcyclopentyl)cyclopentan-1-ol (105) was unexpected as the unsubstituted alcohol, cyclopentylcyclopent--anol, readily gave the acetyl derivative.[70]

Initially an effort was made to synthesize the compounds (115), (66), (64) and (65) by the series of reactions outlined in Scheme III.11.



Scheme III.11.

Treatment of 3-t-butylcyclohexanone (114) with dimethyl carbonate and sodium hydride gave the keto-ester (116) which was shown to be homogeneous by spectral and gas-liquid chromatographic techniques. As the 2 position is much less accessible than the 6 position of the ketone (114), it is reasonable to expect that the product is methyl 4-t-butyl-2-oxocyclohexanecarboxylate (116). This is in agreement with the work of Eisenbraun[182] and co-workers who concluded that carbomethoxylation of 3-methylcyclohexanone,

which is less hindered at the 6 position, by virtue of the smaller alkyl substituent, gave methyl 4-methyl-2-oxocyclohexanecarboxylate almost exclusively (see also ref. 196). A similar result was obtained in the thallium triacetate oxidation[187] of the morpholine enamine of 3-t-butylcyclohexanone (114).

When the keto-ester (116) was heated with 1,4-dibromobutane and sodium hydride in a mixture of benzene and N,N-dimethylformamide, 6-(4-bromobutyl)-3-t-butyl-6-carbomethoxycyclohexanone (117) was formed. This compound (117) was, in turn, converted to 6-(4-bromobutyl)-3-t-butylcyclohexanone (118) by the action of 48% hydrobromic acid in acetic acid.

Attempts to convert (118) into the tertiary alcohol (115) by -

(i) normal Grignard reaction

(ii) Grignard reaction in the presence of mercuric chloride

(iii) cyclization with lithium naphthenilide and nickel tetraphenylporphine

were all unsuccessful. Infra-red analysis of the crude product from (iii) revealed the lack of any hydroxyl absorption and this indicated that the desired product (115) was not present. T.l.c. analysis indicated the absence of 6-(4-bromobutyl)-3-t-butylcyclohexanone (118).

An alternative route (Scheme III.12.) from the readily accessible 7-t-butyltetral-1-one (119)* to the required decalyl system was investigated.

A series of attempts utilizing the catalysts -

(i) 5% rhodium on alumina and

(ii) platinum black

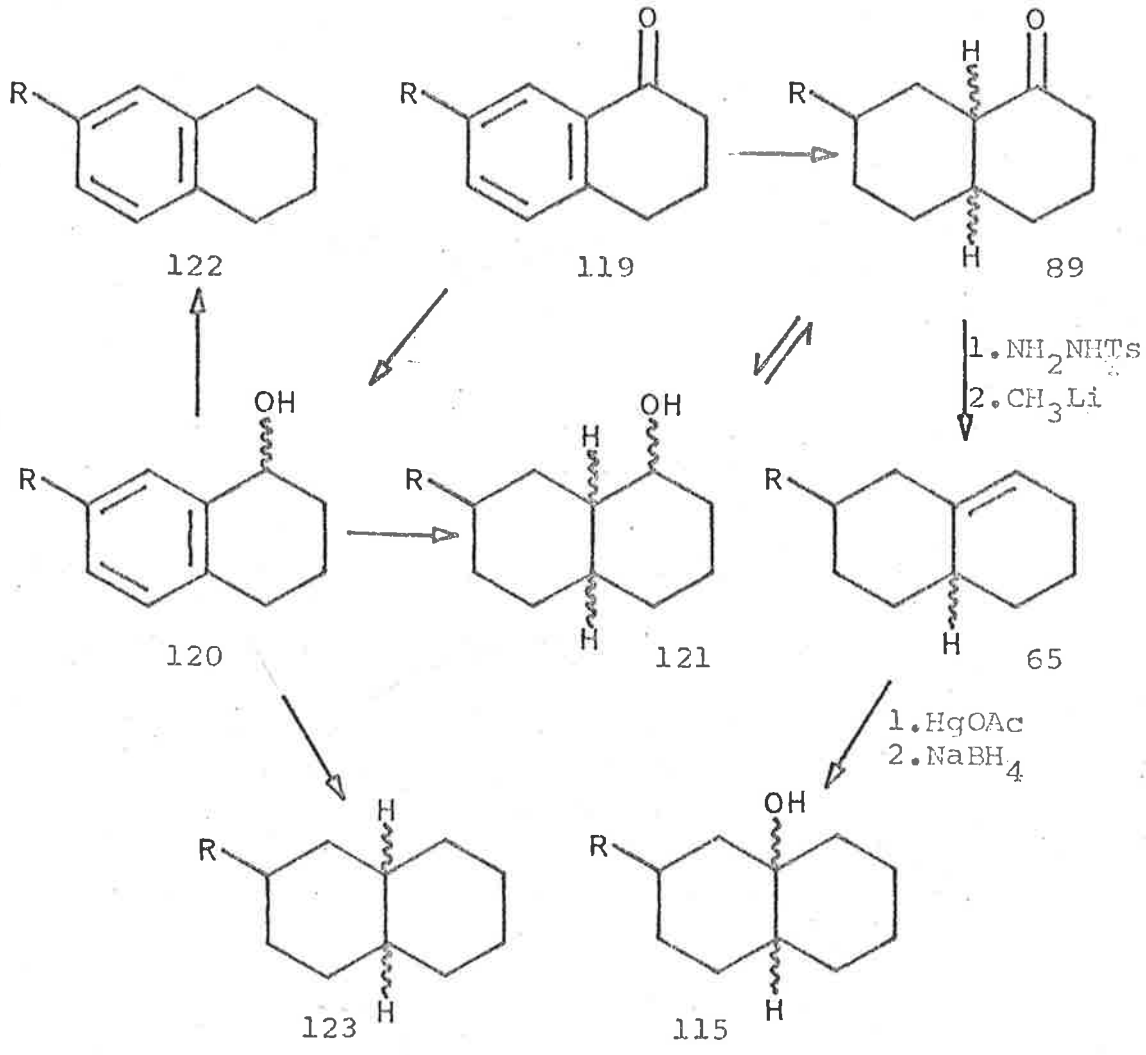
under varying conditions of hydrogen pressure, temperature and solvent failed to yield the desired product from the reduction of 7-t-butyltetralone (119) and 7-t-butyltetralol (120). The latter was prepared by sodium borohydride reduction of the ketone (119).

Infrared and nuclear magnetic resonance data indicated that hydrogenolysis of the oxygen function always preceded hydrogenation and the extent of these reductions was dependent on the severity of the reaction conditions.

---

* The reduction of 3-(p-t-butylbenzoyl)propionic acid (an intermediate in the preparation of (119)) with zinc and hydrochloric acid yielded the required 4-(p-t-butylphenyl)--butyric acid and a by-product, the lactone of 4,4'-(di-p-t-butylphenyl)-4,4'-dihydroxysuberic acid. Similar products, which probably arise by radical coupling on the surface of the metal, have been reported in the literature,[183] but have never been thoroughly characterized.

In order to assess the reaction products of hydrogenolysis and hydrogenation, the following ir and n.m.r. characteristics were used. (Ir: presence or absence of C=O and OH str. vibrations. n.m.r.: position and magnitude of the signal for the t-butyl group i.e. t-Bu-Ar, τ 8.72 and t-Bu-saturated linkage, τ 9.15).



Scheme III.12.

Even the catalyst, platinum black, which was used successfully by Huckel[184] in the reduction of α-tetralol to α-decalol, caused 7-t-butyltetralol (120) to be converted into a mixture of 7-t-butyltetralin (122) and isomeric 2-t-butyldecalins (123). Reference to Table III.4. emphasizes the fact that the conditions necessary for reduction to occur lead to an initial hydrogenolysis with subsequent reduction of the aromatic nucleus.

Table III.4.

Results of the reduction of 7-t-butyltetralol (120) in the presence of platinum black catalyst.

REACTION CONDITIONS			PRODUCTS		
Temp. (°C)	Time (h)	hydrogen pressure (p.s.i.)	7-t-butyl--tetralol (120)	7-t-butyl--tetralin[a] (122)	7-t-butyl--decalin[a] (123)
20	64	60	-	ca. 20	ca. 80
20	16	60	-	ca. 78	ca. 22
20	16	15	100	-	-

a. Estimated from n.m.r. and g.l.c. data

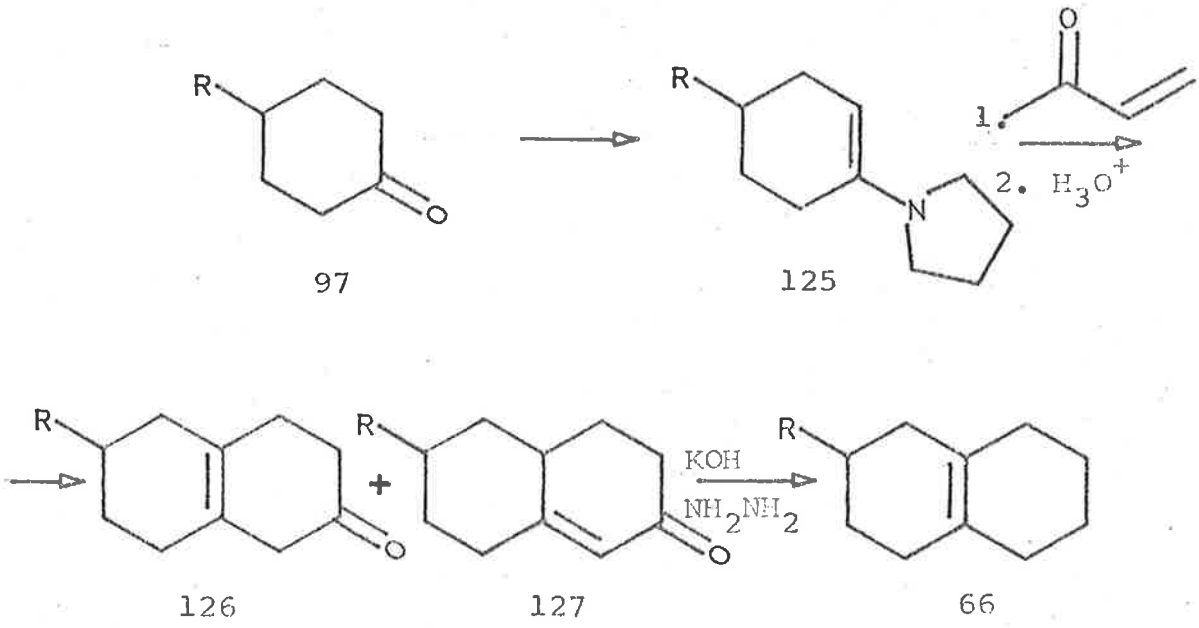
The bulk of the t-butyl substituent may interfere with the approach of the aromatic nucleus to the surface of the catalyst, thus retarding the reduction of the aromatic ring and allowing hydrogenolysis of the benzylic oxygen function to become the predominant reaction.

Treatment of 7-t-butyltetralol (120) with lithium in ammonia, gave the anticipated product, 7-t-butyltetralin

(122) which arose by cleavage of the benzylic hydroxyl group. Although this reaction was attempted in the hope that it might possibly lead to disruption of the aromatic nucleus, the result is nevertheless consistent with the observed cleavage of benzylic oxygen functions under these conditions.[185]

Although naphthalene can be converted successfully to a mixture of $\Delta^{1,9}$- and $\Delta^{9,10}$-octalin (30 and 31, respectively) by treatment with lithium in a mixture of ethyl--amine and diethylamine (Benkeser reaction[186]), the reduction of 2-t-butylnaphthalene (124) resulted in a mixture of at least seven compounds (g.l.c. analysis). This mixture was separated into four fractions by preparative gas-liquid chromatography; the first three contained mono-, di- and tri-olefinic material (estimated from the molecular ions in the mass spectrum of each fraction), while that of longest retention time contained 7-t-butyltetralin (122). The complexity of the product mixture and the difficulty encountered in the separation of the components precluded this as a satisfactory route for the preparation of the olefins (64, 65 and 66).

A successful synthesis of 2-t-butyl-$\Delta^{9,10}$-octalin (66) was achieved as follows (Scheme III.13.).

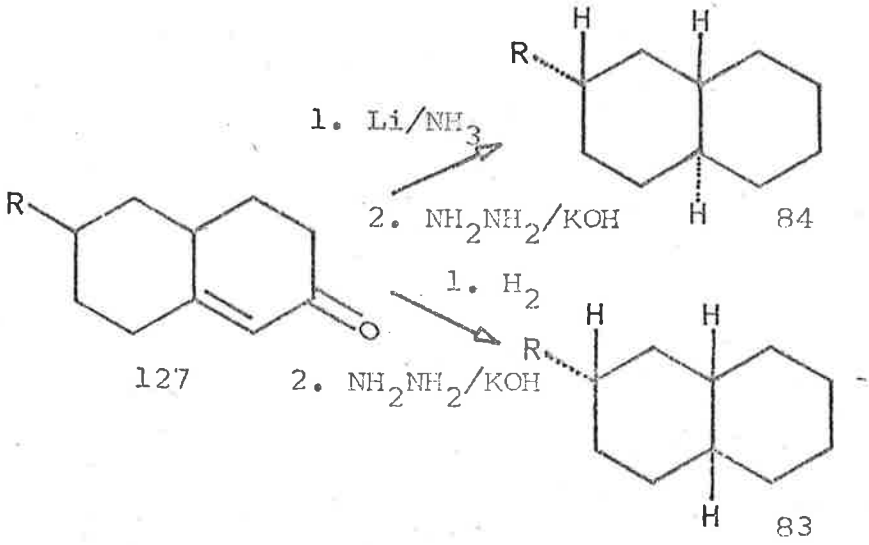


Scheme III.13.

The mixture of unsaturated ketones (126 and 127), formed from the pyrrolidine enamine of 4-t-butylcyclo-hexanone (125) and methyl vinyl ketone, was reduced with hydrazine and potassium hydroxide in diethyleneglycol to give a mixture of products from which 2-t-butyl-$\Delta^{9,10}$-octalin (66) was obtained by preparative gas-liquid chromatography. The product exhibited a weak absorption (1670cm^{-1}) in its ir spectrum which is characteristic of a tetra-substituted olefinic bond and no resonance characteristic of an olefinic hydrogen in the n.m.r. spectrum. The mass spectral and the microanalytical data were in accord with the structure assigned to the olefin (66).

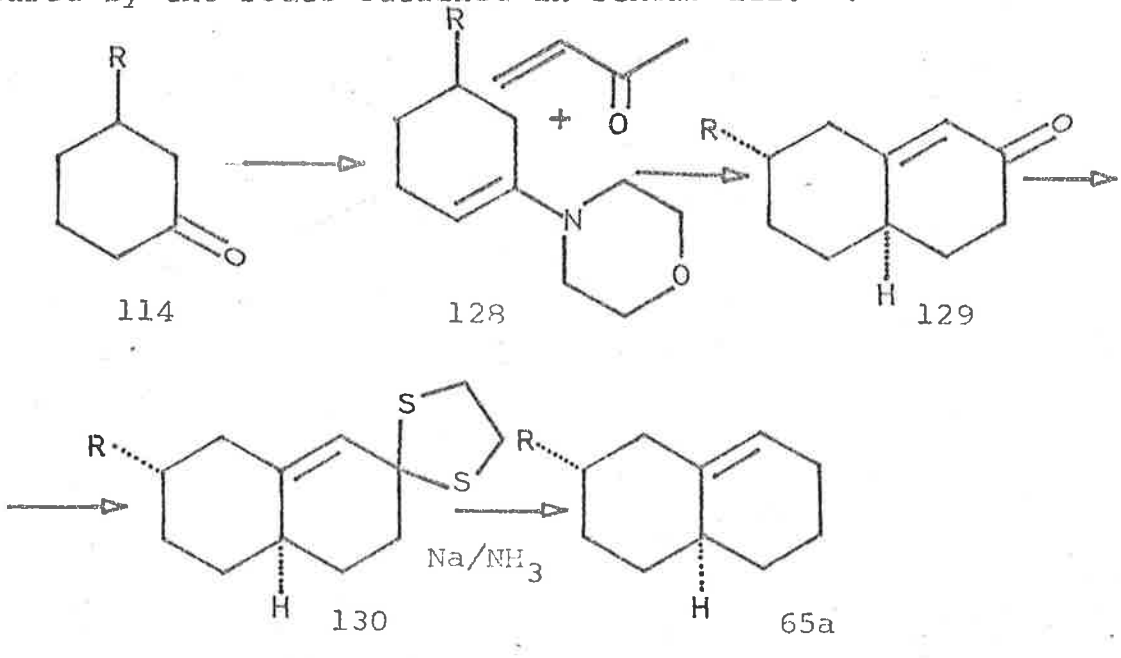
The isomeric cis-cis- and trans-trans-2-t-butyldecalin

(83 and 84, respectively) were prepared from the unsaturated ketone (127) by recognized methods.[154] (Scheme III.14.)



Scheme III.14.

The isomeric trans-7-t-butyl-$\Delta^{1,9}$-octalin (65a) was prepared by the route outlined in Scheme III.15.

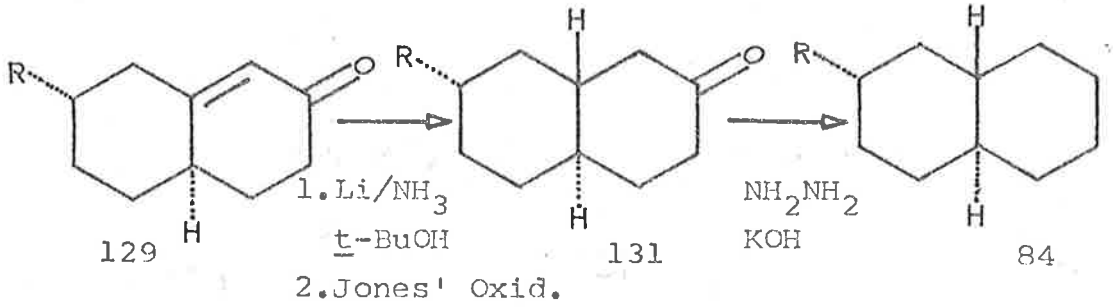


Scheme III.15.

The morpholine enamine of 3-t-butylcyclohexanone (128) was treated with methyl vinyl ketone to give a mixture of at least seven compounds. The major component (ca. 35%) was separated by preparative g.l.c. followed by recrystallization and was shown to be trans-7-t-butyl-$\Delta^{1,9}$-octal-2-one (compare ref. 187) on the basis of microanalytical and spectral evidence (ir C=O str. 1675, C=C 1625cm^{-1}; n.m.r. τ4.32 olefinic hydrogen).

Conversion of the octalone (129) to the ethylene--dithioketal (130) with ethylenedithiol in boron trifluoride etherate was followed by desulphurization of the ketal (130), with sodium in liquid ammonia, to give the required octalin (65a) (n.m.r., τ4.82-2.85, olefinic hydrogen) whose structure was confirmed as follows.

The stereospecific reduction of the octalone (129) with lithium in ammonia[188] containing t-butyl alcohol gave trans-trans-7-t-butyldecal-2-one (131). This ketone (131) was subsequently treated with hydrazine and potassium hydroxide in diethyleneglycol to yield exclusively trans-trans-2-t-butyldecalin (84), identified by g.l.c. and spectral comparison with an authentic sample prepared by the method of House.[154] (Scheme III.16.)

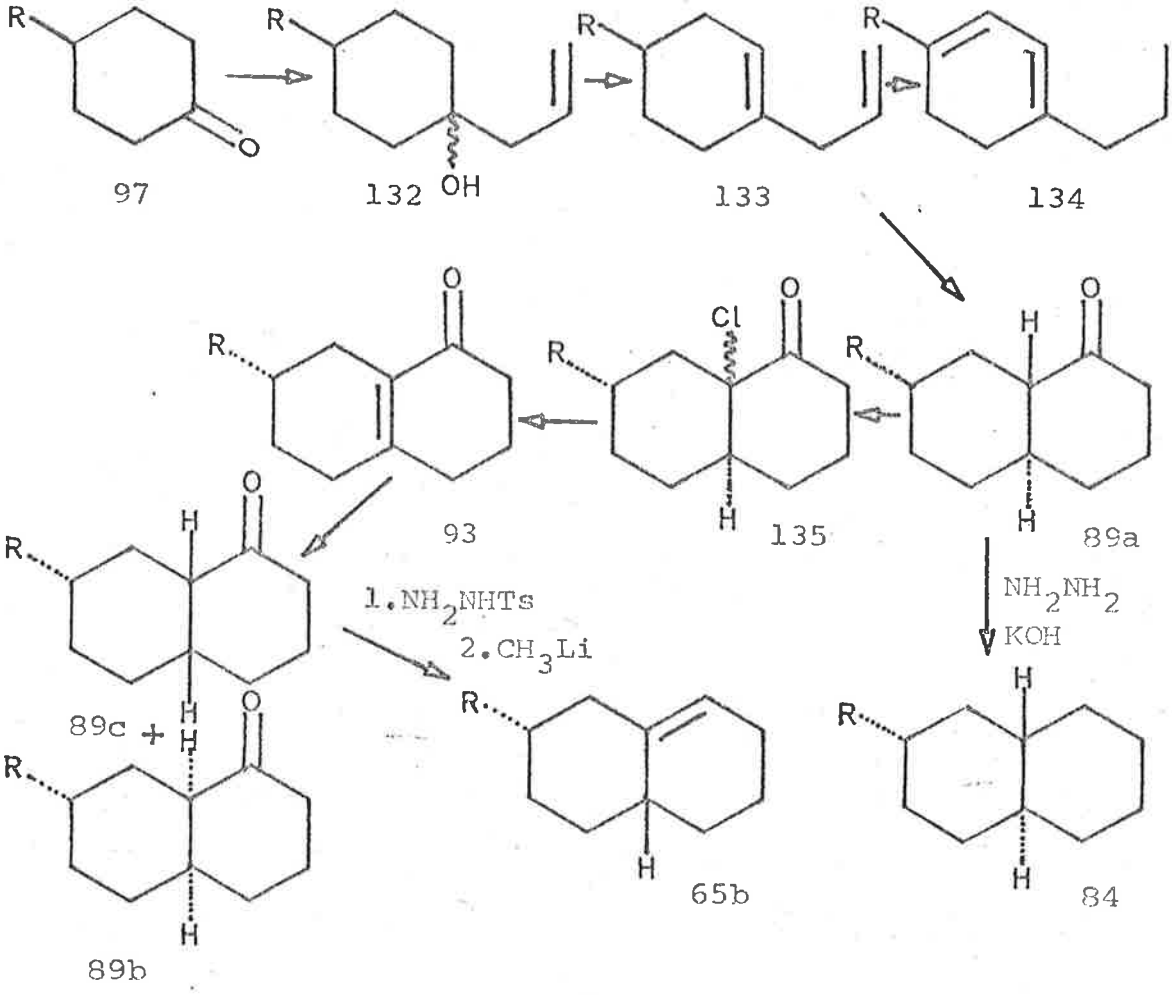


Scheme III.16.

A possible route to cis-7-t-butyl-$\Delta^{1,9}$-octalin (65b) is outlined in Scheme III.17.

1-Allyl-4-t-butylcyclohexene (133) was obtained by dehydration, with p-toluenesulphonic acid in benzene, of the mixture of isomeric 1-allyl-4-t-butylcyclohexanols (132), formed by the addition of allylmagnesium halide to the ketone (97).

Confirmation of the structure of the olefin (133) was obtained from its spectral properties as follows - (ir, C=C-H str. 3080, 3070 and 3010cm^{-1} and C=C str. 1635cm^{-1}, uv, 218nm (ε_{max} 675) which indicates the absence of a conjugated diene; n.m.r., τ 7.57 =CR-CH_2-CH=CH_2, 5.27-3.90, four olefinic hydrogens). (compare ref. 194)



Scheme III.17.

The mixture of isomeric 1-allyl-4-t-butylcyclo--hexanols (132) was separated by column chromatography on neutral alumina. The first alcohol to be eluted (hexane) was assigned the cis- configuration and the second alcohol to be eluted (50% ether/50% hexane) was assigned the trans- configuration. (In this context the cis- and trans- assignments refer to the t-butyl and hydroxyl groups.) These assignments are based on the observation of Winstein

and Holness[119] who reported that cis-4-t-butylcyclohexanol (51, X=OH) was eluted before the trans-epimer (52, X=OH) when a mixture of the two alcohols (51 and 52 where X=OH) was chromatographed on neutral alumina.

