INVESTIGATION OF ROUTES TO CERTAIN NONCLASSICAL CARBONIUM IONS

A THESIS

PRESENTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in the

UNIVERSITY OF ADELAIDE

by

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1965.

CONTENTS

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SUMMARY

The acetolysis of (+)-α-campholenyl [β-(2,2,3-trimethylcyclopent-3-enyl)ethyl] p-nitrobenzenesulphonate has been shown to proceed with direct participation of the double bond in the ionisation step. Thus at 60° (+)-α-campholenyl p-nitrobenzenesulphonate solvolysed *ca.* 200 times faster than the corresponding saturated sulphonate in acetic acid containing sodium acetate. The major product of the acetolysis was (-)-camphene, and this reaction therefore provides the π-route to the isobornyl-camphenehydro cation.

The trifluoroacetates of isoborneol, camphene hydrate and methylcamphenilol solvolysed by alkyl oxygen fission mechanism in acetic acid and yielded camphene as the main product. The acetolysis of bornyl trifluoroacetate, however, proceeded by an acyl oxygen fission process, and yielded only borneol and bornyl acetate.

The acetolysis of (-)-isobornyl trifluoroacetate yielded (+)-camphene. Since (+)-α-campholenyl p-nitrobenzenesulphonate and (-)-isobornyl trifluoroacetate were both obtained from (+)-camphor, (+)-camphor has thus been converted into (-)-camphene and (+)-camphene by the π- and σ-routes of solvolysis, respectively.

Syntheses of 2-*exo* and 2-*endo*-carboxybornane of high optical purity are described. The oxidative decarboxylation of these acids with lead tetraacetate in benzene-pyridine yielded mainly camphene together with the acetates of borneol, isoborneol and camphene hydrate. Products derived from the free 2-bornyl radical were not observed. The formation of some *endo* substitution product, bornyl

acetate, suggests that the classical 2-bornyl cation is the first intermediate. It is proposed that this rearranges to the non-classical isobornyl-camphenehydro cation to account for the formation of tertiary exo substitution product (the acetate of camphene hydrate) and the complete absence of tertiary endo substitution product (methylcamphenilyl acetate).

The crystalline byproduct $C_{12}H_{18}O_2$ formed by the action of lead tetraacetate on camphene in acetic acid has been shown to be a mixture (ca. 4:1) of the exo and endo lactones of 3-(2-hydroxy-3,3-dimethyl-2-norbornyl)propionic acid. The lactone formed by the action of strong acids on tricycloekasantalic acid has been shown to be a mixture (ca. 7:3) of the same exo and endo lactones, respectively, and not the pure endo lactone as reported in the literature. The formation of the exo lactone from tricycloekasantalic acid via exclusive exo methyl group migration in a 3,2-shift has been established, and the nature of the intermediate carbonium ions is discussed.

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STATEMENT

This thesis contains no material which has been accepted for the award of any other 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 when due reference is made in the text.

Dieter Wege.

ACKNOWLEDGEMENTS.

I wish to sincerely thank Dr. G.E. Gream for his guidance and encouragement, and for the many stimulating discussions during his supervision of this work.

This research was carried out during the tenure of a Commonwealth Postgraduate Award, which I gratefully acknowledge.

PUBLICATIONS.

Part of the work described in this thesis has been published in the following paper:

CONVERSION OF (+)-CAMPHOR TO THE ENANTIOMORPHIC HYDRO-CAMPHENYL-ISOBORNYL CATIONS BY THE σ- AND π-ROUTES OF SOLVOLYSIS. G.E. Gream and D. Wege, Tet. Letters, 535 (1964).

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INTRODUCTION

I. Solvolytic Routes to Carbonium Ions.

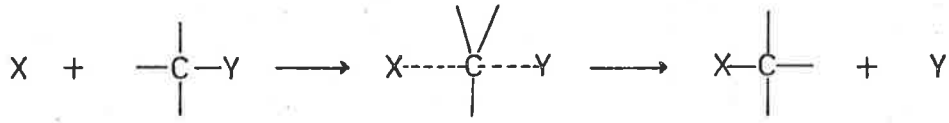
1. General.