The normally simple dehydration process was complicated by isomerization of the diene (133) to the thermodynamically more stable 4-t-butyl-1-propylcyclohexa-1,4-diene (134), whose structure was assigned on the basis of its n.m.r, ultraviolet and mass spectra as follows. The ultraviolet absorption maximum at 266nm (ε_{max} 7700) is characteristic[189] of a 1,4-dialkylcyclohexa-1,4-diene; n.m.r., τ 4.43, two olefinic hydrogens; mass spectrum, molecular ion at m/e 178.

It was necessary to monitor the reaction by gas-liquid chromatography so that 1-allyl-4-t-butylcyclohexene (133) could be isolated before contamination with the conjugated diene (134) could occur. The slow formation of 4-t-butyl-1-propylcyclohexa-1,4-diene (134) in the course of the acid-catalysed dehydration is shown in Table III.5.

Table III.5.

Dehydration of a mixture of alcohols (132a and 132b) with p-toluenesulphonic acid in benzene.

Time of analysis (h)	% Products[a]		
	cis- and trans-1-allyl-4-t-butylcyclohexanol (132a & 132b, respectively)	1-allyl-4-t-butylcyclohexene (133)	4-t-butyl-1-propylcyclohexa-1,4-diene (136)
1.25	99	1	0
3.5	99	1	0
23	97	3	0
27	94	6	0
45	85	15	0
53	79	21	0
67	69	30	1
250	-	-	ca. 100

a. No correction has been made for response of the compounds to the g.l.c. detector.

Treatment of the diene (133) with "thexyl" borane in tetrahydrofuran using the "simultaneous dilution technique" (ref. 190) followed by carbonylation at high pressure and oxidation with hydrogen peroxide in the presence of sodium acetate gave a mixture of compounds containing trans-trans-7-t-butyldecal-1-one* (89a, ca. 80% of the mixture). Two

* Compelling evidence for this assignment appears later.

recrystallizations from light petroleum (b.p. 30-40°) of this mixture yielded a white crystalline solid (m.p. 69.5-70.5°) which was homogeneous by g.l.c. analysis. This compound was treated with hydrazine and potassium hydroxide in diethyleneglycol and gave exclusively trans-trans-2-t-butyldecalin (84). The structure of this decalin (84) was confirmed by a comparison of its physical and spectral properties with the authentic compound. Coupled with Brown's observation[191] that carbonylation of 1-allylcyclo-hexene results in the exclusive formation of trans-decalone, this provides further evidence that the t-butyldecalone produced in the carbonylation of the olefin (133) is the trans-trans-isomer (89a).

The trans-trans-ketone (89a) was treated with sulphuryl chloride in carbontetrachloride to give 7-t-butyl-9-chlorodecal-1-one (135) (Scheme III.17.), which was converted, without purification to 7-t-butyl-$\Delta^{9,10}$-octal-1-one (93) by heating with 2,4,6-trimethylpyridine. The absence of a signal in the n.m.r. spectrum corresponding to an olefinic hydrogen showed that less than 5% of the isomeric 7-t-butyl-$\Delta^{8,9}$-octal-1-one had been formed (compare ref. 154). This was undoubtedly due to the inability of the base to approach H_8, which is shielded by the bulky t-butyl group. The major component (ca. 70%) was separated by preparative g.l.c. and was shown to be 7-t-butyl-$\Delta^{9,10}$-

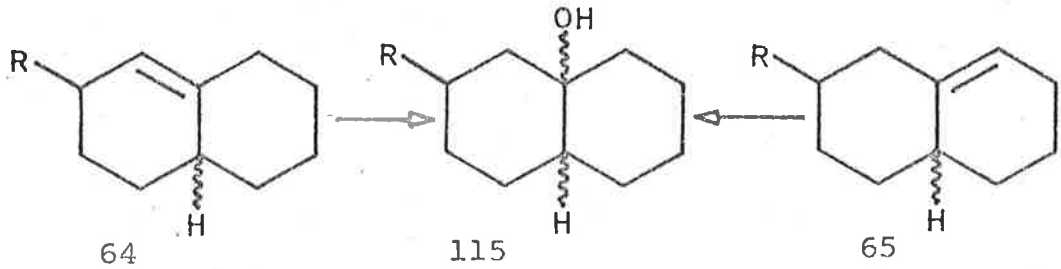
octal-1-one on the basis of microanalytical and spectral evidence as follows - ir, C=O str. 1665, C=C str. 1640cm^{-1}; n.m.r., no resonance characteristic of olefinic hydrogens was observed.

Unfortunately, time did not permit this reaction sequence to be completed (Scheme III.17.). It was envisaged that hydrogenation of the octalone (93) could lead to a mixture of cis- decalones (89b and 89c). Formation of the p-toluenesulphonylhydrazone of cis-cis-7-t-butyldecalone (89c) followed by treatment with methyl lithium in ether should give a mixture of two olefins[192] from which cis-7-t-butyl-$\Delta^{1,9}$-octalin (65b) could be isolated and easily distinguished by n.m.r. spectroscopy.

Although the synthesis, by unambiguous routes, of the four isomeric 2-t-butyldecal-9-yl acetates (67) and cis- and trans-2-t-butyl-$\Delta^{1,9}$-octalin (64b and 64a, respectively) was considered most desirable it was not achieved in this work.

It was envisaged that a mixture of isomeric axial alcohols (115) could be obtained by the oxymercuration-demercuration of either of the two octalins (64 and 65) (Scheme III.18).

When the oxymercuration-demercuration reaction was applied to a small quantity of the octalin (64), isolated from the mixture of olefins formed by the acetolysis of



Scheme III.18.

<u>trans</u>-9-<u>t</u>-butylspiro[4.5]dec-6-yl <u>p</u>-toluenesulphonate (48, X=OTs), no reaction occurred. The quantity of the olefin (64) available and the lack of time did not allow an investigation of this route to the alcohol (115).

EXPERIMENTAL

IV.1.

General

Melting points were determined on a Reichert micro hot-stage and both melting and boiling points are uncorrected.

Microanalyses were carried out by the Australian Microanalytical Service, Melbourne.

Unless otherwise stated, organic extracts were dried over magnesium sulphate or molecular sieves (4A).

Spectroscopic Apparatus and Techniques

Infrared spectra were determined with Perkin-Elmer 237 and 337 Grating Spectrophotometers and a Unicam SP200 Spectrophotometer. Spectra of liquids were determined as liquid films and of solids as nujol mulls or in carbon tetrachloride solution, as indicated. The characteristics of the absorption maxima (cm^{-1}) are expressed as follows - (s), strong; (m), medium; (w), weak; (sh), shoulder; (b), broad.

Ultraviolet spectra were recorded with a Perkin-Elmer 137UV spectrophotometer and a Unicam SP800 UV spectrophotometer.

Mass spectra were measured with an Hitachi Perkin-Elmer RMU 6D double focussing spectrometer operating at ca. 75eV.

Nuclear magnetic resonance spectra were recorded

with either a Varian DP 60 or a Varian T 60 spectrometer at 60 Mc/s and chemical shifts were measured relative to tetramethylsilane as internal standard.

Solvents

Diethyl ether was dried over calcium chloride, distilled twice from phosphorous pentoxide and stored over sodium wire. "Super-dry" ether was obtained by distillation of "sodium-dry" ether from lithium aluminium hydride.

Light petroleum (b.p. 30-40°) and (b.p. 50-60°) were distilled from phosphorous pentoxide and stored over sodium wire.

Halogenated solvents were distilled and stored over molecular sieves (4A).

All other solvents were dried and distilled according to literature procedures.

Gas liquid chromatography (g.l.c.)

Routine purity checks were carried out with Perkin-Elmer 800 and 881 instruments; quantitative determinations were performed on the latter, which was equipped with a Perkin-Elmer 194B printing integrator. Preparative separations were accomplished with either an Aerograph A700 or A705 instrument. All machines were fitted with flame ionization detectors and nitrogen was used as the carrier gas.

The following g.l.c. columns were used -

A. UCON LB 550X, 5%, 5' x $\frac{1}{4}$"

B. BDS, 5%, 5' x $\frac{1}{4}$"

C. CARBOWAX 20M, 5%, 12' x $\frac{1}{8}$"

D. SE52, 10%, 12' x $\frac{1}{4}$"

E. FFAP, 5%, 12' x $\frac{1}{8}$"

F. FFAP, 30%, 20' x $\frac{3}{8}$"

G. APIEZON M, 5%, 12' x $\frac{1}{8}$", (glass)

H. UCON LB 550X, 5%, 12' x $\frac{1}{8}$", (glass)

I. SE30, 20%, 20' x $\frac{3}{8}$"

J. UCON LB 550X, 5%, 12' x $\frac{1}{4}$"

K. APIEZON M, ca. 5%, 3' x $\frac{1}{8}$"

L. APIEZON M, 20%, 5' x $\frac{3}{8}$"

M. APIEZON M Golay, 150' x 0.01"

N. BDS, Golay, 150' x 0.02"

O. UCON, Golay, 300' x 0.01"

P. APIEZON M Golay, 300' x 0.01"

Q. APIEZON M, 20%, 36' x $\frac{1}{4}$"

R. FFAP, 5%, 20' x $\frac{1}{8}$"

S. FFAP, 5%, 12' x $\frac{1}{8}$", (glass)

T. CARBOWAX 20M, 20%, 12' x $\frac{1}{4}$"

Unless otherwise stated, for $\frac{1}{8}$" diameter columns, the carrier gas flow rate was ca. 30ml/min, while for $\frac{1}{4}$" columns it was 60ml/min. For the preparative columns, F, I, L, Q and T, the flow rate was ca. 150ml/min.

Thin layer chromatography (t.l.c.)

Thin layer chromatographic plates (75 x 25mm) were prepared in the usual way, from a mixture of Kieselgel G and HF254 in equal proportions and were not activated before use.

Kinetic Studies

Materials

Acetic Acid: A.R. grade acetic acid was refluxed over potassium permanganate for 24h. The acid was distilled and the fraction (b.p. 117-119°) to which A.R. acetic anhydride (ca. 2% by volume) was added, was heated under reflux for 24h. Distillation through a 50cm "Fenske" column, fitted with a "Human head" device, gave a fraction (b.p. 117·5-118°), which was stored under nitrogen. For kinetic determinations, the acetic acid contained A.R. acetic anhydride (1% by volume).

Acetic Anhydride: A.R. grade acetic anhydride was distilled through a 20cm "Fenske" column, and the fraction b.p. 136° was stored under nitrogen.

Anhydrous Sodium Acetate: A.R. sodium acetate was dried at 250° under a stream of dry nitrogen and stored under nitrogen.

Sodium Acetate-Acetic Acid: For rate measurements, solutions of sodium acetate (ca. 0.02M) were prepared by dissolving anhydrous sodium acetate in anhydrous acetic acid and these were standardized against perchloric acid, using bromophenol blue (saturated soln. in acetic acid) as the indicator.

Standard Perchloric Acid: A solution of perchloric acid (ca. 0.01M) in acetic acid was prepared according to the procedure of Moriarty and D'Silva[250] and was standardized against potassium hydrogen phthalate (A.R.) in acetic acid.

Bromophenol blue was used as the indicator.

Acetolyses

Acetolyses were carried out using the ampoule technique and the rates were measured titrimetrically.

In a typical run, an accurately weighed sample of the p-toluenesulphonate ester (ca. 0.182g, ca. 0.01M) was dissolved in standard sodium acetate-acetic acid solution (50ml, ca. 0.02M). The solution was transferred to a burette and divided into 9 portions (ca. 5.5ml) which were sealed in pyrex glass ampoules* under an atmosphere of dry nitrogen. The ampoules were placed in a constant temperature bath (± 0.05°) and allowed to reach the temperature of the bath (ca. 15min). Periodically the ampoules were withdrawn, cooled in a dry-ice/acetone bath, opened and allowed to attain room temperature (5min). The time of removal of the first ampoule was taken as "zero" time. An aliquot (5.10ml, withdrawn with a constant volume pipette) of the solution was titrated against standardized perchloric acid (0.011M) in acetic acid, containing acetic anhydride (1%), using bromophenol blue as indicator. The remaining ampoules were removed after the appropriate time intervals and treated in a similar manner. The first order rate constants were determined graphically, in the first instance, by measuring the slope of plots of log $(V_t - V_\infty / V_0 - V_\infty)$

---

* Ampoules were cleaned in the usual manner and finally steam-cleaned before use.

versus time, where V_t is the value of the titre at time t, V_∞ is the value of the "infinity" titre (i.e. at ca. 10 half-lives) and V_0 is the value of the titre at "zero" time. First order plots (i.e. straight lines) were obtained for 80-90% reaction (ca. 3 half-lives) and the values for the rate constants were the mean for two runs. The experimental values (of k) deviated from the mean by less than 2.5%, while the "infinity" titres were generally reproducible to within 2% of the theoretical value. Values for the first order rate constants (appearing in the text) were also obtained by using values of log $(V_t - V_\infty / V_0 - V_\infty)$ and t in a least squares computer programme.

Activation Parameters

In accord with the Arrhenius equation (a),

$$k = \frac{KT}{h} \cdot e^{\frac{\Delta S^{\ddagger}}{R}} \cdot e^{\frac{-\Delta H^{\ddagger}}{RT}} \qquad (a)$$

which can be expressed in the following way (b),

$$\log \frac{k}{T} = \log \frac{K}{h} + \frac{\Delta S^{\ddagger}}{2.303R} - \frac{\Delta H^{\ddagger}}{2.303RT} \qquad (b)$$

the enthalpy of activation, $\Delta H^{\ddagger}$ was obtained from the slope of a plot of $\log \frac{k}{T}$ versus $\frac{1}{T}$, where k is the first order rate constant at the temperature T and K, h and R are universal constants. Further manipulation of the equation (b) gives (c), from which the entropy of activation, $\Delta S^{\ddagger}$,

was calculated.

$$\Delta S^{\ddagger} = 2.303R \log \frac{k}{T} + \frac{\Delta H^{\ddagger}}{2.303RT} - \log \frac{K}{h}$$

Analyses of products from the acetolyses of cis- and trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively).

In a typical run, an accurately weighed sample of the p-toluenesulphonate ester (ca. 18mg) was dissolved in a solution* (ca. 0.02M) of sodium acetate in acetic acid (5ml). The solution was then sealed under nitrogen in an ampoule** and, after being heated at ca. 52.6°, for a period corresponding to ca. ten half-lives, the ampoule was removed from the constant temperature bath. After the solution had been cooled, it was diluted with water and extracted with light petroleum (b.p. 30-40°). An accurately weighed sample of the internal standard, 2-t-butylnaphthalene, (ca. 5mg) was added at the same time. The organic extracts were washed successively with saturated sodium bicarbonate

---

* The acetic acid-sodium acetate solution was flushed with dry oxygen-free nitrogen before use.

** All ampoules were washed in the usual way and finally steam-cleaned before use.

solution and water and dried. The solvent was removed by careful distillation through a column (20cm), packed with glass helices, with the water-bath temperature being kept below 45°. The concentrate (ca. 1ml) was then analysed by VPC as follows -

(a) Qualitative Analyses

Qualitative analyses of the product mixtures were carried out by comparison of retention times of authentic compounds and by the technique of peak enhancement, on appropriate g.l.c. columns.

(b) Quantitative Analyses

In order to estimate absolute yields of products, the responses (to the g.l.c. flame ionization detector) of the authentic compounds were compared with that of the internal standard. Accurately weighed samples of the compound (ca. 5-15mg) and the internal standard (ca. 5mg) were mixed and dissolved in light petroleum (30-40°) (10ml). Three solutions, varying in the ratio of compound to internal standard, were prepared for each compound. The light petroleum solutions were then analysed by g.l.c. under the same conditions as those used for the product analyses and the areas of the peaks were determined by integration. The values of weight of compound/weight of standard were plotted against area of compound/area of standard, to give a straight line graph, from which the absolute yields of the

products obtained from the acetolyses could be determined. The total yield of products was invariably 100 ± 5% of the expected return. The values in Table II.1.4. were normalized to 100%.

The products from the acetolyses were separately (where possible)* subjected to the conditions of the acetolysis. Accurately weighed samples of the olefins (ca. 9mg) were dissolved in a standard solution (ca. 0.02M) of sodium acetate in acetic acid (5ml) and the usual procedure for analysis was followed. All olefins were essentially unchanged (95% recovery) after a time corresponding to ten half-lives of acetolysis.

---

* Mixtures of (a) 2-t-butyl-$\Delta^{9,10}$-octalin (66) and (3-t-butylcyclopentylidene)cyclopentane (69) and (b) 2-t-butyl-$\Delta^{1,9}$-octalin (64) and 1-(3-t-butylcyclopentyl)cyclopent-1-ene (68) were used.

Table IV.1.1.

G.l.c. data for the acetolyses of *cis*- and *trans*-9-*t*-butylspiro[4.5]dec-6-yl tosylate (47 and 48 where X=OTs, respectively).

Column	RETENTION TIMES OF COMPOUNDS																	
	(61)		(64) and (68) (unidentified olefin)				(65)				(66) and (69) (unidentified acetate)							
G,132° [a]	18min	43s		24min	13s	28min	38s	30min	7s		32min	19s		48min	57s			
S,160°	2	31		2	52			3	26		3	36						
P,195°	15	53		16	14			17	22		17	34						
H,148°	9	55		11	59			14	54		16	44						
O,150°	17	57		20	51	23	40	24	50		25	53						
M,185°	6	02	(64)	6	42			shoulder on (66)			7	21						
			(68)	6	32													
M,158°	7	45		9	15			shoulder on (66)			11	00						

a. 2-*t*-butylnaphthalene (standard) had a retention time of 48min 57s.

Equilibrations with Raney Nickel

To determine the composition of the mixtures obtained by equilibration of 9-t-butylspiro[4.5]decan-6-one (96), trans-9-t-butylspiro[4.5]decan-6-ol (48, X=OH) and cis-9-t-butylspiro[4.5]decan-6-ol (47, X=OH) with Raney nickel, the following general procedure was used.[142]

A solution of trans-9-t-butylspiro[4.5]decan-6-ol (48, X=OH) (0.25g) in dry isopropyl alcohol (20ml) was refluxed (constant temperature bath 94.4°) in the presence of W-2 Raney nickel* (ca. 2.0g), under nitrogen. Periodically, samples (ca. 0.2ml) were withdrawn from the solution with a syringe, and after having been filtered to remove nickel catalyst, they were analysed by g.l.c. (R, 170°) and the areas of the peaks corresponding to the cis-alcohol (47, X=OH) (R_t 31min 12s) and the trans-alcohol (48, X=OH) (R_t 33min 21s) were determined by integration. Sampling was continued until two consecutive determinations were the same.

At equilibrium, the composition of the mixture is 37% cis- (47, X=OH), 63% trans- (48, X=OH) and thus the equilibrium constant, K, is 1.70. Using the relationship $\Delta F = -RT\ln K$, (where R is the universal gas constant and T

---

* W-2 Raney nickel was prepared according to the procedure of Eliel and Schroeter.[142]

is the temperature of equilibration), it can be calculated that the ground state free energy difference, ΔF, between the two epimers is 0.37Kcal/mole.

IV.2.

Syntheses leading to 9-t-butylspiro[4.5]dec-6-yl derivatives

4-t-Butylcyclohexanone (97)

(a) A solution of 4-t-butylcyclohexanol (200g, 1.28 mole) in ether (600ml) was stirred vigorously and treated with a solution of sodium dichromate (127.3g, 0.43mole) in aqueous sulphuric acid (701ml of ca. 10% v/v solution) while the temperature was maintained at ca. 25°.[195] After being stirred for an additional 3h, the organic layer was separated and the aqueous layer was extracted with ether (3 x 200ml). The combined ethereal fractions were washed successively with water and saturated sodium bicarbonate solution, dried and concentrated to yield a white crystalline solid (185g, 94%), b.p. 79-81°/4.5mm which was shown by g.l.c. (A, 137°) to consist of the required ketone (ca. 90%) and starting material (ca. 10%). Pure 4-t-butylcyclo--hexanone* (97), b.p. 104-105°/15mm (lit.[242] b.p. 106-108°/18mm) was obtained by conversion, with subsequent decom-

---

* Oxidation of 4-t-butylcyclohexanol with sodium dichromate solution (2 equivalents), according to the method of Brown, Garg and Liu,[198] gave 4-t-butylcyclohexanone (97) (84%) which was homogeneous by g.l.c. (G, 155°).

position, of the crude product to the bisulphite addition compound, in the usual manner.[197]

9-t-Butylspiro[4.5]decan-6-one (96)

A suspension of potassium t-butoxide, prepared from an excess of t-butyl alcohol and potassium metal (76.0g, 2.0mole), in dry benzene (2l.) was stirred under nitrogen. A solution of 4-t-butylcyclohexanone (97) (154g, 1.0mole) in benzene (ca. 100ml), followed by 1,4-dibromobutane (216g, 1.0mole) was added rapidly, and the mixture was refluxed for 12h (ref. 199). After the reaction had been quenched with water, the organic layer was separated and washed with water (3 x 300ml), saturated brine (200ml), dried and concentrated. Distillation of the residue gave 9-t-butylspiro[4.5]decan-6-one as a colourless oil (143g, 69%), b.p. 74-76°/0.1mm (lit.[200] b.p. 99-101°/0.5mm) which was homogeneous by g.l.c. (C, 127°). The compound exhibited the following spectral properties, ν_{max}^{film}: 1705(s), 1385(m), 1365(s)cm^{-1}; n.m.r. (CCl_4): τ 9.03 (9H, singlet), 8.72-7.27 (15H, complex); mass spectrum: M^+ at m/e 208 and base peak at m/e 167. The 2,4-dinitrophenylhydrazone derivative of the ketone (96), m.p. 167.5-168.5°, was prepared. (Found: C, 61.7; N, 14.6; H, 7.2. Calc. for $C_{20}H_{28}N_4O_4$: C, 61.8; N, 14.4; H, 7.3%).

When the above reaction was carried out in toluene

and t-butyl alcohol[201] as solvents, the yields of 9-t-butyl--spiro[4.5]decan-6-one (96) were 55 and 58%, respectively.

trans-9-t-Butylspiro[4.5]decan-6-ol (48, X=OH)

(a) A solution of lithium tri-t-butoxyaluminium--hydride (prepared from lithium aluminium hydride (2.08g, 0.055mole) and t-butyl alcohol (12.2g, 0.17mole) in tetrahydrofuran (50ml)) was added to a stirred solution of 9-t-butylspiro[4.5]decan-6-one (96) (10.0g, 0.05mole) in tetrahydrofuran (50ml) under nitrogen.[202] After 10 hours, the reaction was quenched with ice-water (750ml) and the mixture was extracted with ether (3 x 150ml). The combined ether extracts were dried and concentrated to yield a white solid (10.1g, 100%), which was shown to contain both trans- and cis-9-t-butylspiro[4.5]decan-6-ol (48 and 47 where X=OH, respectively, ca. 93 and 7% respectively), by g.l.c. analysis (A, 170° and R, 167°). The mixture was recrystallized once from light petroleum (30-40°) and three times from aqueous methanol (ca. 75%) to give the trans-spiro alcohol (48, X=OH), m.p. 78.5-79° after sublimation at ca. 60°/2mm, which was homogeneous by g.l.c. analysis. No satisfactory analytical values, however were obtained after three microanalyses. (Found: C, 78.7; H, 12.4. Calc. for $C_{14}H_{26}O$: C, 79.9; H, 12.5%). The compound exhibited the following spectral properties, ν_{max}^{nujol}: 3400(b), 1385(m), 1359(s), 1046(s)cm^{-1}; n.m.r. (CCl_4): τ 9.14 (9H, singlet),

9.10-7.33 (16H, complex, hydrogen count reduced to 15 by deuterium exchange), 6.97-6.5 (1H, complex, ½Δv 20c/s, C<u>H</u>-OH); mass spectrum: M^+ at m/e 210 and base peak at m/e 155.

(b) A solution of 9-<u>t</u>-butylspiro[4.5]decan-6-one (96) (15.0g, 0.072mole) in dry methanol (20ml), at 0-5°, was treated with sodium borohydride (2.73g, 0.072mole) and the mixture was stirred at room temperature, under nitrogen, for 24h.[203] After the mixture had been worked up in the usual way, a white solid (15g, 100%) was obtained, which was a mixture of <u>cis</u>- and <u>trans</u>-spiro alcohols (47 and 48 where X=OH, respectively)(<u>ca.</u> 10 and 90% respectively). This mixture was treated as in (a) and <u>trans</u>-9-<u>t</u>-butylspiro-[4.5]decan-6-ol (48, X=OH)(11.4g, 76%) was isolated.

(c) A solution of 9-<u>t</u>-butylspiro[4.5]decan-6-one (96) (0.199g, 0.001mole) in glacial acetic acid (5ml) was hydrogenated in the presence of platinum oxide catalyst[119] under one atmosphere of hydrogen. After the theoretical quantity of hydrogen had been absorbed, the catalyst was removed by filtration and a white solid (0.19g, 94%) was isolated by the usual procedure. G.l.c. analysis (R, 167°) showed that the product was a mixture of <u>cis</u>- and <u>trans</u>-9-<u>t</u>-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, respectively) (22 and 78%, respectively).

(d) The reduction of 9-<u>t</u>-butylspiro[4.5]decan-6-one

(96) with lithium aluminium in ether was carried out in the usual way[203] and gave a mixture of cis- and trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, respectively) (9 and 91%, respectively).

trans-9-t-Butylspiro[4.5]dec-6-yl acetate (63)

A solution of trans-9-t-butylspiro[4.5]decan-6-ol (48, X=OH) (0.7g, 0.003mole) in dry pyridine (2ml), at 0°, was treated dropwise with acetic anhydride (2ml). After the mixture had been kept at room temperature for three days, it was acidified, at 0°, with 10% sulphuric acid, and extracted with ether (3 x 50ml). The usual working-up procedure yielded a slightly coloured residue which was distilled to give trans-9-t-butylspiro[4.5]dec-6-yl acetate (63) (0.65g, 79%) as a colourless oil, b.p. 101-102°/0.15mm. G.l.c. analysis (B, 169° and E, 149°) indicated that the product was homogeneous. (Found: C, 76.1; H, 11.1. Calc. for $C_{16}H_{28}O_2$: C, 76.1; H, 11.2%). The compound exhibited the following spectral properties, ν_{max}^{film}: 1740(s), 1385(m), 1365(s), 1245(s)cm^{-1}; n.m.r. (CCl_4): τ 9.18 (9H, singlet), 9.11-8.07(15H, complex), 8.08 (3H, singlet), 5.70-5.45 (1H, complex, $\frac{1}{2}\Delta\nu$ = 18c/s, $CHOCOCH_3$); mass spectrum: $[M-CH_3COOH]^+$ at m/e 192 and base peak at m/e 135.

trans-9-t-Butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs)

A solution of trans-9-t-butylspiro[4.5]decan-6-ol (48, X=OH) (2.8g, 0.014mole) in dry pyridine (6ml), at 0°, was treated with p-toluenesulphonyl chloride[204] (7.58g, 0.04mole), which was added in one portion. After being kept at 0°, for 2 days, under nitrogen, the reaction mixture was carefully diluted with water, so that the temperature did not rise above 10°, and extracted with ether (2 x 60ml). The organic layer was washed successively with 10% hydrochloric acid solution (2 x 50ml), water and saturated sodium bicarbonate solution (1 x 60ml) and dried at 0° under nitrogen. After the solution had been concentrated under reduced pressure, a solid residue (5.8g) was collected, which was recrystallized three times from light petroleum (30-40°) at 0°, to yield trans-9-t-butylspiro[4.5]--dec-6-yl p-toluenesulphonate (48, X=OTs) (3.24g,76%) m.p. 65-67°. This was homogeneous by t.l.c. (70% ether/30% light petroleum (30-40°)), (R_f 0.65). (Found: C, 68.9; H, 8.9. Calc. for $C_{21}H_{32}SO_3$: C, 69.2; H, 8.9%). The compound exhibited the following spectral properties, ν_{max}^{nujol}: 1595(m), 1385(m), 1365(s), 1190(s), 1095(s)cm^{-1}; n.m.r. (CCl_4): τ 9.21 (9H, singlet), 9.08-8.00 (15H, complex), 7.59 (3H, singlet), 5.94-5.55 (1H, complex, $\frac{1}{2}\Delta\nu$ = 19c/s, C<u>H</u>-OTs), 2.84, 2.29 (4H, centres of gravity of the two doublets of the ~~A_2B_2~~ $AA'BB'$ system, ~~$J_{AB} = J_{A'B'} = 8Hz$~~); mass spectrum: $[M-p\text{-}CH_3C_6H_4SO_3H]^+$ at m/e 192 and the base peak at m/e 135.

9-t-Butylspiro[4.5]decan-6-one p-toluenesulphonylhydrazone

(98)

A mixture of 9-t-butylspiro[4.5]decan-6-one (96) (3.39g, 0.016mole) and p-toluenesulphonylhydrazine* (3.0g, 0.016mole) in ethanol (20ml) was refluxed for 2h.[205] On being cooled in an ice bath, the solution deposited a solid which was collected by filtration. It was recrystallized from ethanol to yield 9-t-butylspiro[4.5]decan-6-one p-toluenesulphonylhydrazone (98) (4.0g, 89%), m.p. 157-158°. (Found: C, 67.1; H, 8.7; N, 7.4. Calc. for $C_{21}H_{32}N_2O_2S$: C, 67.0; H, 8.6; N, 7.4%). The compound exhibited the following spectral properties, ν_{max}^{nujol}: 1595(w), 1390(m), 1330(s), 1170(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 9.22 (9H, singlet), 9.05-7.08 (15H, complex), 7.62 (3H, singlet), 2.70, 2.17(4H, centres of gravity of the two doublets of the $AA'BB'$ A_2B_2 system, ~~$J_{AB} = J_{A'B'} = 8Hz$~~), 2.47 (1H, broad singlet); mass spectrum: M^+ at m/e 376 and base peak at m/e 91.

9-t-Butylspiro[4.5]dec-6-ene (61)

(a) A stirred suspension of 9-t-butylspiro[4.5]decan-6-one p-toluenesulphonylhydrazone (98) (30.3g, 0.08mole) in

---

* p-toluenesulphonylhydrazine m.p. 108.5-110° (lit.[106] m.p. 104-107°) was prepared according to the standard procedures.[206]

ether (100ml) was treated at 0° with a solution of methyl--lithium (0.36mole) in ether (250ml), under an atmosphere of nitrogen.[192] The mixture was maintained at 15° for 2h, with an ice-water bath, then stirred at room temperature for an additional 48h. After the excess of methyllithium had been destroyed by the addition of ice, the aqueous layer was extracted with ether (3 x 75ml) and the combined ether extracts were dried and concentrated to yield a crude product. A solution of the latter, in light petroleum, was filtered through an alumina column (30g) (eluted in light petroleum (b.p. 50-60°)) and the resulting solution was concentrated and distilled to give 9-t-butylspiro[4.5]dec-6-ene (61) (15.5g, quantitative yield) as a colourless oil, b.p. 131°/20mm, which was homogeneous by g.l.c. analysis (D, 180°). (Found: C, 87.7; H, 12.2. Calc. for $C_{14}H_{24}$: C, 87.4; H, 12.6%). The compound exhibited the following spectral properties, ν_{max}^{film}: 3020(m), 1645(w), 1385(m), 1365(s), 710 (s)cm^{-1}; n.m.r. (CCl_4): τ 9.18 (9H, singlet), 9.07-8.02 (13H, complex), 4.72-4.52 (2H, complex, olefinic hydrogens); mass spectrum: M^+ at m/e 192 and base peak at m/e 135.

(b) trans-9-t-Butylspiro[4.5]decan-6-ol (48, X=OH) was converted to the corresponding methyl xanthate ester (48, $X=OCS_2CH_3$) (ν_{max}^{film}: 1390(w), 1365(m), 1220(s), 1050(s), 725(s)cm^{-1}), according to the method of Nace.[174]

9-t-Butylspiro[4.5]dec-6-yl methyl xanthate (48, X=OCS_2CH_3) (2.14g), without purification, was added (dropwise) onto powdered glass, in a distillation flask maintained at 320°. The distillate (1.43g) was refluxed over, and distilled from, sodium (in an attempt to remove the strong disagreeable "sulphur" odour) to give a colourless liquid (0.74g), b.p. 160-175°/25mm. G.l.c. analysis (D, 178°) indicated that the mixture consisted of the required olefin (61) (ca. 55%) and other impurities (ca. 45%).

cis- and trans-9-t-Butyl-cis-6,7-epoxyspiro[4.5]decane (99 and 100, respectively)

(a) m-Chloroperbenzoic (0.65g, 0.0038mole) in di--chloromethane (10ml) was added slowly to a stirred solution of 9-t-butylspiro[4.5]dec-6-ene (61) (0.50g, 0.0026mole) in dichloromethane, at room temperature.[207] After being stirred for 6h, the solution was washed successively with aqueous sodium sulphite, sodium carbonate solution (3 x 20ml) and water (3 x 20ml), dried and concentrated to give a residue which was distilled to yield a mixture of the cis- and trans-epoxides (99 and 100, respectively) (0.51g, 93%), b.p. 95°/1.3mm. G.l.c. analysis (E, 131°) indicated the presence of the cis- and trans-epoxide (99 and 100, respectively) (retention time, 17min 10s, ca. 75% and 15min 51s, ca. 25%, respectively) while t.l.c. (20% ether/80% light petroleum) (b.p. 50-60°) resulted in the appearance of one spot R_f 0.52).

Microanalyses were determined for the mixture of the two epoxides. (Found: C, 81.0; H, 11.8. Calc. for $C_{14}H_{24}O$: C, 80.7; H, 11.6%). The following spectral properties were obtained for the mixture of cis- and trans-epoxides (99 and 100, respectively), ν_{max}^{film}: 1385(m), 1365(s), 1240(m), 840(m)cm^{-1}; n.m.r. (CCl_4): τ 9.22 (9H, singlet), 9.08-8.00 (13H, complex), 7.38, 7.37 (1H, two superimposed doublets, J 3.5Hz, $-CH_2-\underset{O}{CH}-\underline{CH}-CR_3$), 7.05-6.73 (1H, complex, $-CH_2-\underline{CH}-\underset{O}{CH}-CR_3$); mass spectrum: M^+ at m/e 208.

(b) A solution of 9-t-butylspiro[4.5]dec-6-ene (61) (1.0g, 0.005mole) in dry ether (50ml) was mixed with a solution of monoperphthalic acid[208] (1.9g, 0.01mole) in ether (15ml) and the mixture was heated at reflux for 6h. After the solvent had been removed, the residue was mixed with dry chloroform and filtered to give phthalic acid (1.41g, 82%) and a filtrate which was concentrated to give a colourless oil (0.35g, 32%). G.l.c. analysis (E, 131°) indicated the presence of the cis- and trans-epoxides (99 and 100, ca. 75 and 25%, respectively).

(c) A mixture of 9-t-butylspiro[4.5]dec-6-ene (61) (0.46g, 0.0024mole) and percamphoric* acid (0.67g, 0.003mole) in dry chloroform (80ml) was maintained at room temperature for 3 days.[209] After being washed successively with sodium

---

* See footnote on page 144.

hydroxide (2 x 50ml, 10% aqueous solution), and water (2 x 50ml), the solution was dried and concentrated to yield a colourless oil (0.49g, 98%) which was shown to contain cis- and trans-9-t-butyl-6,7-epoxyspiro[4.5]decane (99 and 100, ca. 75 and 25%, respectively), by g.l.c. analysis (E, 131°).

Preliminary investigation of the epoxidation reaction of 9-t-butylspiro[4.5]dec-6-ene (61)

Reductive opening of a mixture (3:1) of cis- and trans-9-t-butyl-cis-6,7-epoxyspiro[4.5]decane (99 and 100, respectively).

(a) A solution of the cis- and trans-epoxides (99 and 100, respectively) (0.20g, 0.001mole) in dry ether (10ml)

---

* Percamphoric acid was prepared from camphoric anhydride according to the method of Milas and McAlevy.[210] Initially, the procedure of Edgerton[211] was used to prepare camphoric anhydride; the following procedure proved however to be more convenient and efficient.

Camphoric acid (10g, 0.05mole) was distilled from glass beads through a short "Vigreux" column. Camphoric anhydride (5.2g, 76%) was obtained as white needles (ex methanol), m.p. 219-221° (lit.[211] m.p. 221°).

was heated to reflux, for 3h under nitrogen, with lithium aluminium hydride (0.04g, 0.0015mole, excess).[212] After the reaction had been quenched with water (50ml), the aqueous layer was extracted with ether (3 x 30ml) and the combined organic fraction was dried and concentrated to yield a white solid (0.19g, 95%) which was shown to consist of cis- and trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, ca. 70 and 5% respectively) and cis- and trans-9-t-butylspiro[4.5]decan-7-ol (101b and 101a, ca. 5 and 20% respectively) by g.l.c. (R, 173°). (See Section III) The product showed the following infrared absorptions, ν_{max}^{nujol}: 3300(s), 1385(m), 1365(s), 1240(s), 1020(s), 960(m) cm^{-1}. The T.l.c. analysis (15% ether/85% light petroleum (b.p. 50-60°)) gave one spot (R_f 0.23).

(b) A solution of cis- and trans-epoxide (99 and 100, respectively) (0.20g, 0.001mole) in dry ethylamine (10ml) was treated under nitrogen with finely-cut lithium wire (0.048g, 0.002g atom). After the solution had been stirred overnight, the solvent was allowed to evaporate, the residue was extracted with ether (3 x 25ml) and a white solid (0.16g, 75%) was isolated. G.l.c. analysis (R, 173°) indicated the presence of the cis-alcohol (47 where X=OH, ca. 70%) and the trans-alcohol (101a, ca. 30%).

Oxidation of product from reductive opening of the mixture (3:1) of cis- and trans-9-t-butyl-cis-6,7-epoxyspiro[4.5]-decane (99 and 100, respectively)*

(a) from lithium aluminium hydride

The mixture of 9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH) and 9-t-butylspiro[4.5]decan-7-ol (101a and 101b) (0.18g, 0.0086mole) in acetone was oxidized with Jones' reagent[213] according to the method of Meinwald, Crandall and Hymans.[214] The crude product was distilled to give a colourless oil (0.11g, 72%), b.p. ca. 100°/1.1mm with infrared absorption at ν_{max} 1705(s)cm^{-1}. G.l.c. analysis (A, 134°) indicated the presence of 9-t-butylspiro[4.5]decan-6-one (96) and 9-t-butylspiro[4.5]decan-7-one** (102) (See Table III.2.).

---

* The mixture (3:1) of cis- and trans-9-t-butyl-cis-6,7-epoxyspiro[4.5]decane (99 and 100, respectively) obtained from the reaction of 9-t-butylspiro[4.5]dec-6-ene (61) with (a) monoperphthalic acid and (b) percamphoric acid, was subjected to the same sequence of reactions as these described above for the mixture of epoxides from the reaction with m-chloroperbenzoic acid. (For results see Table III.2., Section III).

** Physical data for this compound appears later.

(b) from lithium in ethylamine

The mixture of the spiro alcohols (47) and (101a) was oxidized as described in part (a) and gave, after distillation, a colourless oil (0.13g, 86%), b.p. ca. 100°/1.0mm with infrared absorption at 1705(s), 1385(w), 1365(m), 1185(m)cm^{-1}, which was shown to consist of 9-t-butylspiro[4.5]decan-6-one (96, ca. 68%) and 9-t-butyl--spiro[4.5]decan-7-one (102, ca. 32%) by g.l.c. (A, 147°).

9-t-Butylspiro[4.5]decan-6-ol (47 and 48) and 9-t-butyl--spiro[4.5]decan-7-ol (101a and 101b)

A solution of 9-t-butylspiro[4.5]dec-6-ene (61) (1.0g, 0.005mole) in dry tetrahydrofuran was treated with gaseous diborane, generated in a separate flask, from boron trifluoride etherate (1.28g, 0.009mole) and sodium borohydride (0.19g, 0.005mole).[215] After the reaction mixture had been stirred at room temperature, for 2½h, sodium hydroxide (5ml of a 3N solution) was added, followed by hydrogen peroxide (5ml of a 30% solution), while the temperature was maintained below 50°. The mixture was stirred at 30° for one hour then extracted with ether (3 x 30ml) and the combined organic fractions were washed successively with sodium sulphite solution (2 x 30ml) and water (2 x 30ml), dried and concentrated to yield a white solid. Recrystallization from n-pentane gave a product (1.1g, 97%),

which was shown by g.l.c. (R, 173°) to be a mixture of cis- and trans-9-t-butylspiro[4.5]decan-6-ol (47 and 48 where X=OH, ca. 14 and 32%, respectively) and cis- and trans-9-t-butylspiro[4.5]decan-7-ol (101b and 101a, ca. 30 and 24% respectively). This mixture exhibited infrared absorption at 3300(b), 1385(m), 1365(s), 1240(s)cm^{-1}.

9-t-Butylspiro[4.5]decan-6-one (96) and 9-t-butylspiro[4.5]-decan-7-one (102). (From the product of hydroboration of 9-t-butylspiro[4.5]dec-6-ene (61)).

The mixture of alcohols (47, 48, 101a and 101b) obtained from the hydroboration of the olefin (61) (0.18g, 0.009mole) was oxidized with Jones' reagent according to the procedure of Meinwald et.al.[214] Distillation of the crude product gave a colourless oil (0.15g, 94%) b.p. 90°/0.6mm, which was shown by g.l.c. analysis (A, 134°) to consist of the two spiro ketones (96, ca. 43%) and (102, ca. 57%). The two ketones were separated by preparative g.l.c. (F, 195°). The one with the shorter retention time was identified as 9-t-butylspiro[4.5]decan-6-one (96) by a comparison of its g.l.c. characteristics and physical properties (ir, n.m.r. and mass spectrum) with those of the authentic compound. The 2,4-dinitrophenylhydrazone of this ketone, m.p. 168-169° was identical to the analogous derivative of the ketone (96). The other fraction was dis-

tilled to give as a colourless oil b.p. 101°/0.5mm 9-t-butylspiro[4.5]decan-7-one (102). (Found: C, 80.8; H, 11.5. Calc. for $C_{14}H_{24}O$: C, 80.7; H, 11.6%). The ketone (102) exhibited the following spectral properties, ν_{max}: 1707(s), 1450(s), 1385(w), 1365(s), 1230(s)cm^{-1}; n.m.r. (CCl_4): τ 9.12 (9H, singlet), 9.12-7.75 (15H, complex, includes a singlet for -CO-CH_2-CR_2-); mass spectrum: M^+ at m/e 208.

cis- and trans-9-t-Butylspiro[4.5]decan-7-ol (101b and 101a)

A solution of 9-t-butylspiro[4.5]decan-7-one (102) (42mg, 0.0002mole) in methanol (5ml) was stirred at 0° with sodium borohydride (16mg, 0.0004mole, excess) for 4h. After the usual working-up procedure, a white solid (36mg, 86%) was isolated and exhibited infrared absorption at 3450(s), 1395(m), 1370(s), 1240(m), 1130(m)cm^{-1}. The mixture was shown to contain the cis- and trans-alcohols (101b and 101a, ca. 14 and 86%, respectively) by g.l.c. (R, 173°) (See Section III).

cis-9-t-Butylspiro[4.5]decan-6-ol (47, X=OH)

A mixture (3:1) of cis- and trans-9-t-butyl-cis-6,7-epoxyspiro[4.5]decane (99 and 100, respectively) was separated by preparative g.l.c. (F, 181°) to give the cis-isomer (100) which was homogeneous by g.l.c. analysis (E, 130°).

A solution of cis- (99) (1.21g, 0.006mole) in dry

ether (20ml) was refluxed for 4h under nitrogen with lithium aluminium hydride (0.3g, excess). After the usual working-up procedure, a white solid (1.2g, 100%) was obtained, which was recrystallized from 75% aqueous methanol followed by sublimation (ca. 70°/0.3mm) to give cis-9-t-butylspiro[4.5]decan-6-ol (47, X=OH) m.p. 86.5-88.5°. The product was homogeneous by g.l.c. analysis (E, 170°). (Found: C, 79.9; H, 12.5. Calc. for $C_{14}H_{26}O$: C, 79.9; H, 12.5%). The product exhibited the following spectral properties, ν_{max}: 3400(b), 1385(w), 1365(s), 1310(m), 1010(s)cm^{-1}; n.m.r. (CCl_4): τ 9.14(9H, singlet), 8.03-7.43 (16H, complex, reduced to 15H by deuterium exchange), 6.80-6.60 (1H, complex, $\frac{1}{2}\Delta\nu$ = 7c/s); mass spectrum: M^+ at m/e 210 and base peak at m/e 136.

Oxidation of cis-9-t-butylspiro[4.5]decan-6-ol (47, X=OH)

Oxidation of cis-9-t-butylspiro[4.5]decan-6-ol (47, X=OH) (0.02g, 0.0001mole) with Jones' reagent in the usual manner gave a colourless oil (0.016g, 80%) which was identified as 9-t-butylspiro[4.5]decan-6-one (96) on the basis of its infrared spectrum and g.l.c. (A, 148°) characteristics. The absence of 9-t-butylspiro[4.5]decan-7-one (102) was confirmed by the g.l.c. technique of "spiking" with the authentic compound.

Attempted preparation of cis-9-t-butylspiro[4.5]decan-6-ol (47, X=OH)

The attempted reduction* was carried out according to the procedure described by Eliel.[160]

(a) A solution of chloroiridic acid (0.16g, 0.0003 mole) in concentrated hydrochloric acid (0.11ml) was treated with water (4.5ml), followed by trimethylphosphite (1.25ml). This reagent was mixed with a solution of the spiro ketone (96) (1.0g, 0.005mole) in isopropyl alcohol (16ml) and the reaction mixture heated at reflux for 6h. After the isopropyl alcohol had been removed by distillation, the residue was diluted with water (30ml) and extracted with ether (2 x 40ml) and the combined organic fractions were dried and concentrated. The residue was distilled to give a colourless oil (1.0g) b.p. 68°/0.02mm with infra-red absorption at 1705(s)cm^{-1}. G.l.c. analysis (A, 128°) indicated unchanged starting material, (96) only.

---

* The reduction of 4-t-butylcyclohexanone (97) (0.92g, 0.006mole) was carried out, using the conditions described in part (a), and yielded a mixture of cis- and trans-4-t-butylcyclohexanol (51 and 52 where X=OH, ca. 85 and 15%, respectively) (g.l.c. analysis (B, 119°)) which was in close agreement with the results of Eliel.[160]

(b) Chloroiridic acid (0.08g, 0.00015mole) in concentrated hydrochloric acid (0.06ml) was mixed with water (2.25ml) and trimethyl phosphite (0.65ml). The mixture was sealed in a "Carius" tube with a solution of 9-t-butylspiro[4.5]decan-6-one (0.5g, 0.0025mole) in iso-propyl alcohol (8ml) and the tube was heated at 150° for 7 days. After the usual working-up procedure, a colourless oil (0.29g, 48%), b.p. ca. 70°/0.1mm, was isolated with infrared absorption at 1705cm^{-1} and with the same g.l.c. characteristics as 9-t-butylspiro[4.5]decan-6-one (96).

cis-9-t-Butylspiro[4.5]decan-6-ol (47, X=OH)

The Meerwein-Pondorf reduction of 9-t-butylspiro-[4.5]decan-6-one (96) was carried out according to the method of Vogel.[216]

A mixture of freshly distilled aluminium isopropoxide (4.13g, 0.048mole) in dry isopropyl alcohol (50ml) was heated (water bath) with 9-t-butylspiro[4.5]decan-6-one (96) (10.0g, 0.048mole) so that slow distillation occurred (ca. 5 drops/min). The distillate was tested for the presence of acetone at 10min intervals. When the reduction was complete (absence of acetone in the distillate), the remaining isopropyl alcohol was removed by distillation and the residue was hydrolysed with cold hydrochloric acid solution (10% aqueous). After the mixture had been extracted with ether (3 x 50ml), the combined organic fractions were washed

successively with water (2 x 50ml) and sodium carbonate solution (2 x 75ml), dried and concentrated to give a white solid (4.2g, 100%) which yielded colourless needles after recrystallization from light petroleum (b.p. 30-40°). The product was shown to contain cis- and trans-9-t-butyl--spiro[4.5]decan-6-ol (47 and 48 where X=OH, ca. 37 and 63%, respectively) by g.l.c. (R, 160°). Chromatography* of the mixture (ca. 1.0g) on Woelm neutral alumina, activity 1 (120g) gave the cis-alcohol (47) (0.2g) (eluted in 50% ether/ 50% light petroleum (b.p. 50-60°)) which was identified by a comparison of its spectral properties (ir, n.m.r.) and g.l.c. characteristics with the authentic compound.

cis-9-t-Butylspiro[4.5]dec-6-yl p-toluenesulphonate (47, X=OTs)

cis-9-t-Butylspiro[4.5]decan-6-ol (47, X=OH) (0.71g, 0.003mole) was converted into its p-toluenesulphonate ester (47, X=OTs) (1.12g, 91%) using the procedure previously described for the trans-alcohol (48, X=OH).