Nucleophilic substitution at a saturated carbon atom constitutes an important class of reactions in organic chemistry. The overall reaction may be represented by

where X and Y are Lewis bases and the atom at which substitution is taking place is a tetrahedral carbon atom. When the incoming nucleophile X is a solvent molecule, the reaction is termed a solvolytic displacement. Nucleophilic substitution and solvolytic displacement reactions are the subjects of several recent reviews.[1,2,3]

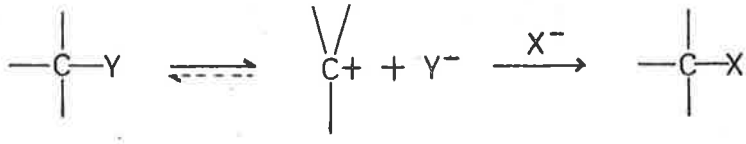
Two extreme classifications of nucleophilic substitution may be made.

(a) That in which the two reacting species undergo a simultaneous covalency change, is labelled S_N2 (bimolecular nucleophilic substitution). The transition state (1) here contains both the entering group X and the leaving group Y, and an inversion of configuration occurs at the reaction centre.



(1)

(b) That in which a relatively slow heterolytic fission of the substrate into ions is followed by rapid addition of X, is labelled S_N1 (unimolecular nucleophilic substitution).



(2)

The transition state here involves only the carbonium ion (2). The energy for the initial ionisation in the vapour state is generally too high to permit reaction, but is considerably lowered in solution by solvation of the ions.[4] S_N1 reactions are thus favoured in highly polar solvents.

The rate of a nucleophilic displacement reaction is determined by the energy difference between the ground state and the transition state of the rate determining step. The factors which increase the energy content of the ground state and lower that of the transition state will therefore lead to an increased reaction rate.

2. Neighbouring group participation.

When a substituent influences a reaction by becoming bonded or partially bonded to the reaction centre, the substituent is said to

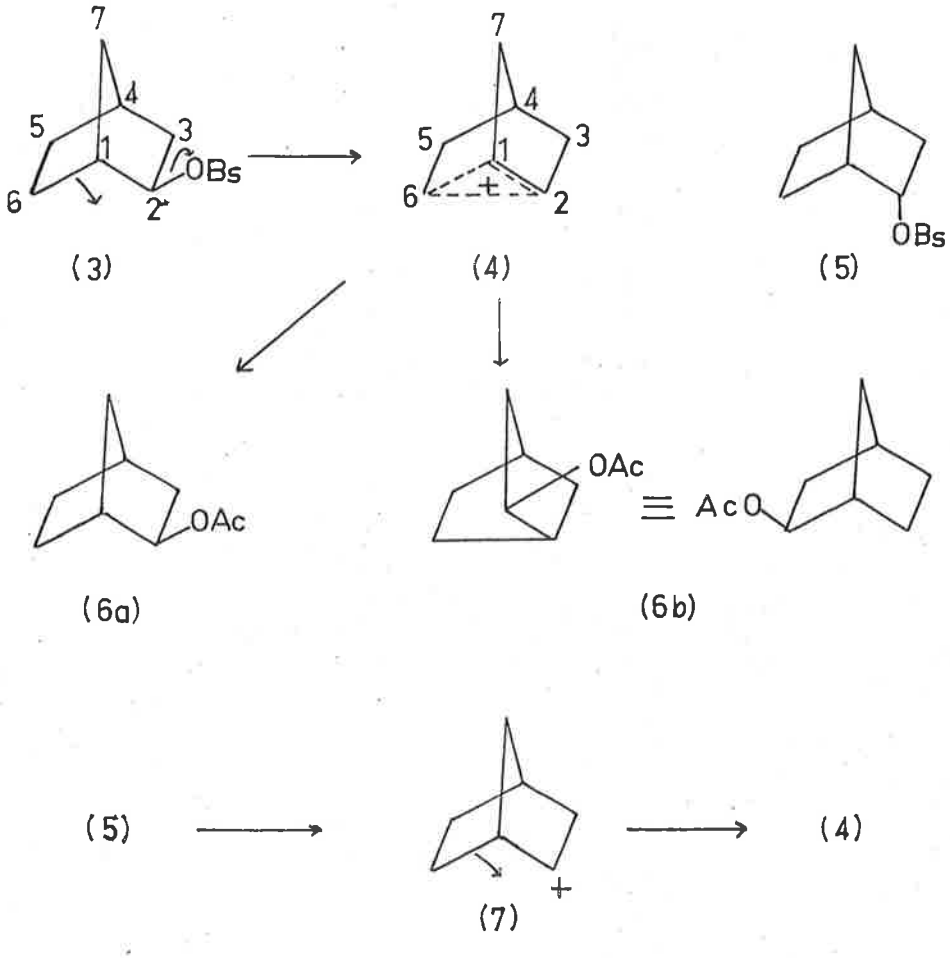
exhibit neighbouring group participation.[5] If the transition state of a rate determining step is stabilised by such participation, an increased reaction rate results and the neighbouring group is said to provide anchimeric assistance.[6] Neighbouring group participation is observed in many types of systems[5] and of particular interest are those examples where the neighbouring groups are carbon-carbon single, and carbon-carbon double bonds.