The crude product was recrystallized from light

---

* It was necessary to flush all solvents with dry nitrogen before use and to elute the alcohols as quickly as possible in order to avoid oxidation on the column.

petroleum (30-40°), at 0°, to give colourless crystals m.p. 94-95° (sinters 62-62.5°) which were homogeneous by t.l.c. analysis (R_f 0.60) (20% ether/80% light petroleum) (30-40°). The compound was too unstable to obtain a reliable microanalysis. The compound exhibited the following spectral properties, ν_{max}^{nujol}: 1595(m), 1385(w), 1365(s), 1350(sh), 1185(s), 1175(s), 675(s)cm^{-1}; n.m.r. (CCl_4): τ 9.17(9H, singlet), 9.00-7.70 (15H, complex), 7.55 (3H, singlet), 5.80-5.60 (1H, complex, C<u>H</u>-OTs, $\frac{1}{2}\Delta\nu$ = 7Hz), 2.77, 2.30 (4H, calculated centres of gravity of the two doublets of the ~~$A_2^{AA'BB'}B_2'$~~ system, ~~$J_{AB} = J_{A'B'} = 8.5Hz$~~); mass spectrum: $\left[M\text{-}p\text{-}meC_6H_4SO_3H\right]^+$ at m/e 192 and base peak at m/e 135.

<u>cis</u>-9-<u>t</u>-Butylspiro[4.5]dec-6-yl acetate (62)

<u>cis</u>-9-<u>t</u>-Butylspiro[4.5]decan-6-ol (0.25g, 0.0012 mole) was converted into its acetyl derivative (62) (0.16g, 55%) by the procedure previously described for the <u>trans</u>-isomer (63). The ester (62), a colourless oil, b.p. 98°/0.18mm, was homogeneous by g.l.c. analysis (G, 160°). (Found: C, 76.4; H, 11.2. Calc. for $C_{16}H_{28}O_2$: C, 76.1; H, 11.2%). It exhibited the following spectral properties, ν_{max}^{film}: 1730(s), 1385(w), 1365(s), 1250(s)cm^{-1}; n.m.r. (CCl_4): τ 9.13 (9H, singlet), 9.00-8.13 (15H, complex), 8.02 (3H, singlet), 5.52-5.30 (1H, complex, -C<u>H</u>-OCOCH$_3$, $\frac{1}{2}\Delta\nu$ = 7Hz); mass spectrum: M^+ at m/e 192 and base peak at m/e 135.

Attempted preparation of cis-9-t-butylspiro[4.5]dec-6-yl acetate (62)

(a) A mixture of trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs) (0.029g, 0.00008mole) and potassium acetate (0.043g, 0.0004mole) in dimethylformamide (5ml) was heated at reflux for 6h under nitrogen (ref. 158). After being cooled, the reaction mixture was diluted with water, extracted with chloroform (3 x 50ml) and the combined organic fractions were washed successively with aqueous hydrochloric acid (0.5N) and water, dried and concentrated to give a colourless oil (0.011g). The product exhibited no infrared absorption characteristic of an acetyl derivative and g.l.c. analysis (B, 168°) indicated the presence of olefinic material (similar retention time to that of the olefin(61)).

(b) When a mixture of trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs) (0.05g, 0.0001mole) and potassium acetate (0.034g) in dimethylformamide (5ml) was stirred at 5° for 3 days, unchanged ester (48, X=OTs) was recovered after the usual working-up procedure.

IV.3.

Syntheses leading to (3-t-butylcyclopentyl)cyclopentyl derivatives

3-t-Butylhexane-1,6-dioic acid

3-t-Butylhexane-1,6-dioic acid, m.p. 115-116° (lit.[217] m.p. 117°) was prepared according to the procedure of Niederl and Smith.[218]

3-t-Butylcyclopentanone (88)

3-t-Butylhexane-1,6-dioic acid was converted into 3-t-butylcyclopentanone (88) (64%), b.p. 89°/21mm, (lit.[217] b.p. 200-201°/759mm) by the method of Pines and Ipatieff.[217] The product was homogeneous by g.l.c. (A, 146°).

3-t-Butylcyclopentanol (138)

A mixture of 3-t-butylcyclopentanone (88) (0.24g, 0.0017mole) and sodium borohydride (0.34g, excess) in methanol (8ml) was stirred for 2 h. After the usual working-up procedure, 3-t-butylcyclopentanol (138) (0.24g, quantitative yield), b.p. ca. 90°/12mm (lit.[180] 98°/15mm) was obtained and shown to be homogeneous by g.l.c. (A, 121°).

3-t-Butylmethylenecyclopentane (111)

A suspension of potassium t-butoxide (11.95g, 0.107 mole) in dry ether (300ml) was stirred with triphenylmethyl-

-phosphonium bromide* (39.3g, 0.107mole) at 0°, for 1h, under dry nitrogen.[219] After a solution of 3-t-butylcyclo--pentanone (88) (15.0g, 0.107mole) in dry ether (100ml) had been added dropwise at -40°, the resulting solution was stirred for 8h at this temperature and then for 24h at room temperature. After being filtered, the solution was washed with aqueous methanol (4 x 50ml, 80% solution) (to remove the triphenylphosphine oxide), dried, concentrated and the residue was distilled to give 3-t-butylcyclopentanone (88) (2.4g), b.p. 93.5-94°/25mm and 3-t-butylmethylenecyclopentane (111) (3.53g, 28%), b.p. 63-64.5°/25mm. The olefin (111) was homogeneous by g.l.c. analysis (H, 179°). (Found: C, 86.6; H, 13.0. Calc. for $C_{10}H_{18}$: C, 86.8; H, 13.1%). The following spectral data were recorded for 3-t-butyl--methylenecyclopentane (111), ν_{max}^{film}: 3050(w), 1655(m), 1385(m), 1365(s), 655(s)cm^{-1}; n.m.r. (CCl_4): τ 9.13 (9H, singlet), 8.83-7.55 (7H, complex), 5.42-5.20 (2H, $R_2C{=}C\underline{H}_2$, $\frac{1}{2}\Delta\nu$ = 6Hz); mass spectrum: M^+ at m/e 138.

(3-t-Butylcyclopentyl)methyl alcohol (112)

A solution of 3-t-butylmethylenecyclopentane (111) (2.1g, 0.015mole) in dry tetrahydrofuran (20ml), under

---

* Methyltriphenylphosphonium bromide was prepared by the method of Miles and Priesing.[220]

nitrogen, was treated with gaseous diborane, prepared in a separate flask, from sodium borohydride (2.0g, 0.05mole, excess) and borontrifluoride etherate (17.0g, 0.12mole) in diglyme (15ml). After being stirred for 36h, the alkyl borane was oxidized by the addition of sodium hydroxide (10ml, 3N) and hydrogen peroxide (10ml, 30%), while the temperature was maintained between 30° and 50°. After the mixture had been stirred for 2h, it was diluted with water (100ml) and extracted with ether (3 x 50ml). The combined organic fractions were washed with a saturated brine solution (50ml), dried and concentrated to give a residue which yielded, after distillation, (3-t-butylcyclopentyl)methyl alcohol (112) (1.59g, 66%), b.p. 109-110°/12mm, as a colourless oil. This was homogeneous by g.l.c. (A, 90°, E, 120°, R, 157°, J, 126°). (Found: C, 77.1; H, 12.9. Calc. for $C_{10}H_{20}O$: C, 76.9; H, 12.9%). The compound exhibited the following spectral properties, ν_{max}^{film}: 3600-3200(b), 1470(s), 1385(m), 1365(s), 1045(s), 1005(s)cm^{-1}; n.m.r. (CCl_4): τ 9.13 (9H, singlet), 8.98-7.62 (8H, complex), 7.53 (1H, broad singlet, removed by deuterium exchange), 6.58 (2H, doublet, J 6Hz); mass spectrum: $\left[M\text{-}t\text{-}Bu\right]^+$ at m/e 99.

3-t-Butylcyclopentanecarboxylic acid (113)

(a) A solution of (3-t-butylcyclopentyl)methyl alcohol (112) (1.28g, 0.08mole) in acetone (15ml) was treated with Jones' reagent according to the usual procedure.[214]

The reaction mixture was diluted with water (100ml), extracted with ether (3 x 50ml) and the combined organic layers were successively washed with water and extracted with saturated sodium bicarbonate solution (3 x 50ml). After being acidified, the combined aqueous fractions were extracted with ether (3 x 50ml) and following the usual procedure, 3-t-butylcyclopentanecarboxylic acid (113) (0.56g, 41%) b.p. 93-94°/0.3mm (lit.[180] b.p. (cis) 106°/0.5mm) was obtained as a viscous liquid. (Found: C, 70.4; H, 10.9. Calc. for $C_{10}H_{18}O_2$: C, 70.5; H, 10.7%). The acid (113) exhibited the following spectral properties, ν_{max}^{film}: 3400-2400(b), 1699(s), 1420(s), 1385(m), 1365(s), 1295(s), 1235(s), 940(s)cm^{-1}; n.m.r. (CCl_4): τ 9.12 (9H, singlet), 8.67-7.77 (7H, complex), 7.57-6.90(1H, complex), -1.80 (1H, singlet); mass spectrum: m/e 155, 137, 115.

(b) cis-3-t-Butylcyclopentanecarboxylic acid (113) was prepared from 4-t-butylcyclohexanone (97) by the method of Payne and Smith.[181]

A solution of 4-t-butylcyclohexanone (97) (40.0g, 0.259mole) in t-butyl alcohol (150ml) was added dropwise to a stirred mixture of hydrogen peroxide (29.5ml of a 30% solution), selenium dioxide (0.43g, 0.004mole) and t-butyl alcohol (150ml) at 80°. After the reaction mixture had been stirred for 20h at 80°, the solvent was removed and the residue was extracted with ether. After the usual working-

up procedure (described in (a)) distillation yielded cis-3-t-butylcyclopentylcarboxylic acid (113) (13.1g, 30%), b.p. 100-101°/0.2mm as a colourless viscous liquid, whose spectral properties (ir and n.m.r.) were identical to the acid prepared in (a).

(c) 3-t-Butylcyclohexanone* (114) (20.0g, 0.129mole) was subjected to the same reaction conditions as described in part (b). This procedure gave trans-3-t-butylcyclopentyl--carboxylic acid (113) (12.2g, 55%) b.p. 95-97°/0.2mm, whose spectral properties (ir and n.m.r.) were identical to the cis-isomer (113).

Methyl cis-3-t-butylcyclopentanecarboxylate (104a)

A solution of freshly distilled diazomethane (0.42g, 0.01mole) in ether (ca. 20ml) was added to a solution of cis-3-t-butylcyclopentylcarboxylic acid (113) (0.50g, 0.003mole) in ether (20ml) at 0° (ref. 221). After being kept for 12h at 0°, the reaction mixture was concentrated and the residue was distilled to give the cis-ester (104a) (0.37g, 69%), b.p. ca. 90°/8mm, as a colourless oil, which was homogeneous by g.l.c. analysis (H, 174°). (Found: C, 71.8; H, 11.1. Calc. for $C_{11}H_{20}O_2$: C, 71.7; H, 11.0%). The ester (104a) exhibited the following spectral properties,

* For preparation of 3-t-butylcyclohexanone see later.

ν_{max}^{film}: 1735(s), 1385(w), 1365(s), 1160(s)cm^{-1}; n.m.r. (CCl_4): τ 9.14 (9H, singlet), 8.75-7.90 (7H, complex), 7.77-7.05 (1H, complex), 6.43 (3H, singlet); mass spectrum: $\left[M-CH_3\right]^+$ at m/e 169 and the base peak at m/e 87.

Methyl trans-3-t-butylcyclopentanecarboxylate (104b)

Methyl trans-3-t-butylcyclopentanecarboxylate (104b), b.p. 104°/7mm was obtained from the trans-acid (113) by the usual procedure.[221] G.l.c. analysis (G, 159°; E, 129°; J, 110°; O, 153°) indicated that the trans-ester (104b) was homogeneous and could not be distinguished from the cis-ester (104a). The spectral properties (ir and n.m.r.) exhibited by the trans-ester (104b) were identical with those of the cis-ester (104a).

cis-(3-t-Butylcyclopentyl)cyclopentan-1-ol (105a)

A solution of methyl cis-3-t-butylcyclopentane--carboxylate (104a) (11.28g, 0.061mole) in tetrahydrofuran (100ml) was slowly added to a stirred solution, at 0°, of the Grignard reagent prepared from 1,4-dibromobutane (39.81g, 0.184mole) and magnesium (9.70g, 0.404g atom), in tetrahydro--furan (120ml).[108] After being stirred for 18h at room temperature, the reaction mixture was hydrolysed with ammonium chloride solution (200ml) and extracted with light petroleum (30-40°) (3 x 100ml). The combined organic fractions were dried and concentrated to give a residue, which

was successively chromatographed on neutral alumina (eluted in 17.5% ether/82.5% light petroleum (b.p. 50-60°)) and distilled. cis-(3-t-Butylcyclopentyl)cyclopentan-1-ol (105a) (10.89g, 85%), b.p. 98-100°/0.75mm was recovered as a viscous oil, which was homogeneous by both g.l.c. (G, 150°; R, 163°; N, 170°) and t.l.c. analysis (30% ether/70% light petroleum (50-60°)). (Found: C, 79.9; H, 12.5. Calc. for $C_{14}H_{26}O$: C, 79.9; H, 12.5%). The alcohol (105a) exhibited the following spectral properties, ν_{max}^{film}: 3400(b), 1450 (sh, m), 1385(m), 1365(s), 995(s)cm^{-1}; n.m.r. (CCl_4): τ 9.18 (9H, singlet), 9.00-8.00 (17H, complex, reduced to 16H by deuterium exchange); mass spectrum: M^+ at m/e 210 and base peak at m/e 85.

trans-(3-t-Butylcyclopentyl)cyclopentan-1-ol (105b)

trans-(3-t-Butylcyclopentyl)cyclopentan-1-ol (105b) (85%), b.p. 136°/7mm was prepared from the trans-ester (104b) by the method described above. The spectral and chromatographic properties of the trans-alcohol (105b) were identical to those of the cis-alcohol (105a).

cis-(3-t-Butylcyclopentyl)cyclopent-1-ene (68a) and (3-t-butylcyclopentylidene)cyclopentane (69)

A solution of cis-(3-t-butylcyclopentyl)cyclopentan-1-ol (105a) (2.0g, 0.009mole) in dry pyridine (30ml), at 0°, was treated with phosphorous oxychloride (3.7g, 0.022mole)

over a period of 30min.[222] After being stirred at 0° for a further 30min and then for 2h at room temperature, the reaction mixture was diluted with water (100ml) and extracted with ether (3 x 50ml). The combined organic layers were washed successively with dilute hydrochloric acid solution (5 x 50ml) and sodium bicarbonate solution (3 x 50ml), dried and concentrated. The residue was distilled to give a mixture of cis-(3-t-butylcyclopentyl)cyclopent-1-ene (68a) and (3-t-butylcyclopentylidene)cyclopentane (69) (1.37g, 75%), b.p. 83-86°/1.1mm, which were separated by preparative g.l.c. (I, 218° and F, 165°, 130ml/min) and both were shown to be homogeneous by g.l.c. analysis (C, 155°).

Redistillation gave the cis-olefin (68a) as a colourless oil, b.p. 80-83°/0.8mm. (Found: C, 87.3; H, 12.4. Calc. for $C_{14}H_{24}$: C, 87.4; H, 12.6%). This compound (68a) exhibited the following spectral properties, ν_{max}^{film}: 3010(m), 1640(m), 1385(s), 1365(s), 799(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 9.17 (9H, singlet), 8.85-7.88 (9H, complex), 7.88-7.20 (5H, complex, allylic hydrogens), 4.82-4.50 (1H, complex, part of ABX system R_2-C=C<u>H</u>-CH_2-); mass spectrum: M^+ at m/e 192 and base peak at m/e 135.

(3-t-Butylcyclopentylidene)cyclopentane (69), b.p. 76-82°/0.6mm, was obtained as a colourless oil. (Found: C, 87.0; H, 12.7. Calc. for $C_{14}H_{24}$: C, 87.4; H, 12.6%). The olefin (69) exhibited the following spectral properties,

ν_{max}^{film}: 1690(w), 1385(m), 1365(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 9.12 (9H, singlet), 8.92-7.53 (15H, complex); mass spectrum: M^+ at m/e 192 and base peak at m/e 135.

trans-(3-t-Butylcyclopentyl)cyclopent-1-ene (68b) and (3-t-butylcyclopentylidene)cyclopentane (69)

trans-(3-t-Butylcyclopentyl)cyclopentan-1-ol (105b) (2.0g, 0.009mole) was converted into a mixture of the olefins trans-(68b) and (69) (1.59g, 87%) by the same procedure as described for the cis-olefin (68a) and (69). G.l.c. analysis (G, 159°) indicated the presence of the compounds (69 and 68b, ca. 70 and 30%, respectively) (retention times: 15min 35s and 12min 10s respectively). The spectral (ir and n.m.r.) properties and g.l.c. characteristics (G, 140°; M, 132°; P, 147°; R, 110°) of trans-(3-t-butylcyclopentyl)cyclopent-1-ene (68b) were identical to the cis-epimer (68a).

Attempted preparation of 1-(3-t-butylcyclopentyl)cyclopentyl acetate (70)

(a) A solution of cis-(3-t-butylcyclopentyl)cyclo--pentan-1-ol (105a) (0.3g, 0.0014mole) in freshly distilled dimethylaniline (5ml) was treated at -5° with acetyl chloride (0.18g, excess).[249] After being stirred overnight, the mixture was taken up in ether (300ml) and the organic fraction was washed extensively with 5% hydrochloric acid solution (10 x 20ml) followed by 20% sodium carbonate solution

(2 x 30ml), dried and finally concentrated. The product (0.21g, ca. 70%) was shown to be mainly unchanged alcohol (105a) by a comparison of its spectral properties (ir; ν_{max}^{film}: 3400-3500(s) and 1740(very weak)* cm^{-1}) and t.l.c. characteristics (10% ether/90% light petroleum (b.p. 50-60°).

(b) The same result was obtained when a solution of cis-(3-t-butylcyclopentyl)cyclopentan-1-ol (105a) (0.21g, 0.001mole) in tetrahydrofuran (30ml) was treated under nitrogen with sodium hydride (0.048g, 0.002mole), followed by acetyl chloride (0.1ml, ca. 0.001mole). Distillation of the product yielded a colourless oil (0.17g, 90%), b.p. 103°/15mm whose spectral properties (ir; ν_{max}^{film}: 3400-3500(s), 1740(w)cm^{-1}; and n.m.r. (CCl_4): τ 9.14 (9H, singlet), 8.10 ($\ll$1H, singlet, -O-$COCH_3$)) showed that it was mainly unchanged alcohol (105a, ca. 95%) contaminated with the acetate (70, ca. 5%).

Attempted preparation of (3-t-butylcyclopentylidene)cyclopentane (69)

A suspension of potassium t-butoxide (1.62g, 0.014 mole) in dry ether (150ml) was stirred with triphenylcyclopentylphosphonium bromide (5.88g, 0.014mole) for 2h at 0° under nitrogen.[219] The mixture was cooled to -40° and a

* This showed the presence of a small amount of acetate (70).

solution of 3-t-butylcyclopentanone (88) (2.0g, 0.014mole) in dry ether (20ml) was slowly added. After being allowed to warm to room temperature, the reaction mixture was stirred for 24h before being filtered. The resulting solution was washed successively with aqueous methanol (2 x 50ml of an 80% solution) and water (2 x 50ml), dried and concentrated to give a residue, from which triphenylphosphine oxide (1.83g) was precipitated by addition of light petroleum (b.p. 50-60°). A portion (1g) of the crude product was chromatographed on neutral alumina (50g) and the following compounds were successively eluted (hexane), firstly 3-t-butylcyclopentanone (88) (0.18g) and then 4-t-butyl-2-(3-t-butylcyclopentylidene)cyclopentanone (0.73g, 55%). The latter exhibited infrared absorption at 1705(s), 1640(s), 1385(w), 1365(s), 1165(s), 730(s) and 685(s)cm^{-1} which was identical to the authentic compound.[200]

(3-t-Butylcyclopentyl)cyclopentane (82)

A solution of cis-(3-t-butylcyclopentyl)cyclopent-1-ene (68a) and (3-t-butylcyclopentylidene)cyclopentane (69) (0.10g, 0.0005mole) in acetic acid (10ml) was hydrogenated (15p.s.i.), at 20°, for 16h, in the presence of 5% palladium on carbon catalyst (0.04g). The crude product was isolated in the usual way and distilled to give (3-t-butylcyclopentyl)--cyclopentane (82) (0.089g, 88%) as a colourless oil, b.p. 110°/1.0mm, which was homogeneous by g.l.c. analysis (G,

148°; R, 130°; P, 163°). (Found: C, 86.7; H, 13.6. Calc. for $C_{14}H_{26}$: C, 86.5; H, 13.5%). The compound (82) exhibited the following spectral properties, ir, ν_{max}^{film}: 1385(m), 1365(s)cm^{-1}; n.m.r. (CCl_4): τ 9.14 (9H, singlet), 8.98-7.50 (17H, complex); mass spectrum: $[M\text{-}t\text{-}Bu]^+$ at m/e 137.

2-(3-t-Butylcyclopentyl)cyclopentanone (85)

Hydroboration of a mixture (1:4) of olefins (69) and (68b) (0.99g, 0.005mole) with diborane[215] followed by an oxidative working-up procedure (described previously) gave a colourless oil which was treated, without further purification, with Jones' reagent.[214] After the usual working-up procedure, a crude product (1.2g) was obtained which was chromatographed on neutral alumina (40g), to give the product (85) (0.151g, ca. 56%). Distillation yielded 2-(3-t-butylcyclopentyl)cyclopentanone (85) (0.14g) b.p. 150°/7mm as a colourless oil which was homogeneous by g.l.c. analysis (H, 183°). (Found: C, 80.7; H, 12.0. Calc. for $C_{14}H_{24}O$: C, 80.7; H, 11.6%). The ketone (85) exhibited the following spectral properties, ir, ν_{max}^{film}: 1735(s), 1385(w), 1365(s), 1145(s)cm^{-1}; n.m.r. (CCl_4): τ 9.15 (9H, singlet), 8.99-7.55 (15H, complex); mass spectrum: M^+ at m/e 208 and base peak at m/e 84.

cis-2-Bromo-4-t-butylcyclohexanone (106a)

cis-2-Bromo-4-t-butylcyclohexanone (106a), m.p. 66-

67.5° (lit.[225] m.p. 67-68.2°) was prepared according to the method of Allinger and Allinger.[223] The bromo ketone (106a) exhibited the following spectral properties, ir, ν_{max}^{nujol}: 1737cm^{-1} (s, lit.[224] C=O for equatorial bromine in a cyclohexone ring 1737cm^{-1}); n.m.r. (CCl_4): τ 9.06 (9H, singlet), 8.63-7.12 (7H, complex), 5.62-5.25 (1H, complex, part of ABX system); mass spectrum: M^+ at m/e 234,232.

Attempted preparation of cis-2-bromo-4-t-butylcyclohexanone (106a)

The bromination was carried out according to the method of Fieser and Dominguez[226].

A solution of 4-t-butylcyclohexanone (97) (30.0g, 0.195mole) in acetic acid (150ml) was treated, over 10h, with a solution of bromine (31.2g, 0.195mole) in a mixture of hydrobromic acid (20 drops) and acetic acid (100ml), while the temperature was maintained at ca. 15°. After it had been stirred for 12h, the reaction mixture was diluted with water (500ml), extracted with ether (3 x 200ml) and the combined organic fractions were washed with sodium thiosulphate solution (3 x 50ml), sodium carbonate solution(3 x 50ml), dried and concentrated. The residue was distilled to give 6 fractions (total yield 20.5g) and boiling range 80-149°/2mm. 2,6-Dibromo-4-t-butylcyclohexanone (138) (3.98g, 7%), m.p. 146-147° (lit.[227] m.p. 147.5-149°) was isolated from the residue and recrystallized from ether/light petroleum

(50-60°) (50/50 mixture). The dibromo-ketone (138) exhibited the following spectral properties, ir, ν_{max}: 1738(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 9.06 (9H, singlet), 8.40-7.10 (5H, complex), 5.57-5.07 (2H, complex, part of ABX system): mass spectrum: M^+ at m/e 314, 312, 310.

cis-2-Bromo-4-t-butylcyclohexanone (106a) (4.63g, 10%), m.p. 64-68° (containing some dibromide (138)) (ref. 227) was isolated from the high boiling distillate while the low boiling fractions contained a mixture of approximately five compounds, including starting material (97).

Attempted preparation of methyl-3-t-butylcyclopentane--carboxylate (104)

(a) Polar Solvent:

cis-2-Bromo-4-t-butylcyclohexanone (106a) (1.0g, 0.0043mole) was added to a solution of sodium methoxide (0.134g, 0.0058mole) in anhydrous methanol (100ml) and after being stirred at 0° for 7h under nitrogen, the reaction was quenched with a saturated brine solution (400ml) and extracted with ether (3 x 100ml). The combined organic fractions were washed with water (2 x 100ml), dried and concentrated to give a crude viscous product (0.90g), which solidified on standing and showed infrared absorption at 3460(s, sharp) and 1724(s)cm^{-1}. 4-t-Butyl-2-hydroxy-cyclo--hexanone (108), a colourless oil, (0.42g), b.p. ca. 130°/

6.5mm, with infrared absorption at 3600-3100(b) and 1725 (s)cm^{-1} (monomer) was recovered after distillation and this rapidly reverted, on standing, to its dimer (107), m.p. 168-193° (dependent on sample). (Found: C, 70.4; H, 10.4. Calc. for $C_{20}H_{36}O_4$: C, 70.5; H, 10.7%). The following spectral data were recorded*, ir, ν_{max}^{nujol}: 3400(s), 1095 (s, cyclic ether)cm^{-1}; mass spectrum: M^+ (monomer) at m/e 170.

(b) Non-polar Solvent:

The general procedure of Kende[177] was followed.

A solution of cis-2-bromo-4-t-butylcyclohexanone (106a) (1.0g, 0.0043mole) in dry ether (7ml) was slowly added, over 15min, to a stirred suspension of sodium methoxide (0.24g, 0.0048mole) in ether (100ml) under an atmosphere of dry nitrogen. After it had been heated at reflux for two hours, the reaction mixture was cooled and the usual working-up procedure (see part (a)) yielded a slightly purple liquid (0.98g). The crude product was distilled and gave a colourless oil (0.37g, 51%) b.p. (bath 140-160°)/0.25mm which solidified on standing and was identified as the dimer of 4-t-butyl-2-hydroxycyclohexanone (107) by a comparison of its spectral properties with the authentic compound.

---

* An n.m.r. spectrum was not obtained because of the insolubility of the dimer in suitable solvents.

IV.4.

Syntheses leading to 2-t-butyldecalyl derivatives

3-t-Butylcyclohexanol (139)

The procedure* used was essentially that of Burgstahler and Bithos,[228] with some modifications.

A solution of 3-t-butylphenol (17.6g, 0.12mole) in absolute ethanol (15ml) was hydrogenated at 1400p.s.i. and 200° for 48h in the presence of 5% rhodium on alumina catalyst (0.49g). After being cooled, the reaction mixture was filtered, concentrated and distilled to yield a colourless oil (17.2g, 98%) b.p. 78-79°/2.1mm which was a mixture of cis- and trans-3-t-butylcyclohexanol (139) (g.l.c., C, 130°).

3-t-Butylcyclohexanone (114)

3-t-Butylcyclohexanone (114), b.p. 106-109°/18mm (lit.[119] b.p. 92-95°/10mm) was prepared in 64% yield, by the method described for the synthesis of 4-t-butylcyclo-hexanone and was homogeneous by g.l.c. analysis (C, 85°).

Methyl 4-t-butyl-2-oxocyclohexanecarboxylate (116)

---

* No hydrogenation of 3-t-butylphenol was observed when the method of Joris and Vitrone[229] was used.

A solution of 3-t-butylcyclohexanone (114) (20.0g, 0.12mole) in dry tetrahydrofuran (300ml) was added slowly (2h) to a stirred mixture of sodium hydride (8.59g, 0.18 mole) and dimethyl carbonate (68.6g, 0.74mole) in tetra--hydrofuran (250ml), under nitrogen. After it had been stirred at 50° for 6h, the solution was neutralized with dilute acetic acid and extracted with ether (3 x 75ml). The combined organic fractions were washed with sodium bi-carbonate solution (3 x 50ml), dried and concentrated to yield a colourless oil, from which methyl 4-t-butyl-2-oxo--cyclohexanecarboxylate (116) (22.8g, 85%), b.p. 96-100°/ 0.9mm was isolated by distillation. This was homogeneous by g.l.c. analysis (J, 150°; E, 143°; D, 138°). (Found: C, 68.0; H, 9.6. Calc. for $C_{12}H_{20}O_3$: C, 67.9; H, 9.4%). The compound exhibited the following spectral properties, ir, ν_{max}^{film}: 1742(s), 1715(s), 1660(s), 1627(s), 1385(m), 1365(s), 1225(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 9.12 (9H, singlet), 9.00-7.45 (8H, complex), 6.32 (3H, singlet); mass spectrum: M^+ at m/e 212.

6-(4-Bromobutyl)-3-t-butyl-6-carbomethoxycyclohexanone (117)

(a) A solution of methyl 4-t-butyl-2-oxocyclohexane--carboxylate (116) (6.3g, 0.03mole) in dry benzene (15ml) was added in one portion to a suspension of sodium hydride (1.54g, 50% oil dispersion) in benzene (30ml) and dry

dimethylformamide (20ml) under nitrogen. After the mixture had been refluxed for 1h, 1,4-dibromobutane (7.56g, 0.035 mole) was added and it was heated at reflux for a further 12h then cooled and poured into dilute hydrochloric acid. The aqueous layer was extracted with ether (3 x 50ml) and the combined organic fractions were washed with sodium bi--carbonate solution (3 x 50ml), dried and concentrated. The residue was distilled to give 6-(4-bromobutyl)-3-t-butyl-6-carbomethoxycyclohexanone (117) (3.72g, 37%), b.p. 162°/0.25mm, which was homogeneous by g.l.c. (K, 199°). The bromo-keto-ester (117) exhibited the following spectral properties, ir, ν_{max}^{film}: 1730(s), 1705(s), 1385(w), 1365(m), 1240(m)cm^{-1}; n.m.r. (CCl_4): τ 9.10 (9H, singlet), 9.00-7.73 (13H, complex), 6.62 (2H, triplet, $-CH_2-\underline{CH}_2-Br$, J_{AX}= 6Hz), 6.47 (3H, singlet); mass spectrum: $\left[M-C_4H_7Br\right]^+$ (McLafferty rearrangement)[151] at m/e 212 (base peak).

(b) 6-(4-Bromobutyl)3-t-butyl-6-carbomethoxy-cyclo--hexanone (117) was prepared in 16% yield when sodium methoxide/methanol was used.

6-(4-Bromobutyl)-3-t-butylcyclohexanone (118)

The experimental method of Ritchie and Taylor [251] was used.

A mixture of 6-(4-bromobutyl)-3-t-butyl-6-carbo--methoxycyclohexanone (117) (3.63g, 0.01mole), hydrobromic

acid (10ml of a 48% solution) and glacial acetic acid (10ml) was heated at reflux for 36h, then diluted with water (150ml) and extracted with ether (3 x 50ml). The combined organic fractions were washed with sodium bicarbonate solution (3 x 50ml) and after the usual procedure, there was obtained a viscous liquid, 6-(4-bromobutyl)-3-t-butylcyclohexanone (118) (1.45g, 53%), b.p. 128°/0.2mm, which gave a single peak when exposed to g.l.c. analysis (K, 120°) and was homogeneous by t.l.c. analysis (R_f 0.89) (10% ether/90% hexane). The bromoketone (118) exhibited the following spectral properties, ir, ν_{max}^{film}: 1705(s), 1380(w), 1365(m), 1245(m)cm^{-1}; n.m.r. (CCl_4): τ 9.13 (9H, singlet), 8.95-7.50 (14H, complex), 6.68 (2H, triplet, CH_2-CH_2-Br, J 6Hz); mass spectrum: M^+ at m/e 290 and 288 and base peak at m/e 154.

meso-Tetraphenylporphin

meso-Tetraphenylporphin was prepared, according to the method of Adler et.al.[230] in 15% yield, with ultraviolet absorption at 420, 515, 548, 590, and 645nm.

Nickel tetraphenylporphin

meso-Tetraphenylporphin* (0.96g) in dimethylformamide (300ml) was heated at reflux with an excess of nickel acetate (1.0g) for 60min. After being cooled, the mixture was filtered and the solution was washed successively with water and benzene. The crude product (0.82g), which was isolated by concentrating the organic layer, was purified by chromatography (Fluka, acid alumina activity 1, developed with chloroform**). Pure nickel tetraphenylporphin (0.35g, 34%) was obtained with ultraviolet absorption ($CHCl_3$) at 415, 520nm.

Attempted preparation of 2-t-butyldecal-9-ol (115)

(a) The cyclization of 6-(4-bromobutyl)-3-t-butylcyclohexanone (118) was attempted, using the method of Corey and Kuwajima.[232]

The green lithium naphthalene anion was prepared

---

* In the first instance, nickel tetraphenylporphin was prepared by the method of Dorough, Miller and Huennekens[231] but this gave a very inferior yield of product.

** It was necessary to use a large volume of solvent to dissolve the metal complex and thus only a small quantity of nickel tetraphenylporphin could be chromatographed at one time.

by addition of the calculated quantity of finely cut lithium wire (0.015g, 0.002mole) to a solution of naphthalene (0.264g, 0.002mole) in tetrahydrofuran (25ml),.under dry nitrogen. Nickel tetraphenylporphin (0.68g, 0.001mole) was added in one portion and after the mixture had been stirred for 1h, 6-(4-bromobutyl)-3-t-butylcyclohexanone (118) (0.099g, 0.0003mole) was mixed with the solution which was stirred at 0^{o} for 72h and then diluted with water. After it had been filtered, the solution was extracted with ether (3 x 50ml) and the combined organic fractions were dried and concentrated to yield a crude product which showed a weak absorption in the carbonyl region of its infrared spectrum and no hydroxyl absorption. T. l. c. analysis (15% ether/ 85% light petroleum) indicated the absence of starting material (118). The residue was chromatographed on neutral alumina to give naphthalene (0.21g) (eluted in hexane). Three further fractions were recovered from the column, all of which were porphin residues. The first, eluted in 50% ether/50% hexane was bright green, the second, eluted in 100% ether was olive-red, and the final fraction was dark green (eluted in 50% ethanol/50% ether). Nickel tetraphenyl--porphin (0.47g) was recovered when the reaction mixture was filtered.

(b) 6-(4-Bromobutyl)-3-t-butylcyclohexanone (118) (1.0g, 0.004mole) was added over 6h, under nitrogen, to

magnesium (0.11g, 0.005mole) in refluxing anhydrous tetra--hydrofuran. After it had been heated at reflux for a further 48h, the mixture was diluted with water, extracted with ether (3 x 100ml) and the combined organic fractions were dried and concentrated. The product was identified as the bromoketone (118) by a comparison of its t.l.c. behaviour and infrared spectrum with the authentic compound.

(c) The method of Schmalzl and Mirrington[233] was used in an attempt to cyclize the bromoketone (118).

Magnesium (0.33g, 0.0014mole) and mercuric chloride (0.16g) were mixed in dry tetrahydrofuran (10ml), under nitrogen, and 6-(4-bromobutyl)-3-t-butylcyclohexanone (118) (0.16g, 0.0005mole) was added slowly. After being stirred at 20° for 1.5h then 45° for 15h, the reaction mixture was treated as in (b) and yielded starting bromoketone (118) (0.12g) as the sole product.

3-(4-t-Butylbenzoyl)propanoic acid (141)

3-(4-t-Butylbenzoyl)propanoic acid (141) was prepared as a white solid, m.p. 120-121.5° (lit.[234] 121-122°) in 49% yield, according to the procedure of Fieser and Price,[234] and exhibited the following spectral properties, ir, ν_{max}^{nujol}: 3200-2500(b), 1700(s), 1680(s), 1245(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 8.75 (9H, singlet), 7.33 (2H, triplet, J 6Hz), 6.84 (2H, triplet, J 6Hz), 2.54, 2.10 (4H, calculated centre of gravity of the two doublets of the ~~A_2B_2~~ $AA'BB'$ system

$J_{AB}=J_{A'B'}=8Hz$), -1.66 (1H, singlet, $-CO_2\underline{H}$); mass spectrum: M^+ at m/e 234 and base peak at m/e 161.

4-(4-t-Butylphenyl)butanoic acid (142)

4-(4-t-Butylphenyl)butanoic acid (142), b.p. 161-162°/5mm (lit.[234] 164-167°/5mm) and m.p. 58-59.5° (lit.[236] 59-60°) was prepared, as a white crystalline solid, in 42% yield, according to the method of Martin.[235]

The acid (142) exhibited the following spectral properties, ir, ν_{max}^{nujol}: 3300-2300(b), 1705(s), 1460(s), 1240(m)cm^{-1}; n.m.r. (CCl_4): τ 8.79 (9H, singlet), 8.22-6.65 (8H, complex; includes a triplet, J 6½Hz for $-C\underline{H}_2-CO_2H$), 3.09, 2.92 (4H, calculated centres of the doublets of the $AA'BB'$ A_2B_2 system, $J_{AB}=J_{A'B'}=8Hz$), -1.68 (1H, singlet); mass spectrum: M^+ at m/e 220 and base peak at m/e 205.

A white solid which was also isolated from the reaction mixture was recrystallized three times (50% benzene/50% light petroleum (b.p. 30-40°) and sublimed (230°/0.1mm) to give the lactone of 4,4-(di-p-t-butylphenyl)-4,4'-di-hydroxysuberic acid[183] (ca. 5%), m.p. 249-251°. T.l.c. analysis (20% ethyl acetate/80% benzene) indicated two compounds (R_f 0.75 and 0.66) whose proportions (from the intensity of the t.l.c. spots) were unaltered by successive recrystallizations, and these may have been caused by the presence of two isomeric lactones. (Found: C, 77.6; H, 7.9. Calc. for $C_{28}H_{34}O_4$: C, 77.4; H, 7.9%). The lactone

exhibited the following spectral properties, ir, ν_{max}^{nujol}: 1765 (s, C=O, γ-lactone), 1170(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 8.68 (18H, singlet), 8.22-6.65 (8H, complex), 3.22-2.43 (8H, complex); mass spectrum: $\left[M-C_{14}H_{17}O_2\right]^+$ at m/e 217 which also was the base peak.

4-(4-t-Butylphenyl)butyryl chloride (143)

4-(4-t-Butylphenyl)butyryl chloride (143), b.p. 157-159°/9mm (lit.[236] b.p. 152-154°/14mm) was prepared as a colourless oil (65% yield), by the method of Bromby, Peters and Rowe,[236] and exhibited the following spectral properties, ir, ν_{max}^{film}: 1785(s)cm^{-1}; mass spectrum: M^+ at m/e 238 and the base peak at m/e 187.

7-t-Butyltetral-1-one (119)

(a) 7-t-Butyltetral-1-one (119), m.p. 99-100° (lit. (ref.236) 101-102.5°) was obtained as colourless plates (89% yield) by the procedure of Bromby, Peters and Rowe.[236] The ketone (119) exhibited the following spectral properties, ir, ν_{max}^{nujol}: 1675(s), 1605(s)cm^{-1}; n.m.r. ($CDCl_3$): τ 8.65 (9H, singlet), 8.22-7.59 (2H, complex), 7.34 (2H, triplet, part of an A_2X_2 system, J 6Hz), 7.05 (2H, triplet, part of an A_2X_2' system, J 6Hz), 2.97-1.80 (3H, complex); mass spectrum: M^+ at m/e 202 and base peak at m/e 187. G.l.c. analysis (C, 150°) indicated the product was homogeneous.

(b) When the fraction (b.p. 50-60°) of light petroleum was used as solvent rather than the fraction (b.p. 100-102°), the yield of ketone (119) was reduced to 63%.

(c) 7-t-Butyltetral-1-one (119) was prepared in 76% yield according to the method of Snyder and Werber.[237] This was the most facile procedure and was thus the method of choice.

7-t-Butyltetral-1-ol (120)

A solution of 7-t-butyltetral-1-one (119) (0.25g, 0.0013mole) in dry methanol (5ml) was treated with sodium borohydride (0.10g, excess) and the mixture was stirred for 2h at 20°. After the usual working-up procedure, a white solid was isolated, which, after recrystallization from hexane, gave 7-t-butyltetral-1-ol (120) (0.24g, 99%), m.p. 124-124.5° as colourless crystals. Although the product (120) was homogeneous by t.l.c. (20% ether/80% hexane), g.l.c. analysis (C, 150°) indicated the presence of two compounds (retention times 2min 13s, ca. 20%; and 8min 45s, ca. 80%). The former probably arises by the elimination of the elements of water from the tetralol (120) at the elevated temperature of the g.l.c. column. (Found: C, 82.5; H, 9.8. Calc. for $C_{14}H_{20}O$: C, 82.3; H, 9.9%). The alcohol (120) showed the following spectral properties, ir, ν_{max}^{nujol}: 3200 (s,b), 1385(s), 1270(m), 1075(m)cm^{-1}; n.m.r. (CCl_4): τ

8.65 (9H, singlet), 8.35 (1H, singlet, removed by deuterium exchange), 8.30-7.65 (4H, complex), 7.55-7.08 (2H, complex), 5.50-5.07 (1H, complex, part of ABX system), 3.17-2.52 (3H, complex); mass spectrum: $\left[M-OH\right]^+$ at m/e 187 and the base peak at m/e 171.

Attempted preparation of 7-t-butyldecal-1-one (89) from 7-t-butyltetral-1-one (119)

(a) A solution of 7-t-butyltetral-1-one (119) (0.5g, 0.0025mole) in dry methanol (20ml) and glacial acetic acid (0.02ml) was hydrogenated at 20° for 4h in the presence of 5% rhodium on alumina catalyst (0.05g) under an atmosphere of hydrogen (60p.s.i.).[238] After the solution had been filtered and diluted with water, it was extracted with ether and the combined organic fractions were washed successively with water and sodium bicarbonate solution, dried and concentrated. The residue was distilled to give unchanged starting material (0.5g) which was identified by a comparison of infrared spectral data with the authentic compound.

(b) The procedure in (a) (above) was repeated at 70° but only 7-t-butyltetral-1-one (0.47g, 94%) was recovered and identified by a comparison of its spectral (ir) and g.l.c. characteristics with the authentic ketone (119).

(c) A solution of 7-t-butyltetralone (119) (0.10g, 0.0005mole) in glacial acetic acid (75ml) was shaken for

24h at 70°, under an atmosphere of hydrogen (1000p.s.i.), in the presence of 5% rhodium on alumina catalyst (0.10g). After the usual working-up procedure (described in part (a)), a product (0.08g, 80%) was recovered, with infrared absorption at ν_{max}^{nujol}: 3300(b), 1675(s), 1601(s)cm^{-1} and aromatic bands in the "fingerprint" region of the spectrum. T.l.c. analysis (20% ether/80% hexane) indicated 7-t-butyltetralone (R_f 0.40) and two minor unidentified products (R_f 0.22 and 0.10). G.l.c. analysis (H, 156°) indicated the presence of the ketone (119) (ca. 85%) in the mixture.

Attempted preparation of 7-t-butyldecal-1-ol (115) from 7-t-butyltetral-1-ol (120)

(a) A solution of 7-t-butyltetral-1-ol (120) (0.20g, 0.0009mole) in absolute methanol (100ml) and glacial acetic acid (0.2ml) was stirred, at 100°, for 35h, in the presence of 5% rhodium on alumina catalyst (0.10g) under an atmosphere of hydrogen (1200p.s.i.). After the usual working-up procedure (page 181), the isolated product (0.2g) exhibited infrared absorptions identical to the starting tetralol (120). G.l.c. analysis (C, 150°) indicated the presence of 7-t-butyltetral-1-ol (120) and a second product*

* This product had the same g.l.c. characteristics as the compound formed by passage of pure 7-t-butyltetral-1-ol through the g.l.c. column (see page 180).

(retention times 8min 44s and 2min 13s, respectively).

(b) A solution of 7-t-butyltetral-1-ol (120) (0.4g, 0.002mole) in glacial acetic acid (50ml) was stirred for 60h at 70° in the presence of Adam's catalyst (0.1g) under an atmosphere of hydrogen (1000p.s.i.). After the usual working-up procedure (see Page 181), a product (0.33g), b.p. ca. 130°/7mm was obtained, as a colourless oil whose infra-red spectrum showed no absorption in the region 3600-3000cm^{-1} and no absorption characteristic of an aromatic compound. G.l.c. analysis (H, 133°) indicated the presence of cis- , cis-2-t-butyldecalin (83, ca. 30%), trans-trans-2-t-butyl--decalin (84, ca. 40%) and at least two unidentified compounds.

(c) Experiment (b) was repeated under an atmosphere of hydrogen (60p.s.i.).[239] The only product isolated was 7-t-butyltetral-1-ol (120).

(d) A solution of 7-t-butyltetral-1-ol (120) (0.29g, 0.0015mole) in glacial acetic acid (3ml) was hydrogenated at 20° for 64h in the presence of platinum black catalyst* (0.05g) under an atmosphere of hydrogen (60p.s.i.).[184] After the normal working-up procedure, a colourless oil

---

* The platinum black catalyst was prepared from chloroplatinic acid, according to the procedure of Willstatter and Waldschmidt-leitz.[240]

(0.15g) was obtained and this exhibited no infrared absorption in the region 3600-3100cm^{-1}. A quantitative recovery of the product was obtained after chromatography of the oil (0.15g) on neutral alumina (eluted in hexane). The following features of the n.m.r. spectrum of the product were of diagnostic value; (a) τ 9.15 (ca. 7.5H, $(CH_3)_3C$-CH), (b) τ8.72 (ca. 1.5H, singlet, $(CH_3)_3C$-Ar), (c) τ 7.48-7.08 (complex, Ar-CH_2), (d) τ 3.03-2.70 (complex, Ar-H). The ratio of the resonances (a) and (b) was ca. 5:1 while the ratio of (b), (c) and (d) was ca. 9:4:3, and this evidence was in accord with the presence of isomeric 2-t-butyldecalins (including 83 and 84 ca. 80%) and 7-t-butyltetralin (122) (ca. 20%) in the product. This was confirmed by g.l.c. analysis (R, 127°) by a comparison with the characteristics of the authentic compounds (83, 84 and 122) under these conditions.

(e) A solution of 7-t-butyltetral-1-ol (120) (0.55g, 0.027mole) in glacial acetic acid (10ml) was hydrogenated at 20°, for 16h in the presence of platinum black catalyst (0.10g) under an atmosphere of hydrogen (60p.s.i.). The product was isolated in the usual way and chromatographed on neutral alumina to give a colourless oil (0.49g) (eluted in hexane), which exhibited no O-H stretching absorption in its infrared spectrum but some bands characteristic of an aromatic structure. Analysis of the n.m.r. spectrum (as

described in (d)) indicated the presence of 2-t-butyl--decalin (123) (ca. 22%) and 7-t-butyltetralin (ca. 78%) in the product. This was confirmed by g.l.c. analysis (R, 129°) (see part (d)).

(f) A solution of 7-t-butyltetral-1-ol (120) (0.10g, 0.0005mole) was hydrogenated at 20° for 16h, in the presence of platinum black catalyst (0.025g), under an atmosphere of hydrogen (15p.s.i.). After the usual procedure (see part (a)), the product was shown to be identical to 7-t-butyl--tetral-1-ol (120) by a comparison of spectral properties (ir) and g.l.c. characteristics (E, 161°).

(g) A solution of 7-t-butyltetral-1-ol (120) (0.97g, 0.0047mole) in liquid ammonia* was treated with finely cut lithium wire (0.04g, 0.005g atom) and after the mixture had been stirred for 30min, a second portion of lithium (0.67g, 0.09g atom) was added.[185] After 15h, the ammonia was allowed to evaporate and the residue was diluted successively with methanol, water and 10% sulphuric acid and then extracted with ether (3 x 50ml). The combined organic fractions were washed with sodium bicarbonate, dried, concentrated and distilled to yield a colourless oil, 7-t-butyl--tetralin (122) (0.71g, 77%), b.p. 138°/85mm (lit.[252] b.p. 100-102°/6mm), which was homogeneous by g.l.c. analysis

---

* The liquid ammonia was distilled from sodium metal.

(C, 105°). The hydrocarbon (122) exhibited the following spectral properties, ir, ν_{max}^{film}: 1610(m), 1385(m), 1365(s) cm^{-1}; n.m.r. (CCl_4): τ 8.70 (9H, singlet), 8.50-7.87 (4H, complex), 7.55-7.00 (4H, complex), 3.28-2.62 (3H, complex); mass spectrum: M^+ at m/e 188 and the base peak at m/e 173.

2-t-Butylnaphthalene (124)

2-t-Butylnaphthalene (124), b.p. 132-134°/9.5mm (lit.[234] b.p. 127-131°/9mm) was prepared as a colourless oil (44% yield) according to the method of Fieser and Price[234] and was homogeneous by g.l.c. analysis (K, 110°). The compound (124) exhibited the following spectral properties, ir, ν_{max}^{film}: 1595(m), 1385(w), 1365(m)cm^{-1}; n.m.r. (CCl_4): τ 8.63 (9H, singlet), 2.92-2.12 (7H, complex); mass spectrum: M^+ at m/e 184 and the base peak at m/e 169.

Reduction of 2-t-butylnaphthalene (124)

2-t-Butylnaphthalene (124) was reduced according to the procedure of Benkeser and Kaiser.[186]

A solution of 2-t-butylnaphthalene (124) (4.0g, 0.022mole) in a mixture of anhydrous ethylamine (50ml) and dimethylamine (50ml) was treated with finely cut lithium wire (1.22g, 0.174g atom), under an atmosphere of dry nitrogen. After the mixture had been stirred for 17h, the amine solvent was allowed to evaporate and the grey powdery residue was decomposed with ice and extracted with ether.

The combined organic fractions were dried and concentrated and the residue was distilled to yield the product (3.3g, ca. 79%), b.p. 108-114°/7.5mm. G.l.c. analysis (E, 150°) indicated the presence of at least seven major compounds (retention times: 3min 15s to 8min 23s compared to 2-t-butylnaphthalene: 14min 24s). The product was separated into four fractions by preparative g.l.c. (F, 200°, 175ml/min) and each (fractions 1,2 and 3) contained a mixture of compounds except the last (fraction 4), which contained 7-t-butyltetralin (122) (identified by a comparison of its properties (g.l.c., ir) with the authentic compound). Mass spectral analysis of fractions 1-3 indicated:

Fraction (3) contained di- and tri-olefins (mass spectrum*: 190 (32), 188 (21)).

Fraction (2) contained mono-, di- and tri-olefins (mass spectrum: 192 (27), 190 (12), 188 (14)).

Fraction (1) contained a mixture of mono-olefins (mass spectrum: 192 (7)).

4-t-Butylcyclohexanone pyrrolidine enamine (125)

The enamine (125), b.p. 114-115°/0.45mm (lit.[253] b.p. 117-119°/0.35mm) was prepared according to the method of Stork et.al.[241]

---

* The spectral data is expressed as m/e (relative abundance).

6-t-Butyl-$\Delta^{1,9}$octal-2-one (127) and 6-t-butyl-$\Delta^{9,10}$-octal-2-one (126)

The mixture of octalones (126) and (127) b.p. 104-107°/0.3mm (lit.[154] b.p. 72-75°/0.01mm) was synthesized as a colourless oil, according to the procedure of House et.al. (ref. 154) The n.m.r. spectrum (CCl_4) indicated the presence of (127, ca. 75%) and (126, ca. 25%) that is, τ 9.05 (9H, singlet), 4.27 (ca. ¾H, singlet, $R_2C=CH-C=O$). G.l.c. analysis (G, 159°) also indicated the presence of the two octalones (126 and 127, ca. 25 and 75%, respectively).

2-t-Butyl-$\Delta^{9,10}$-octalin (66)

The procedure of Arnal[110] was used in the Wolf Kishner reduction of the octalones (126) and (127), with slight modification.

A solution of 6-t-butyl-$\Delta^{1,9}$-octal-2-one and 6-t-butyl-$\Delta^{9,10}$-octal-2-one (127 and 126, respectively) (0.61g, 0.003mole) in diethyleneglycol (10ml) was treated with potassium hydroxide (0.39g) and hydrazine hydrate (0.3ml of an 85% solution) and the mixture was heated at reflux for 1h. After the lower boiling components had been distilled from the mixture (bath temperature, ca. 190°), the solution was refluxed for another 3h, cooled and diluted with water (30ml). The aqueous layer was extracted with light petroleum (30-40°) (2 x 30ml) and the combined organic fractions were washed with water (2 x 50ml), dried and concentrated to give

a residue, which, when chromatographed on neutral alumina (elution with hexane) gave the product (0.24g, 54%). G.l.c. analysis (G, 159°) indicated the presence of the required octalin (66, ca. 60%, retention time 15min 14s) together with unidentified impurities (ca. 40% retention time 11min 19s to 13min 35s) in the product. A pure sample of the octalin (66) which was obtained by preparative g.l.c. (F, 155°) of the mixture, had the same physical and spectral properties (g.l.c., ir, n.m.r. and mass spectrum) as 7-t-butyl-$\Delta^{9,10}$-octalin, which was isolated from the solvolytic reactions.

cis-cis-2-t-Butyldecalin (83)

cis-cis-2-t-Butyldecalin (83), b.p. 105-108°/0.9mm (lit.[154] b.p. 72-75°/0.1mm) was obtained as a colourless oil according to the procedure of House et.al.[154]

trans-trans-2-t-Butyldecalin (84)

trans-trans-2-t-Butyldecalin (84), b.p. 125-130°/11mm (lit.[154] b.p. 100-110°/0.05mm) was obtained as a colourless oil according to the procedure of House et.al.[154]

3-t-Butylcyclohexanone morpholine enamine (128)

The enamine (128), b.p. 109-110°/0.6mm was prepared according to the method of Kuehne and Giaeobbe.[187]

trans-7-t-Butyl-$\Delta^{1,9}$-octal-2-one (129)

The octalone (129) was prepared by condensation of the enamine (128) with methylvinyl ketone according to the method of synthesis of the isomeric octalones (126 and 127).

A solution of 3-t-butylcyclohexanone morpholine enamine (128) (8.70g, 0.039mole) in dry benzene (60ml) was treated with freshly distilled methyl vinyl ketone (2.80g, 0.041mole) over 25min while the temperature was maintained below 30°. After the solution had been refluxed for 21h, a buffer (sodium acetate (2.1g), acetic acid (4.3ml) and water (4.3ml)) was added and the mixture was heated at reflux for a further 3h. The organic layer was washed successively with hydrochloric acid (2 x 100ml of 10% solution), sodium carbonate solution (3 x 100ml) and brine solution (100ml), dried and concentrated to yield a residue which was distilled to give a colourless oil (5.97g), b.p. 99-108°/0.4mm. G.l.c. analysis (H, 199°) indicated the presence of at least eight compounds, including the octalone (129) (ca. 35%) (retention time 24min 20s), which was separated by preparative g.l.c. (L, 175°) and then recrystallized (light petroleum (b.p. 30-40°)) at ca. -40° to yield trans-7-t-butyl-$\Delta^{1,9}$-octal-2-one (129), m.p. 57.5-58.5, as colourless needles. (Found: C, 81.7; H, 10.8. Calc. for $C_{14}H_{22}O$: C, 81.5; H, 10.8%). The product was homogeneous by g.l.c. (H, 199°) and exhibited the following spectral

properties, ir, ν_{max}^{nujol}: 1675(s), 1625(m), 1385(w), 1365(m), 805(w)cm^{-1}; n.m.r. (CCl_4): τ 9.10 (9H, singlet), 9.10-7.40 (12H, complex), 4.32 (1H, singlet); mass spectrum: M^+ at m/e 206 and the base peak at m/e 57.

7-t-Butyldecal-2-one (131)

7-t-Butyl-$\Delta^{1,9}$-octal-2-one (129) (0.091g, 0.0004 mole) was reduced with lithium (0.013g, 0.0018g atom) in ammonia (20ml) containing t-butyl alcohol (0.04g, 0.0005 mole) according to the procedure used by House et.al.[154] to prepare trans-6-t-butyldecal-2-one. The crude product was oxidized with Jones' reagent in the usual manner[214] to give, after distillation, 7-t-butyldecal-2-one (131) (0.045g, 50%), b.p. 95-99°/0.4mm as a colourless oil which was homogeneous by g.l.c. (H, 191°). The ketone exhibited the following spectral properties, ir, ν_{max}^{film}: 1710(s), 1365(w), 1385(m), 1225(w)cm^{-1}; n.m.r. (CCl_4): τ 9.14 (9H, singlet), 9.04-7.49 (15H, complex); mass spectrum: M^+ at m/e 208 and the base peak at m/e 57.

trans-trans-2-t-butyldecalin (84)

7-t-Butyldecal-2-one (~~129~~ 131, prepared from the octalone ~~131~~ 129) (0.04g, 0.0002mole) was treated with hydrazine (0.07g) and potassium hydroxide (0.02g) in diethyleneglycol (5ml) according to the procedure used by House et.al.[154] for the preparation of 2-t-butyldecalin.

trans-trans-2-t-butyldecalin (84) (0.019g, 49%) b.p. 111-114°/0.7mm (lit.[154] b.p. 100-110/0.05mm) was obtained as a colourless oil. The structure of the hydrocarbon (84) was confirmed by a comparison of its spectral (ir) and g.l.c. characteristics (G, 128°; R, 138°) with the authentic compound (84) and the cis-cis-isomer (83).

trans-7-t-Butyl-$\Delta^{1,9}$-octal-2-one ethylene dithioketal (130)

The ethylene dithioketal (130) was prepared from the octalone (129) by the general method Sondheimer and Wolf.[243]

A solution of trans-7-t-butyl-$\Delta^{1,9}$-octal-2-one (129) (0.09g, 0.004mole) in ethane-1,2-dithiol (0.08ml) at 0° was treated with boron trifluoride etherate (0.04ml) and after 30min at 0°, the mixture was diluted with cold methanol (0.5ml) and taken up in ether. The organic layer was dried and concentrated to yield an oil (0.11g) which exhibited infrared absorption at 1645(w), 1385(w), 1365(m), 850(m)cm^{-1} and n.m.r. ($CDCl_3$) retained the resonance characteristic of the olefinic hydrogen, τ 4.50 (1H, singlet).

trans-7-t-Butyl-$\Delta^{1,9}$-octalin (65a)

The ethylenedithioketal (130) was desulphurized according to the general procedure of Ireland, Wrigley and Young.[244]

A mixture of trans-7-t-butyl-$\Delta^{1,9}$-octal-2-one ethylenedithioketal (130) (0.07g, 0.0003mole) and sodium metal

(0.13g, 0.005g atom) was dissolved in dry ether (2ml) and ammonia (40ml) and after the mixture had been stirred for 2min, ethanol was added until the deep blue colour of the solution had been dispelled. The ammonia was allowed to evaporate and the residue was diluted with "wet" ether (10ml) followed by water (30ml). After the mixture had been extracted with ether (3 x 30ml), the combined organic layer was dried and concentrated to yield a colourless oil (0.06g) which was distilled to give trans-7-t-butyl-$\Delta^{1,9}$-octalin (65a) (0.02g, 37%), b.p. ca. 110°/4.0mm which was homogeneous by g.l.c. analysis (G, 151°; M, 137°; H, 148°). (Found: C, 87.6; H, 12.6. Calc. for $C_{14}H_{24}$: C, 87.4; H, 12.6%). The octalin (65a) exhibited the following spectral properties, ir, ν_{max}^{film}: 1660(w), 1385(w), 1365(m), 805(w)cm^{-1}; n.m.r. (CCl_4): τ 9.15 (9H, singlet), 9.10-7.33 (14H, complex), 4.82-2.85 (1H, complex, part of ABX system $R_2C{=}C\underline{H}{-}CH_2$); mass spectrum: M^+ at m/e 192 and the base peak at m/e 135.

7-t-Butyldecal-1-one (89)

trans-7-t-butyl-$\Delta^{1,9}$-octalin (65a) (0.035g, 0.0002 mole) was subjected to hydroboration with diborane and after oxidative work-up a crude product was recovered, which was subsequently oxidized with Jones' reagent[213] according to the procedure of Meinwald, Crandall and Hymans.[214] After the residue had been distilled, 7-t-butyldecal-1-one (89) (0.035g, 92%0 b.p. 80°/0.1mm was obtained and g.l.c.analysis

(G, 182°) indicated the decalone (89)* (ca. 80%) and some minor components (20%) in the product. The following spectral data were obtained for the product, ir, ν_{max}^{film}: 1707(s), 1385(w), 1365(m) 1170(m)cm^{-1}; mass spectrum: M^+ at m/e 208 and the base peak at m/e 57.

2-t-Butyldecalin

A solution of 7-t-butyl-$\Delta^{1,9}$-octalin (65a) (0.02g, 0.0001mole) in acetic acid (3ml) was hydrogenated, at 25°, for 12h, in the presence of 5% palladium on carbon catalyst (0.01g) under an atmosphere of hydrogen (15p.s.i.). After the usual working-up procedure the residue (0.014g, ca. 70%) was analysed by g.l.c. (G, 144°) and shown to consist of trans-trans-2-t-butyldecalin (84, ca. 60%), cis-cis-2-t-butyldecalin (83, ca. 20%) and unidentified products (ca. 20%). The mixture exhibited the following infrared absorptions, ν_{max}^{film}: 1385(m) and 1365(s)cm^{-1}.

---

* This was identified as trans-trans-7-t-butyldecalone (89a) by a comparison of g.l.c. characteristics with the authentic compound.

cis- and trans-1-Allyl-4-t-butylcyclohexanol* (132a and 132b, respectively)

A suspension of allylmagnesium chloride[245] (0.34 mole) in ether (500ml), prepared from magnesium (8.15g, 0.35g atom) and allylchloride (26.0g, 0.34mole), was added, over a period of 1h, to a stirred solution of 4-t-butylcyclo--hexanone (97) (50.0g, 0.32mole) in dry ether (100ml) which was maintained at 0°, under an atmosphere of dry nitrogen. After the mixture had been stirred for 14h at room temperature, it was cooled then hydrolysed with a saturated ammonium chloride solution and the organic layer was separated. The aqueous layer was extracted with ether (3 x 100ml) and the combined organic fractions were dried and concentrated to give a crude product (62.8g), which, after being distilled, yielded 4-t-butylcyclohexanone (97) (1.0g) and a mixture of cis- and trans-1-allyl-4-t-butylcyclohexanol (132a and 132b, respectively) (30.5g, 48%), b.p. 121°/17mm. G.l.c. analysis (G, 162°) showed that the mixture consisted of approximately equal amounts of the cis- and trans-alcohols (132a and 132b,

* The assignment of cis- and trans-configuration was based upon the order of elution of the compounds when they were chromatographed on neutral alumina. (Compare ref. 119)

retention times 9min 9s and 8min 40s, respectively).

The mixture of cis- and trans-1-allyl-4-t-butylcyclo--hexanol (~~123~~132a and ~~123~~132b, respectively) (3.6g) was separated into its constituents by chromatography on neutral alumina (Fluka, 100g) which had been deactivated by washing with "wet" ether. The cis-alcohol (~~123~~132a), b.p. ca. 110°/9mm, was eluted (hexane) as a colourless oil which was homogeneous by g.l.c. analysis (G, 160°). (Found: C, 79.8; H, 12.2. Calc. for $C_{13}H_{24}O$: C, 79.5; H, 12.3%). The following spectral data were recorded for cis-1-allyl-4-t-butylcyclo--hexanol (132a), ir, ν_{max}^{film}: 3450(s), 3090(m), 1440(m), 1390 (m), 1365(s), 1185(m), 985(s), 950(s), 910(s)cm^{-1}; n.m.r. (CCl_4): τ 9.13 (9H, singlet), 9.03-8.18 (10H, complex; hydrogen count reduced to 9 by deuterium exchange), 7.88 (2H, doublet, $R_3C-\underline{CH}_2-CH=CH_2$, J 7Hz), 5.20-4.73 (2H, complex, $R_3C-CH_2-CH=\underline{CH}_2$), 4.50-3.73 (1H, complex, $R_3C-CH_2-\underline{CH}=CH_2$); mass spectrum: $\left[M-C_3H_5\right]^+$ at m/e 155 which was also the base peak.

The trans-alcohol (132b), b.p. 98°/6mm, was eluted with a solvent mixture containing 50% ether/50% hexane, as a white solid, m.p. 54.5-56°, and was homogeneous by g.l.c. analysis (G, 160°). (Found: C, 79.7; H, 11.9. Calc. for $C_{13}H_{24}O$: C, 79.5; H, 12.3%). The following spectral properties were exhibited by the alcohol (132b), ir, ν_{max}^{nujol}: 3400(b), 3090(w), 1640(m), 1450(b), 1390(w), 1365(m), 1035

(m), 985(m), 905(m)cm^{-1}; n.m.r. (CCl_4): τ 9.13 (9H, singlet), 9.10-8.05 (10H, complex; hydrogen count reduced to 9 by deuterium exchange), 7.78 (2H, doublet, $R_3C-C\underline{H}_2-CH=CH_2$) 5.20-4.75 (2H, complex, $R_3C-CH_2-CH=C\underline{H}_2$), 4.48-3.77 (1H, complex, $R_3C-CH_2-C\underline{H}=CH_2$); mass spectrum: $\left[M-C_3H_5\right]^+$ at m/e 155 which is also the base peak.

In a second experiment a solution of allylmagnesium bromide* [194] (0.27mole) in ether (60ml) was added to 4-t-butylcyclohexanone (97) (37.3g) under the reaction conditions described on page 196. A mixture of cis- and trans-1-allyl-4-t-butylcyclohexanol (132a and 132b, respectively) (21.1g, 44%), unchanged ketone (97) (2.0g) and a residue (21.2g) were obtained.

1-Allyl-4-t-butylcyclohexene (133)

A mixture of cis- and trans-1-allyl-4-t-butylcyclo--hexanol (132a and 132b, respectively) (10.1g, 0.051mole)

---

* Allylmagnesium bromide was the preferred Grignard reagent because of its solubility in ether, a property not shared with the analogous chloride, which formed a suspension.

was dissolved in benzene (15ml) with anhydrous p-toluene-sulphonic acid* (0.043g) and the mixture was refluxed, with separation of water in a Dean-Stark apparatus, for 67h. Samples were withdrawn periodically and analysed (see Table III.5. Section III) by g.l.c. (G, 162°), which enabled the following compounds, in the reaction mixture, to be detected: 4-t-butyl-1-n-propylcyclohexa-1,4-diene (136)** (retention time (R_t), 5min 7s), 1-allyl-4-t-butylcyclohexene (133) (R_t 5min 40s), trans-1-allyl-4-t-butylcyclohexanol (132b) (R_t 9min 8s) and cis-1-allyl-4-t-butylcyclohexanol (132a) (R_t 9min 38s). After 67h, the reaction mixture was cooled, diluted with water and the organic layer was separated, washed with sodium bicarbonate solution, dried and concentrated. The crude product (10.1g) was chromatographed on neutral alumina (Fluka, activity 1, 50g) and a mixture of the cis-alcohol (132a) and 1-allyl4-t-butylcyclohexene (133) (3.16g) was eluted in light petroleum (30-40°), followed by a mixture of the cis- and trans-alcohols (132a and 132b, respectively) (5.9g) as the polarity of the solvent was increased. The latter mixture of alcohols was resubjected to dehydration as described above. Careful fractionation of the mixture (12.2g), which was eluted in light petroleum

---

* A second portion of p-toluenesulphonic acid (0.03g) was added after 23h.

** See later.

through a column (40 x 2cm), packed with glass helices, gave 1-allyl-4-t-butylcyclohexene (133) (7.7g), b.p. 91-92°/6.8mm, which was homogeneous by g.l.c. analysis (G, 162°). (Found: C, 87.6; H, 12.5. Calc. for $C_{13}H_{22}$: C, 87.6; H, 12.4%). The diene (133) exhibited the following spectral properties, ir, ν_{max}^{film}: 3080(m), 3070(w), 3010(m), 1635(m), 1385(m), 1365(s), 985(m), 905(s), 800(w)cm^{-1}; ultraviolet spectrum; $\lambda_{max}^{cyclohexane}$: 218nm ($\varepsilon_{max}$ 675) and no absorption characteristic of a conjugated double bond; n.m.r. (CCl_4): τ 9.12 (9H, singlet), 8.98-8.58 (3H, complex), 8.47-7.75 (4H, complex, allylic hydrogen), 7.57 (2H, doublet, part of ABX system, J 7Hz, $=CR-CH_2-CH=CH_2$), 5.27-3.90 (4H, complex); mass spectrum: M^+ at m/e 178 and the base peak at m/e 57.

4-t-Butyl-1-n-propylcyclohexa-1,4-diene (136)

It was found that prolonged reaction of cis- and trans-1-allyl-4-t-butylcyclohexanol (132a and 132b, respectively) under the conditions for dehydration (described before), led to the formation of 4-t-butyl-1-n-propylcyclohexa-1,4-diene (~~136~~ 134), to the exclusion of 1-allyl-4-t-butylcyclohexene (133).

A mixture of the cis- and trans-alcohols (132a and 132b, respectively) (12.2g, 0.07mole) in benzene (15ml) was dehydrated in the presence of p-toluenesulphonic acid (ca. 0.3g) for 17h, as described above. After the usual

working-up procedure, there was obtained a crude product which was distilled to give a colourless oil (3.02g, 27%), b.p. 64-68°/1.5mm. G.l.c. analysis (G, 162°) indicated the presence of 4-t-butyl-1-n-propylcyclohexa-1,4-diene (136) (ca. 80%). The residue (ca. 9g) was a polymeric glass. A sample (ca. 98%) of the diene (136) which was obtained by preparative g.l.c. (T, 123°, 130ml/min), was distilled to give a colourless oil b.p. 92°/11mm.

The diene (136) exhibited the following spectral properties, ir, $\nu_{max}^{CCl_4}$: 3050(m), 1650(m), 1601(w), 1385(w), 1365(s), 855(s)cm^{-1}; ultraviolet spectrum; $\lambda_{max}^{cyclohexane}$: 266 ($\varepsilon_{max}$ 7700), characteristic of a 1,4-dialkylcyclohexa-1,4-diene; ^{246,189} n.m.r. (CCl_4): τ 9.12 (3H, complex), 8.93 (9H, singlet), 8.82-8.18 (2H, complex), 8.15-7.70 (6H, complex, CH_2-RC=CR-H), 4.43 (2H, singlet); mass spectrum: M^+ at m/e 178 and base peak at m/e 163.

Attempted preparation of 1-allyl-4-t-butylcyclohexene (133)

A solution of cis-1-allyl-4-t-butylcyclohexanol (132a) (0.05g, 0.0003mole) in dimethylsulphoxide (2ml) and water (0.2ml) was heated at 112° with oxalic acid dihydrate (0.04g) for 24h under nitrogen. After being cooled, the solution was diluted with water (50ml) and extracted with ether (2 x 30ml) and the combined organic fractions were washed with water, dried and concentrated.

The residue (0.34g) was analysed by g.l.c. (G, 161°) which indicated unchanged alcohol (132a) and this was confirmed by a comparison of its spectral properties (ir and n.m.r.) with the authentic compound.

2,3-Dimethylbut-2-ylborane

A solution of 2,3-dimethylbut-2-ylborane (hereafter referred to as thexylborane) (0.91Molar)* in tetrahydro--furan was prepared according to the procedure of Brown and Negishi.[247]

trans-trans-7-t-Butyldecal-1-one (89a)

The ketone (89a) was synthesized according to the procedure of Brown and Negishi[191] for the preparation of trans-decal-1-one.

Solutions of 1-allyl-4-t-butylcyclohexene (133) (4.2g, 0.024mole) in dry tetrahydrofuran (25ml) and thexylborane (26.0ml of a 0.91M solution in tetrahydrofuran, 0.024moles) were added, over 3h, separately but simultaneously

---

* The molarity of the solution was determined, immediately before use, by measurement of the volume of hydrogen evolved on hydrolysis of an aliquot of the reagent. (2 moles of hydrogen evolved/mole of thexylborane). (A correction was made for the vapour pressure of water and the volume was corrected to S.T.P.).

(simultaneous dilution technique),[190] to dry tetrahydro--furan (50ml), which was stirred briskly under an atmosphere of nitrogen. After the solution had been stirred for 5h, water (0.83ml) was added and the reaction mixture was transferred, under nitrogen, to an autoclave, which was subsequently charged with carbon monoxide (1000p.s.i.). The autoclave was heated at ca. 50° for 3h, then cooled and the reaction mixture was treated with sodium acetate (10ml of a 3M solution) and hydrogen peroxide (10ml of 30% solution). After being stirred for 15h at 30°, the solution was saturated with potassium carbonate and extracted with ether (2 x 100ml) and the combined organic fractions were dried and concentrated to yield a crude product (7.6g). (The reaction was repeated with a second batch of diene (133) (3.4g) and this was combined with the crude product above). The combined residues were distilled to give a colourless oil (4.04g, 49%), b.p. ca. 104°/3.5mm, which solidified on standing. G.l.c. analysis (G, 180°) indicated trans-trans-7-t-butyldecal-1-one (89a) (retention time, 15min 29s, ca. 80%) with a minor component (retention time, 14min 30s, ca. 10%) and some other minor impurities having shorter retention times. Separation of the major component by preparative g.l.c. (L, 185°, 120ml/min) afforded a solid, m.p. 53-62°, which was raised to 69.5-70.5° by two recrystallizations from light petroleum (b.p. 30-40°). A similar

result could be achieved by two careful recrystallizations (from light petroleum (b.p. 30-40°)) of the distilled product. G.l.c. analysis (E, 179°; M, 194°) indicated 7-t-butyldecal-1-one (89a) (ca. 98%) and a small impurity (ca. 2%, apparent as a shoulder on the major peak) which is probably isomeric with (89a) and which could not be removed by further recrystallization. (Found: C, 80.6; H, 11.3. Calc. for $C_{14}H_{24}O$: C, 80.7; H, 11.6%). The ketone (89a) exhibited the following spectral properties, ir, ν_{max}^{nujol}: 1710(s), 1395(w), 1365(m), 1175(w), 1050(w)cm^{-1}; n.m.r. (CCl_4); τ 9.12 (9H, singlet, a very small shoulder was visible at τ9.20), 8.88-7.90 (12H, complex), 7.90-7.42 (3H, complex); mass spectrum: M^+ at m/e 208 and the base peak at m/e 97.

7-t-Butyl-2,2,9-trideuterodecal-1-one (92)

7-t-Butyldecal-1-one (89a, 0.017g, 0.00008mole) was dissolved in deutero-ethanol (0.5ml), which contained a catalytic amount of sodium ethoxide. The solution was sealed under nitrogen, in a pyrex tube and heated at 80° for 4 days. After being cooled, the reaction was quenched with water (50ml) and the mixture was extracted with ether (3 x 20ml) and the combined organic fractions were washed with water, dried and concentrated. The residue was distilled to give 7-t-butyl-2,2,9-trideuterodecal-1-one (92) (0.013g) b.p.

ca. 90°/0.2mm, as a colourless liquid, which solidified on standing, with the following spectral properties, ir, ν_{max}^{nujol}: 2200(w, C-D), 2100(w, C-D), 1705(s), 1390(w), 1365(s), 1175(m), 1100(s), 1080(m)cm^{-1}; mass spectrum: (see appendix) M^+ at m/e 211 and the base peak at m/e 100.

trans-trans-2-t-Butyldecalin (84)

(Prepared by reduction of 7-t-butyldecal-1-one (89), obtained by carbonylation of 1-allyl-4-t-butylcyclohexene (133)).

The Wolf-Kishner reduction of 7-t-butyldecal-1-one (89) (0.05g), according to the procedure used by House et.al.[154] in the formation of 2-t-butyldecalin, yielded trans-trans-2-t-butyldecalin (84) (0.013g, ca. 27%) b.p. 150-154°/12mm (lit.[154] b.p. 100-110°/0.05mm) as a colourless oil. The structure of the product was confirmed by a comparison of spectral properties (ir) and g.l.c. characteristics (R, 139°; G, 128°) with the authentic compound (84).

7-t-Butyl-9-chloro-decal-1-one (135)

The chloro ketone (135) was prepared according to the procedure of House et.al.[154] for the preparation of 6-t-butyl-9-chlorodecal-1-one.

A solution of 7-t-butyldecal-1-one (89a) (0.73g,

0.0035mole) in dry carbon tetrachloride (4ml) was treated dropwise with a solution of freshly distilled sulphuryl chloride (0.58g, 0.0043mole) in carbon tetrachloride (2ml), under an atmosphere of dry nitrogen. After being stirred at 25-30° for 7h, the solution was subjected to a slight reduction in pressure (ca. 200mm of Hg), to remove the excess of hydrogen chloride. After the reaction mixture had been stirred for another 30min, it was concentrated to give a crude product (1.06g), which exhibited the following spectral properties, ir, ν_{max}^{film}: 1745(m, sh), 1725(s), 1390 (w), 1365(s), 780(s)cm^{-1}; n.m.r. (CCl_4): τ 9.12 (9H, singlet), 8.90-6.80 (14H, complex).

The chloro ketone (135) was used without further purification.

7-t-Butyl-$\Delta^{9,10}$-octal-1-one (93)

The dehydrohalogenation of 7-t-butyl-9-chloro-decal-1-one (135) was carried out according to the method of House et.al.[154] for the preparation of 6-t-butyl-$\Delta^{9,10}$-octal-1-one.

A mixture of 7-t-butyl-9-chloro-decal-1-one (135) (1.06g, 0.0043mole) and 2,4,6-trimethylpyridine (0.70g, 0.0058mole) was heated slowly to 180° and maintained at this temperature for 10min. After being cooled, the reaction mixture was extracted with hexane (3 x 30ml) and the com-

bined organic fractions were washed successively with hydrochloric acid (2 x 30ml of a 10% solution) and brine solution (2 x 30ml), dried and concentrated to give a crude product. The residue was distilled to give a colourless oil (0.63g), b.p. ca. 120°/0.03mm which contained 7-t-butyl-$\Delta^{9,10}$-octal-1-one (93, ca. 70%) by g.l.c. analysis (G, 179°).

The absence of any signal for an olefinic hydrogen in the n.m.r. spectrum of the crude product showed that less than 5% of isomeric octalones was present (compare House et.al.[154]).

Since the product could not be induced to crystallize at low temperatures, a pure sample of 7-t-butyl-$\Delta^{9,10}$-octal-1-one (93), b.p. 110-115°/0.2mm was obtained as a colourless oil, by preparative g.l.c. (L, 185°, 120ml/min). (Found: C, 81.2; H, 10.8. Calc. for $C_{14}H_{22}O$: C, 81.5; H, 10.8%). The octalone (93) exhibited the following spectral properties, ir, ν_{max}^{film}: 1665(s) (C=O), 1640(s) (C=C), 1385(m) and (1365(s) (t-butyl), 1265(s)cm^{-1}; n.m.r. (CCl_4): τ9.07 (9H, singlet), 8.93-7.27 (13H, complex); mass spectrum: M^+ at m/e 206 and the base peak at m/e 149.

IV.5.

Identification of the structures of the olefinic products obtained from the acetolysis of cis- and trans-9-t-butyl--spiro[4.5]dec-6-yl p-toluenesulphonate (47 and 48 where X=OTs, respectively)

A solution of trans-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (48, X=OTs) (2.21g, 0.0064mole) in acetic acid (100ml, containing sodium acetate, 0.012mole) was heated at 52.6° (constant temperature bath) for 20h under an atmosphere of dry nitrogen. After the usual working-up procedure, a colourless oil (1.05g, 91%) was isolated and it was separated into the following components by preparative g.l.c. (I, 180°, 120ml/min) -

(a) 2-t-Butyl-$\Delta^{9,10}$-octalin (66) and (3-t-Butyl--cyclopentylidene)cyclopentane (69)

A mixture* of 2-t-butyl-$\Delta^{9,10}$-octalin (66) and (3-t-butylcyclopentylidene)cyclopentane (69), b.p. 60-65°/0.4mm was obtained as a colourless oil after distillation. G.l.c. analysis (G, 139°; N, 130°; M, 159°; O, 150°) could not resolve the mixture into its components. (Found: C, 87.6; H, 12.4. Calc. for $C_{14}H_{24}$: C, 87.4; H, 12.6%).

---

* It was impossible to separate the two olefins (66) and (69) by g.l.c. but they have both been characterized by independent synthesis.

The mixture of olefins (66) and (69) exhibited the following spectral properties, ir, ν_{max}^{film}: 1670(w) (C=C), 1385(m) and 1365(s)cm^{-1}; n.m.r. (CCl_4): τ 9.18 (<1H, singlet, $(C\underline{H}_3)_3C$-(69)), 9.13 (<u>ca.</u> 9H, singlet $(C\underline{H}_3)_3C$-(66)), 9.04-8.00 (15H, complex); mass spectrum: M^+ at m/e 192 and the base peak at m/e 135.

(b) <u>2-t-Butyl-$\Delta^{1,9}$-octalin (64) and (3-t-butyl--cyclopentyl)cyclopent-1-ene (68)</u>

A mixture of the two olefins (64) and (68), b.p. 70°/0.6mm, was obtained as a colourless oil after distillation. G.l.c. analysis (M, 200°) partially resolved (see section II.1.) the mixture and indicated the presence of 2-t-butyl-$\Delta^{1,9}$-octalin (64) (R_t 4min 54s, <u>ca.</u> 83%) and (3-t-butylcyclopentyl)cyclopent-1-ene (68) (R_t 4min 45s, <u>ca.</u> 17%). No other g.l.c. analyses (G, 150°; O, 150°; P, 195°) afforded any resolution of the two olefins. (Found: C, 87.8; H, 12.8. Calc. for $C_{14}H_{24}$: C, 87.4; H, 12.8%). The mixture of olefins (64) and (68) exhibited the following spectral properties, ir, ν_{max}^{film}: 3010(w, sh) and 1660(w) (R_2C=CHR), 1385(m), 1365(s), 870(s) (R_2C=CHR)cm^{-1}; n.m.r. (CCl_4): τ 9.16 (<u>ca.</u> 1H,* singlet, $(C\underline{H}_3)_3C$-(68)), 9.13 (<u>ca.</u> 8H* singlet, $(C\underline{H}_3)_3C$-(64)), 8.93-7.33 (14H, complex), 4.87-

---

* very approximate value

4.58 (1H, complex, $R_2C=C\underline{H}-R$, J ca. 0 as dihedral angle ca. 90°. in most favourable configuration of olefin (64)); mass spectrum: M^+ at m/e 192 and the base peak at m/e 135.

Hydrogenation of the mixture of 2-t-butyl-$\Delta^{9,10}$-octalin (66) and (3-t-butylcyclopentylidene)cyclopentane (69)

A solution of the two olefins (66) and (69) (0.10g, 0.0005mole) in glacial acetic acid (5ml) was hydrogenated, in the presence of 5% palladium on carbon (0.05g), for 7h, at 20°, under an atmosphere of hydrogen (15p.s.i.). After the mixture had been filtered and concentrated, the residue was distilled to give a colourless oil (0.06g) b.p. 127-131°/17mm. G.l.c. analysis (G, 145°) indicated the presence of (3-t-butylcyclopentyl)cyclopentane (82, ca. 5%), trans-trans-2-t-butyldecalin (84, ca. 75%), cis-cis-2-t-butyldecalin (83, ca. 11%) and an unidentified product* (ca. 9%) by a comparison with the authentic compounds.

Hydrogenation of the mixture of 2-t-butyl-$\Delta^{1,9}$-octalin (64) and (3-t-butylcyclopentyl)cyclopent-1-ene (68)

The mixture of the two olefins (64) and (68) (0.061g, 0.0003mole) was hydrogenated under the same conditions as described above, and the residue was distilled to give a

* See section II.2.

colourless oil (0.04g), b.p. 135°/21mm. G.l.c. analysis (G, 143°) indicated the presence of (3-t-butylcyclopentyl)--cyclopentane (82, ca. 14%), trans-trans-2-t-butyldecalin (84, ca. 60%), cis-cis-2-t-butyldecalin (83, ca. 20%) and an unidentified product* (ca. 6%) by a comparison with the authentic compounds.

Hydroboration and Oxidation of the mixture of 2-t-butyl-$\Delta^{1,9}$-octalin (64) and (3-t-butylcyclopentyl)cyclopent-1-ene (68)

A solution of the two olefins (64) and (68) (0.05g, 0.0002mole) in tetrahydrofuran (15ml) was stirred at 0° with sodium borohydride (0.024g) and borontrifluoride etherate (0.15ml) was added dropwise under nitrogen. The mixture was stirred for 1h and, after the usual working-up procedure (oxidative), there was isolated a crude product which was oxidized, without further pruification, with Jones' reagent, according to the usual procedure.[214] The product (0.064g) was isolated in the usual way and distilled, to give a colourless oil, b.p. ca. 70°/0.1mm. Analysis by g.l.c. (G, 180°) indicated the presence of 2-(3-t-butylcyclopentyl)--cyclopentanone (85, ca. 19%) and 2-t-butyldecal-1-one (86 ca. 81%). The mixture of ketones (85) and (86) exhibited

* See section II.2.

the following spectral properties, ir, ν_{max}^{film}: 1730(sh, w) and 1705(s), 1385(w), 1365(m), 1060(m)cm^{-1}; n.m.r. (CCl_4): τ9.15-9.03 (9H, singlet and an associated shoulder, $(CH_3)_3C$-), 8.85-7.25 (15H, complex); mass spectrum*: M^+ at m/e 208 and the base peak at m/e 84.

2-t-Butyl-2,9-dideutero-decal-1-one (87) and 2-(3-t-butyl--cyclopentyl)-2,5,5-trideutero-cyclopentanone (91)

A mixture of 2-t-butyldecal-1-one (86) and 2-(3-t-butylcyclopentyl)cyclopentanone (85) (0.025g), prepared above, was deuterated as described previously (Page 203). The product (ca. 0.01g) was isolated and its mass spectrum* showed M^+ at m/e 211 and 210 and the base peak at m/e 154.

Attempted oxymercuration-demercuration of the mixture of 2-t-butyl-$\Delta^{1,9}$-octalin (64) and (3-t-butylcyclopentyl)--cyclopent-1-ene (68)

The general procedure of Brown and Geoghegan[248] was used in this experiment.

A mixture (6:1) of 2-t-butyl-$\Delta^{1,9}$-octalin (64) and (3-t-butylcyclopentyl)cyclopent-1-ene (68) (0.10g, 0.0005mole) was added to a solution of mercuric acetate (0.16, 0.0005mole) in water (1ml) and tetrahydrofuran (1ml) and the mixture was stirred for 7 days at 25°, without the disappearance of

* For a detailed discussion of the mass spectrum see Section II.2.

the yellow colour. After the addition of sodium hydroxide (1ml of a 3M solution) and sodium borohydride (1ml of a 0.5M solution in 3M sodium hydroxide solution), the reaction mixture was stirred for 4h, then saturated with brine solution (10ml) and extracted with ether (3 x 50ml). The combined organic fraction was dried and concentrated to give the product (0.1g) which showed physical and spectral properties (t.l.c., n.m.r. and ir) identical to the starting material (68) and (64).

Estimation of the amount of (3-t-butylcyclopentylidene)-cyclopentane (69) present in the mixture of 2-t-butyl-$\Delta^{9,10}$-octalin (66) and (3-t-butylcyclopentylidene)cyclopentane (69)

Ozonolysis of (3-t-butylcyclopentylidene)cyclopentane (69)

An accurately weighed sample of (3-t-butylcyclopentylidene)cyclopentane (69) (ca. 0.028g) was dissolved in light petroleum (b.p. 30-40°) (25ml) and after being cooled to -78°, the solution was treated with ozone* for 55min. The cold solution, together with an accurately weighed sample of the internal standard, 2-t-butyl-naphthalene (124) (ca. 0.018g) in ether (100ml), was transferred to a separating funnel,

* Ozone was generated with an O3Cl Ozonizer operating at 1.0amps and with an oxygen flow of 1000ml/min.

containing a solution of sodium iodide (0.5g) in methanol (8ml) and acetic acid (2ml). After the mixture had been shaken thoroughly, the aqueous layer was extracted with ether (2 x 40ml) and the combined organic layers were washed successively with 30% sodium thiosulphate solution (2 x 50ml) and sodium bicarbonate solution (2 x 50ml), dried and concentrated by careful distillation of the solvent, through a column (25 x 2cm) packed with glass helices, on a water bath (55°). The residue was analysed by g.l.c. (G, 139° for 5min 15s then temperature programme to 200° at 32°/min) which indicated the presence of 3-t-butylcyclopentanone (88) (R_t 4min 49s) and 2-t-butylnaphthalene (124) (R_t 16min 42s). The average yield of 3-t-butylcyclopentanone,* over 3 runs, was 56±3%.

Ozonolysis of the mixture of 2-t-butyl-$\Delta^{9,10}$-octalin (66) and (3-t-butylcyclopentylidene)cyclopentane (69)

An accurately weighed sample of the mixture of the olefins (66) and (69) (ca. 0.046g) was subjected to ozonolysis and oxidation, as previously described, and the internal

* The response to the g.l.c. detector of 3-t-butylcyclo-pentanone (88) relative to the internal standard (124), was calculated in the usual manner (see page 129). The response ratio of the ketone was found to be 1.15.

standard, 2-t-butylnaphthalene (124, ca. 0.008g) was added. The residue was analysed by g.l.c. and the weight of 3-t-butylcyclopentanone (88, ca. 0.00098g) was determined. The amount of (3-t-butylcyclopentylidene)cyclopentane (69) present in the mixture of the two olefins, (66) and (69), could be calculated. (see section II.2.)

A solid product, probably a mixture of isomeric t-butyl-hydroxy-bicyclo[5.3.0]decanones and the analogous α,β-unsaturated ketones, which were formed by intramolecular condensation of 3-t-butylcyclodecan-1,6-dione, was obtained. This was recrystallized from light petroleum (b.p. 30-40°) to give colourless plates, which exhibited the following spectral properties, ir, ν_{max}^{nujol}: 3300(s) (O-H), 1705(s, sh) and 1680(s) (C=O), 1095(s), 1050(s), 960(m), 835(m)cm^{-1}; mass spectrum: M^+ at m/e 224, $[M-H_2O]^+$ at m/e 206 and the base peak at m/e 57. Lack of material prevented however a full characterization of this product.

Proof of the structures of the olefinic products obtained from the acetolysis of cis-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (47, X=OTs)

A solution of cis-9-t-butylspiro[4.5]dec-6-yl p-toluenesulphonate (0.86g, 0.002mole) and acetic acid (56ml, containing sodium acetate 0.43g) was heated at 62° (constant temperature bath) for 10min under dry nitrogen. After the usual working-up procedure, a colourless oil (quantitative)

was isolated and preparative g.l.c. (Q, 155°) yielded 7-t-butyl-$\Delta^{1,9}$-octalin (65).*

Hydroboration and oxidation of 7-t-butyl-$\Delta^{1,9}$-octalin (65)

(see page 214)

7-t-Butyl-$\Delta^{1,9}$-octalin (65) (0.07g) was subjected to hydroboration and the oxidative working-up procedure as has already been described (page 147). After the product had been further oxidized with Jones' reagent,[214] it was isolated by chromatography on neutral alumina (eluted in 5% ether/95% light petroleum (b.p. 50-60°)) and exhibited the following spectral properties, ir, ν_{max}^{film}: 1710(s), 1385(w), 1365(m)cm^{-1}; mass spectrum**: M^+ at m/e 208 and the base peak at m/e 97. G.l.c. analysis (G, 180°) indicated a mixture*** of products.

---

* The olefin (65) could not be completely separated from 2-t-butyl-$\Delta^{9,10}$-octalin (66) and thus the latter was present as an impurity.

** For a more detailed discussion of the mass spectrum (see section II.2.).

*** For a discussion of this result see section II.2.

APPENDIX

Mass Spectra:

1. A mixture of 2-t-butyldecal-1-one (86) and 2-(3-t-butylcyclopentyl)cyclopentanone (85) (prepared from the olefins (64 and 68)):
   208(15), 152(68), 135(42), 109(37), 84(100), 67(51) 57(59).
2. A mixture of 2-t-butyl-2,9-dideuteriodecal-1-one (87) and 2-(3-t-butylcyclopentyl)-2,5,5-trideuteriocyclopent--an-1-one (91):
   211(2), 210(14), 154(100), 109(36), 87(7), 85(49), 57(33).
3. 2-(3-t-Butylcyclopentyl)cyclopentan-1-one (85):
   208(26), 109(13), 84(100), 67(15), 57(21).
4. 7-t-Butyldecal-1-one (89) (prepared from the olefin (65) which was isolated from the acetolysis of the cis-ester (47, X=OTs)):
   208(29), 152(82), 110(73), 109(25), 97(100), 91(26), 84(10), 81(24), 67(24), 57(48).
5. 7-t-Butyldecal-1-one (89) (prepared from the olefin (65a) which had been synthesized):
   208(7), 152(23), 110(40), 97(52), 81(21), 67(30), 57(100).
6. 7-t-Butyl-2,2,9-trideuteriodecal-1-one (92) (prepared from the ketone described in 5):
   211(13), 155(58), 113(67), 100(100), 57(60).
7. 6-t-Butyldecal-2-one (90):
   208(18), 153(20), 152(100), 110(50), 94(37), 57(49).

REFERENCES

1. A. Baeyer and V. Villiger, Chem. Ber., 1902, 35, 1189.

2. A. Baeyer and V. Villiger, Chem. Ber., 1902, 35, 3013.

3. C. D. Nenitzescu in 'Carbonium Ions', ed. G. A. Olah and P. von R. Schleyer, Wiley, New York, 1968, vol. I, p. 1.

4. D. Bethel and V. Gold, 'Carbonium Ions, An Introduction', Academic Press, London, 1967.

5. A. Streitweiser, Chem. Rev., 1956, 56, 571.

6. B. Capon, Quart. Rev., 1964, 18, 45.

7. S. Winstein, B. K. Morse, E. Grunwald, K. C. Schreiber and J. Corse, J. Amer. Chem. Soc., 1952, 74, 1113.

8. S. Winstein and H. Marshal, J. Amer. Chem. Soc., 1952, 74, 1120.

9. I. L. Reich, A. Diaz and S. Winstein, J. Amer. Chem. Soc., 1969, 91, 5635, 5637.

10. D. S. Noyce, B. R. Thomas and B. N. Bastian, J. Amer. Chem. Soc., 1960, 82, 885.

11. G. H. Alt and D. H. R. Barton, J. Chem. Soc., 1954, 4284.

12. S. Winstein, B. K. Morse, E. Grunwald, H. W. Jones, J. Corse, D. Trifan and H. Marshal, J. Amer. Chem. Soc., 1952, 74, 1127.

13. J. Sicher, M. Tichy, F. Sipos and M. Pankova, Coll. Czech. Chem. Comm., 1961, 26, 2418.

14. R. S. Macomber, J. Amer. Chem. Soc., 1970, 92, 7101.

15. S. K. Core and F. J. Lotspeich, J. Org. Chem., 1971, 36, 399.

16. S. Winstein and H. J. Lucas, J. Amer. Chem. Soc., 1939, 61, (a) 1576; (b) 2845.

17. D. J. Cram, J. Amer. Chem. Soc., 1949, 71, 3875.

18. P. W. Austin, J. G. Buchanan and R. M. Saunders, Chem. Comm., 1965, 146.

19. M. Eakin, J. Martin and W. Parker, Chem. Comm., 1965, 206.

20. R. J. Jablonski and E. I. Snyder, Tetrahedron Letters, 1968, 1103.

21. S. Winstein, C. R. Lindegren, H. Marshal and L. L. Ingraham, J. Amer. Chem. Soc., 1953, 75, 147.

22. G. D. Sargent, Quart. Rev., 1966, 20, 301.

23. P. D. Bartlett, 'Non-Classical Ions', Benjamin, New York, 1965.

24. S. Winstein and R. Boschan, J. Amer. Chem. Soc., 1950, 72, 4669.

25. S. Winstein, H. V. Hess and R. E. Buckels, J. Amer. Chem. Soc., 1942, 64, 2796.

26. D. J. Pasto and M. P. Serve, J. Amer. Chem. Soc., 1965, 87, 1515.

27. C. A. Grob and F. A. Jenny, Tetrahedron Letters, 1960, No. 23, 25.

28. J. P. Ward, Tetrahedron Letters, 1965, 3905.

29. A. C. Cope and D. L. Nealy, J. Amer. Chem. Soc., 1965, 87, 3122.

30. L. A. Paquette, G. V. Meehan and D. L. Wise, J. Amer. Chem. Soc., 1969, 91, 3231.

31. K. Gundermann, Angew. Chem. Internat. Edn., 1963, 2, 674.

32. J. Lenard, Chem. Rev., 1969, 69, 625.

33. A. W. P. Jarvie, A. Holt and J. Thompson, J. Chem. Soc., (B), 1969, 852.

34. S. Winstein and P. Carter, J. Amer. Chem. Soc., 1961, 83, 4485.

35. P. B. D. de la Mare in 'Molecular Rearrangements', ed. P. de Mayo, Interscience, New York, 1967, p. 27.

36. M. Hanack and H. J. Schneider, Angew. Chem. Internat. Edn., 1967, 6, 666.

37. M. Simonetta and S. Winstein, J. Amer. Chem. Soc., 1954, 76, 18.

38. S. Winstein,M.Shatavsky, C. Norton and R. B. Woodward, J. Amer. Chem. Soc., 1955, 77, 4183.

39. C. W. Shoppee, J. Chem. Soc., 1946, 1138, 1147.

40. S. Winstein and R. Adams, J. Amer. Chem. Soc., 1948, 70, 838.

41. S. Winstein and A. H. Schlesinger, J. Amer. Chem. Soc., 1948, 70, 3528.

42. C. W. Shoppee and D. F. Williams, J. Chem. Soc., 1955, 686.

43. G. Le Ny, Compt. rend., 1960, 251, 1526.

44. H. L. Goering and M. F. Sloan, J. Amer. Chem. Soc., 1961, 83, 1397.

45. R. G. Lawton, J. Amer. Chem. Soc., 1961, 83, 2399.

46. P. D. Bartlett and S. Bank, J. Amer. Chem. Soc., 1961, 83, 2591.

47. G. E. Gream, Rev. Pure Appl. Chem. (Australia), 1966, 16, 25.

48. J. A. Berson in 'Molecular Rearrangements', ed. P.de Mayo, Interscience, New York, 1967, p. 111.

49. P. D. Bartlett, S. Bank, R. J. Crawford and G. H. Schmid, J. Amer. Chem. Soc., 1965, 87, 1288.

50. P. D. Bartlett and G. D. Sargent, J. Amer. Chem. Soc., 1965, 87, 1297.

51. P. D. Bartlett, W. S. Trahanovsky, D. A. Bolon and G. Schmid, J. Amer. Chem. Soc., 1965, 87, 1314.

52. H. Felkin and C. Lion, Tetrahedron, 1971, 27, 1375.

53. B. Capon and C. W. Rees, Ann. Rept. Progr. Chem. (Chem. Soc. London), 1964, 61, 231.

54. M. Hanack, H. Schneider-Bernlohr, H- J. Schneider, R. Huttinger and G. Wentrup, Annalen, 1968, 717, 41.

55. K. B. Wiberg and J. E. Hiatt, Tetrahedron Letters, 1968, 3009.

56. P. D. Bartlett, Annalen, 1962, 653, 45.

57. W. D. Closson and G. T. Kwiatkowski, Tetrahedron Letters, 1966, 6435.

58. H. L. Goering and G. N. Fickes, J. Amer. Chem. Soc., 1968, 90, 2856.

59. L. A. Spurlock and W. G. Cox, J. Amer. Chem. Soc., 1969, 91, 2961.

60. P. D. Bartlett, W. D. Closson and T. J. Cogdell, J. Amer. Chem. Soc., 1965, 87, 1308.

61. S. A. Roman and W. D. Closson, J. Amer. Chem. Soc., 1969, 91, 1701.

62. P. D. Bartlett, E. M. Nicholson and R. Owyang, Tetrahedron Suppl., 1966, 8, 399.

63. M. Cocivera and S. Winstein, J. Amer. Chem. Soc., 1963, 85, 1702.

64. P. S. Skell and W. L. Hall, J. Amer. Chem. Soc., 1963, 85, 2851.

65. J. Keating, Ph.D. Thesis, Pennsylvania State University, 1968.

66. P. D. Bartlett, R. E. Pinock, J. H. Rolston, W. G. Schindel and L. A. Singer, J. Amer. Chem. Soc., 1965, 87, 2590.

67. F. D. Greene and N. N. Lowry, J. Org. Chem., 1967, 32, 875.

68. D. L. Struble, A. L. J. Beckwith and G. E. Gream, Tetrahedron Letters, 1968, 3701.

69. A. F. Boschung, M. Geisel and C. A. Grob, Tetrahedron Letters, 1968, 5169.

70. G. E. Gream, Unpublished data.

71. R. C. Fort, Jr. and R. E. Hornish, Chem. Comm., 1969, 11.

72. R. C. Fort, Jr., R. F. Hornish and G. A. Liang, J. Amer. Chem. Soc., 1970, 92, 7558.

73. M. Julia, J. M. Surzur, L. Katy and F. Le Goffic, Bull. Soc. Chim. France, 1964, 1116.

74. W. Huckel, R. Daneel, A. Schwartz and A. Gerke, Annalen, 1929, 474, 121.

75. W. G. Dauben, E. C. Martin and G. J. Fonken, J. Org. Chem., 1958, 23, 1205.

76. W. Huckel and H. Naals, Annalen, 1933, 502, 136.

77. W. Huckel, W. Tappe and G. Legutke, Annalen, 1940, 543, 191.

78. I. Moritani, S. Nishida and M. Murakami, J. Amer. Chem. Soc., 1959, 81, 4320.

79. N. C. G. Campbell, D. M. Muir, R. R. Hill, J. H. Parish, R. M. Southam and M. C. Whiting, J. Chem. Soc. (B), 1968, 355.

80. G. A. Olah, D. P. Kelly and R. G. Johanson, J. Amer. Chem. Soc., 1970, 92, 4137.

81. F. T. Bond, Ph.D. Thesis, University of California.

82. W. G. Dauben, J. L. Chitwood and K. V. Scherer,Jr., J. Amer. Chem. Soc., 1968, 90, 1014.

83. D. J. Cram and M. V. Sahyun, J. Amer. Chem. Soc., 1963, 85, 1257.

84. S. Winstein, B. Appel, R. Baker and A. Diaz, J. Chem. Soc., Special Publication No. 19, p. 122.

85. R. L. Buckson and S. G. Smith, J. Org. Chem., 1967, 32, 634.

86. S. G. Smith and D. J. W. Goon, J. Org. Chem., 1969, 34, 3127.

87. K. Becker, A. F. Boschung and C. A. Grob, Tetrahedron Letters, 1970, 3831.

88. J. F. Bunnett, Angew. Chem. Internat. Edn., 1962, 1, 225.

89. H. L. Goering, J. T. Doi and K. D. McMichael, J. Amer. Chem. Soc., 1964, 86, 1951.

90. H. L. Goering, R. G. Briody and J. F. Levy, J. Amer. Chem. Soc., 1963, 85, 3059.

91. H. L. Goering and S. Chang, Tetrahedron Letters, 1965, 3607.

92. F. A. Carey and H. S. Tremper, J. Amer. Chem. Soc., 1968, 90, 2578.

93. F. A. Carey and H. S. Tremper, J. Org. Chem., 1969, 34, 4.

94. F. E. Lack and J. D. Roberts, J. Amer. Chem. Soc., 1968, 90, 6997.

95. A. A. Frost and R. G. Pearson, 'Kinetics and Mechanism', Wiley, New York, 1961.

96. A. K. Serelis, personal communication.

97. C. M. Williams and D. Whittaker, Chem. Comm., 1970, 960.

98. G. A. Olah and J. Lukas, J. Amer. Chem. Soc., 1968, 90, 933.

99. K. S. Pitzer and W. E. Donath, J. Amer. Chem. Soc., 1959, 81, 3213.

100. J. B. Hendrickson, J. Amer. Chem. Soc., 1961, 83, 4537.

101. P. von R. Schleyer, J. E. Williams and K. R. Blanchard, J. Amer. Chem. Soc., 1970, 92, 2377.

102. M. C. Whiting, Chem. in Britain, 1966, 2, 482.

103. P. A. Naro and J. A. Dixon, J. Amer. Chem. Soc., 1959, 81, 1681.

104. A. P. Krapcho and M. Benson, J. Amer. Chem. Soc., 1962, 84, 1036.

105. A. P. Krapcho, J. E. McCullough and K. V. Nahabedian, J. Org. Chem., 1965, 30, 139.

106. A. P. Krapcho and J. E. McCullough, J. Org. Chem., 1967, 32, 2453.

107. P. A. Naro and J. A. Dixon, J. Org. Chem., 1961, 26, 1021.

108. C. Arnal, J-M. Bessiere, H. Christol and R. Vanel, Bull. Soc. Chim. France, 1967, 2479.

109. C. Christol, H. Christol and R. Vanel, Bull. Soc. Chim. France, 1970, 3685.

110. C. Arnal, J-M. Bessiere, H. Christol and R. Vanel, Bull. Soc. Chim. France, 1967, 2485.

111. H. Christol and J-M. Bessiere, Bull. Soc. Chim. France, 1968, 2141.

112. J-M. Bessiere and H. Christol, Bull. Soc. Chim. France, 1968, 2147.

113. C. Arnal and H. Christol, Bull. Soc. Chim. France, 1968, 945.

114. H. Christol, R. Jacquier and M. Mousseron, Bull. Soc. Chim. France, 1957, 1027.

115. H. Christol, A. P. Krapcho, R. C. H. Peters and C. Arnal, Tetrahedron Letters, 1969, 2799.

116. I. Vogel, Chem. Ber., 1952, 85, 25.

117. B. Belleau, J. Amer. Chem. Soc., 1953, 75, 1159.

118. J. McKenna, 'Conformational Analysis of Organic Compounds', The Royal Institute of Chemistry Lecture series, 1966, No. 1, p. 30.

119. S. Winstein and N. J. Holness, J. Amer. Chem. Soc., 1955, 77, 5562.

120. R. D. Stolow, J. Amer. Chem. Soc., 1964, 86, 2170.

121. E. L. Eliel, 'Stereochemistry of Carbon Compounds', McGraw-Hill, New York, 1962, p.220.

122. J. Levisalles, Bull. Soc. Chim. France, 1960, 551.

123. V. J. Shiner, Jr. and J. G. Jewett, J. Amer. Chem. Soc., 1965, 87, 1383.

124. V. J. Shiner, Jr. and J. G. Jewett, J. Amer. Chem. Soc., 1965, 87, 1382.

125. K. Okamoto, S. Saito and H. Shingu, Bull. Chem. Soc. Japan, 1969, 42, 3288; 1969, 42, 3298; 1970, 43, 3008.

126. P. von R. Schleyer and V. Buss, J. Amer. Chem. Soc., 1969, 91, 5880.

127. H. Kwart and T. Takeshita, J. Amer. Chem. Soc., 1964, 86, 1161.

128. J. E. Nordlander, J. M. Blank and S. P. Jindal, Tetrahedron Letters, 1969, 3477.

129. H. C. Brown and G. Ham, J. Amer. Chem. Soc., 1956, 78, 2735.

130. A. H. Fainberg and S. Winstein, J. Amer. Chem. Soc., 1956, 78, 2780.

131. J. L. Mateos and C. Perez, Chem. Comm., 1967, 125.

132. J-C. Richer and P. Belanger, Canad. J. Chem., 1969, 47, 3281.

133. R. Baker and K. L. Rabone, J. Chem. Soc. (B), 1970, 1598.

134. W. G. Dauben, J. L. Chitwood and K. B. Scherer, Jr., J. Amer. Chem. Soc., 1968, 90, 1014.

135. W. G. Dauben and J. L. Chitwood, J. Amer. Chem. Soc., 1970, 92, 1624.

136. C. A. Bunton, 'Nucleophilic Substitution at a Saturated Carbon Atom', Elsevier, New York, 1963, p. 62.

137. Ref. 5, p. 701.

138. S. Kaarsemaker and J. Coops, Rec. Trav. Chim., 1952, 71, 261.

139. Ref. 4, p. 209.

140. W. S. Johnson, J. L. Margrave, V. J. Bauer, M. A. Frisch, L. H. Dreger and W. N. Hubbard, J. Amer. Chem. Soc., 1961, 83, 606.

141. R. Baker, J. Hudec and K. L. Rabone, Chem. Comm., 1969, 197.

142. E. L. Eliel and S. H. Schroeter, J. Amer. Chem. Soc., 1965, 87, 5031.

143. E. L. Eliel, N. L. Allinger, S. J. Angyal and G. A. Morrison, 'Conformational Analysis', Interscience, New York, 1965.

144. Ref. 121, p. 207.

145. E. L. Eliel and C. A. Lukach, J. Amer. Chem. Soc., 1957, 79, 5986.

146. E. L. Eliel, J. Chem. Educ., 1960, 37, 126.

147. E. L. Eliel and M. Gianni, Tetrahedron Letters, 1962, 97.

148. Ref. 4, p. 198.

149. A. Ehret and S. Winstein, J. Amer. Chem. Soc., 1966, 88, 2048.

150. S. Winstein, E. Clippinger, A. H. Fainberg and G. C. Robinson, Chem. and Ind., 1954, 664.

151. F. W. McLafferty, Appl. Spectroscopy, 1957, 11, 148.

152. K. Bieman, 'Mass Spectrometry', McGraw-Hill, New York, 1962, p. 119.

153. K. Bieman, Angew. Chem., 1962, 74, 102.

154. H. O. House, R. W. Giese, K. Kronberger, J. P. Kaplan and J. Simeone, J. Amer. Chem. Soc., 1970, 92, 2800.

155. G. Zweifel and H. C. Brown in 'Org. Reactions', ed. A. C. Cope et.al., Wiley, 1963, 13, 14.

156. W. G. Dauben, G. J. Fonken and D. S. Noyce, J. Amer. Chem. Soc., 1956, 78, 2579.

157. E. L. Eliel and Y. Senda, Tetrahedron, 1970, 26, 2411.

158. A. Allais and C. Hoffmann, Chem. Abstract, 1958, 52, 18531. U.S.P. 2,835,681.

159. H. O. House 'Modern Synthetic Reactions', Benjamin, New York, 1965, p. 17.

160. E. L. Eliel, T. W. Doyle, R. O. Hutchins and E. C. Gilbert, personal communication.

161. Y. M. Haddad, H. B. Henbest, J. Husbands and T. R. B. Mitchell, Proc. Chem. Soc., 1964, 361.

162. H. B. Henbest and T. R. B. Mitchell, J. Chem. Soc.(C), 1970, 785.

163. B. Rickborn and S. Lwo, J. Org. Chem., 1965, 30, 2212.

164. A. A. Akhrem, A. M. Moiseenkov and V. N. Dobrynin, Russ. Chem. Rev., 1968, 37, 448.

165. B. Rickborn and J. Quartucci, J. Org. Chem., 1964, 29, 3185.

166. R. V. Lemieux, R. K. Kullnig, H. J. Bernstein and W. G. Schneider, J. Amer. Chem. Soc., 1958, 80, 6098.

167. L. Joris, P. von R. Schleyer and R. Gleiter, J. Amer. Chem. Soc., 1968, 90, 327.

168. M. M. Green, R. J. Cook, W. Rayle and E. Walton, Chem. Comm., 1969, 81.

169. L. Dolejs and V. Hanus, Coll. Czech. Chem. Comm., 1968, 32, 332.

170. R. E. Parker and N. S. Issacs, Chem. Rev., 1959, 59, 737.

171. B. Rickborn and W. E. Lamke, J. Org. Chem., 1967, 32, 537.

172. J-C. Richer and C. Freppel, Canad. J. Chem., 1968, 46, 3709.

173. N. A. Lebel and G. G. Ecke, J. Org. Chem., 1965, 32, 4316.

174. H. R. Nace in 'Org. Reactions', 1962, 12, 57.

175. J-C. Richer and P. Belander, Canad. J. Chem., 1964, 42, 2398.

176. A. Maercker in 'Org. Reactions', 1965, 14, 270.

177. A. S. Kende in 'Org. Reactions', 1960, 11, 261.

178. F. G. Bordwell, R. R. Frame, R. G. Scamehorn, J. G. Strong and S. Meyerson, J. Amer. Chem. Soc., 1967, 89, 6704.

179. N. L. Allinger, J. Allinger, L. W. Chow and G. L. Wang, J. Org. Chem., 1967, 32, 522.

180. R. Granger, J. Boussinesq, J. P. Girard, J. C. Rossi and J. P. Vidal, Bull. Soc. Chim. France, 1969, 2806.

181. G. B. Payne and C. W. Smith, J. Org. Chem.,1957, 22, 1680.

182. E. J. Eisenbraun, P. G. Hanel, K. S. Schorno, Sr. St. F. Dilgen and J. Osieki, J. Org. Chem., 1967, 32, 3010.

183. S. C. Overbaugh, C. F. H. Allen, E. L. Martin and L. F. Fieser, Org. Synth., 1935, 15, 64.

184. W. Huckel, Annalen, 1925, 441, 1.

185. A. J. Birch, J. Chem. Soc., 1945, 809.

186. R. A. Benkeser and E. M. Kaiser, J. Org. Chem., 1964, 29, 955.

187. M. E. Kuehne and T. J. Giacobbe, J. Org. Chem., 1968, 33, 3359.

188. G. Stork and S. D. Darling, J. Amer. Chem. Soc., 1960, 82, 1512.

189. H. Booker, L. K. Evans and A. E. Gillman, J. Chem. Soc., 1940, 1453.

190. H. C. Brown and C. D. Pfaffenberger, J. Amer. Chem. Soc., 1967, 89, 5475.

191. H. C. Brown and E. Negishi, Chem. Comm., 1968, 594.

192. R. H. Shapiro and M. J. Heath, J. Amer. Chem. Soc., 1965, 89, 5734.

193. D. J. Pasto and J. A. Gontarz, J. Amer. Chem. Soc., 1970, 92, 7480.

194. J. J. Eisch and G. R. Husk, J. Org. Chem., 1966, 31, 3419.

195. H. C. Brown and C. P. Garg, J. Amer. Chem. Soc., 1961, 83, 2952.

196. A. Hassner, V. R. Fletcher and D. P. G. Hamon, J. Amer. Chem. Soc., 1971, 93, 264.

197. A. I. Vogel, 'A Textbook of Practical Organic Chemistry', Longmans, London, 1962, 3rd Edition, p. 342.

198. H. C. Brown, C. P. Garg and K-T. Liu, J. Org. Chem., 1971, 36, 387.

199. M. Mousseron, R. Jacquier and H. Christol, Bull. Soc. Chim. France, 1957, 346.

200. G. T. Poh, Honours Thesis, University of Adelaide, 1965.

201. M. S. Newman, V. DeVries and R. Darlack, J. Org. Chem., 1966, 31, 2171.

202. H. C. Brown and B. C. Subba Rao, J. Amer. Chem. Soc., 1958, 80, 5377.

203. V. J. Shiner, Jr., W. E. Buddenbaum, B. L. Murr and G. Lamaty, J. Amer. Chem. Soc., 1968, 90, 418.

204. R. S. Tipson, J. Org. Chem., 1944, 9, 235.

205. A. P. Krapcho and R. Donn, J. Org. Chem., 1965, 30, 641.

206. L. Friedman, R. L. Little and W. R. Reichle, Org. Synth., 1960, 40, 93.

207. N. N. Schwartz and J. H. Blumbergs, J. Org. Chem., 1964, 29, 1976.

208. H. B. Henbest and R. A. L. Wilson, J. Chem. Soc., 1956, 3289.

209. N. A. Milas and I. S. Cliff, J. Amer. Chem. Soc., 1933, 55, 352.

210. N. A. Milas and A. McAlevy, J. Amer. Chem. Soc., 1933, 55, 349.

211. J. A. Edgerton, Proc. Chem. Soc., 1909, 25, 149.

212. L. W. Trevoy and W. G. Brown, J. Amer. Chem. Soc., 1949, 71, 1675.

213. K. Bowden, I. M. Heilbron, E. R. H. Jones and B. C. L. Weedon, J. Chem. Soc., 1946, 39.

214. J. Meinwald, J. Crandall and W. E. Hymans in 'Org. Synth.', 1965, 45, 77.

215. H. C. Brown and G. Zweifel, J. Amer. Chem. Soc., 1961, 83, 2544.

216. Ref. 197, p. 882.

217. H. Pines and V. N. Ipatieff, J. Amer. Chem. Soc., 1939, 61, 2728.

218. J. B. Nierderl and J. B. Whitman, J. Amer. Chem. Soc., 1937, 59, 717.

219. R. A. Bell, R. E. Ireland and L. N. Mander, J. Org. Chem., 1966, 31, 2536.

220. N. A. Milas and C. P. Priesing, J. Amer. Chem. Soc., 1957, 79, 6295.

221. Ref. 197, p. 973.

222. R. A. Sauers, J. Amer. Chem. Soc., 1959, 81, 4873.

223. J. Allinger and N. L. Allinger, Tetrahedron, 1958, 2, 64.

224. R. N. Jones, D. A. Ramsay, F. Herling and K. Dobriner, J. Amer. Chem. Soc., 1952, 74, 2828.

225. N. L. Allinger and J. Allinger, J. Amer. Chem. Soc., 1958, 80, 5476.

226. L. F. Fieser and X. A. Dominguez, J. Amer. Chem. Soc., 1953, 75, 1704.

227. F. G. Bordwell and K. M. Wellman, J. Org. Chem., 1966, 31, 351.

228. A. W. Burgstahler and Z. J. Bithos, Org. Synth., 1962, 42, 62.

229. G. G. Joris and J. Vitrone, Chem. Abstract, 1958, 52, 14671.

230. A. D. Alder, F. R. Longo and J. D. Finarelli, J. Org. Chem., 1967, 32, 476.

231. G. D. Dorough, J. R. Miller and F. M. Huennekens, J. Amer. Chem. Soc., 1951, 73, 4315.

232. E. J. Corey and I. Kuwajima, J. Amer. Chem. Soc., 1970, 92, 395.

233. K. J. Schmalzl and R. N. Mirrington, Abstracts, Fourth National Convention and Divisional Symposia of the Royal Australian Chemical Institute, Canberra, 1970, AC92, p. 80.

234. L. F. Fieser and C. C. Price, J. Amer. Chem. Soc., 1936, 58, 1838.

235. E. L. Martin, J. Amer. Chem. Soc., 1936, 58, 1438.

236. N. G. Bromby, A. T. Peters and F. M. Rowe, J. Chem. Soc., 1943, 144.

237. H. R. Snyder and F. X. Werber, Org. Synth. Coll. Vol. III, p. 798.

238. J. H. Stocker, J. Org. Chem., 1962, 27, 2288.

239. W. G. Dauben, R. C. Tweit and C. Mannerskantz, J. Amer. Chem. Soc., 1954, 76, 4420.

240. R. Willstatter and E. Waldschmidt-Leitz, Ber., 1921, 54, 113.

241. G. Stork, A. Brizzolara, H. Landesman, J. Szmuszkovicz and R. Terrell, J. Amer. Chem. Soc., 1963, 85, 207.

242. L. Schmerling, J. Amer. Chem. Soc., 1947, 69, 1121.

243. F. Sondheimer and S. Wolfe, Canad. J. Chem., 1959, 37, 1870.

244. R. E. Ireland, T. I. Wrigley and W. G. Young, J. Amer. Chem. Soc., 1958, 80, 4604.

245. M. S. Kharasch and C. F. Fuchs, J. Org. Chem., 1944, 9, 359.

246. C. N. R. Rao, 'Ultra-Violet and Visible Spectroscopy', Butterworths, London, 1961, p. 26.

247. H. C. Brown and E. Negishi, J. Amer. Chem. Soc., 1967, 89, 5285.

248. H. C. Brown and P. Geoghegan, J. Amer. Chem. Soc., 1967, 89, 1522.

249. T. D. Nevitt and G. S. Hammond, J. Amer. Chem. Soc., 1954, 76, 4124.

250. R. M. Moriarty and T. D. J. D'Silva, Tetrahedron, 1965, 21, 547.

251. E. Ritchie and W. C. Taylor, Austral. J. Chem., 1964, 17, 281.

252. F. C. Whitmore and W. H. James, J. Amer. Chem. Soc., 1943, 65, 2088.

253. I. J. Borowitz, G. J. Williams, L. Gross and R. Rapp, J. Org. Chem., 1968, 33, 2013.