The material presented in this thesis is concerned with a study of routes to certain carbonium ions in the bicyclo [2.2.1] heptyl system in which carbon-carbon single, and carbon-carbon double bond participation is possible. This subject has been extensively investigated in recent years, and various aspects of the topic are reviewed in references 1-5. A more detailed review has been published by Berson.[7] A brief review of this early work, together with some of the more recent findings, is given below.

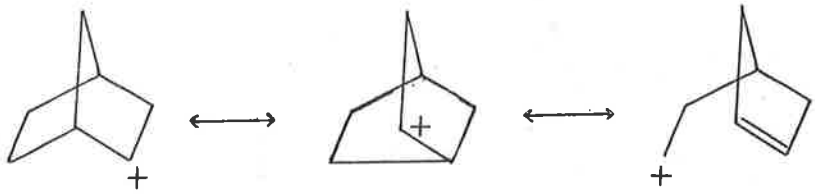
(a) Neighbouring carbon-carbon single bond participation in the bicyclo-[2.2.1] heptyl series.

Winstein and Trifan[8] showed that the acetolysis of exo-norbornyl p-bromobenzenesulphonate (3) proceeded 350 times faster than that of the endo isomer (5), and the sole product of the acetolysis of (3) was exo-norbornyl acetate (6). When optically active sulphonate (3) was used, the acetate (6) was racemic. The bridged carbonium ion (4) was postulated as an intermediate in the reaction. In (4) carbon atom 6 (C_6) was considered to be partly bonded to both C_1 and C_2. Acetate ion attack was considered to be possible only from the side remote to that

of the bridge, and such exo attack at C_2 and C_1 would give rise to enantiomorphic acetate molecules (6a) and (6b). The faster rate of solvolysis of the exo brosylate (3) over that of the endo brosylate (5) was considered to be due to neighbouring group participation by the 1,6- carbon bond in the ionisation of (3). The spatial arrangement of the leaving group and the 1,6- carbon bond was considered to be favourable for such participation in (3), but not in the endo brosylate (5). Solvolysis of optically active (5) also yielded largely racemic exo substitution product.[8b] It was proposed that the classical ion (7) was initially formed and that this then largely rearranged to the nonclassical ion (4) before being captured by the external nucleophile.

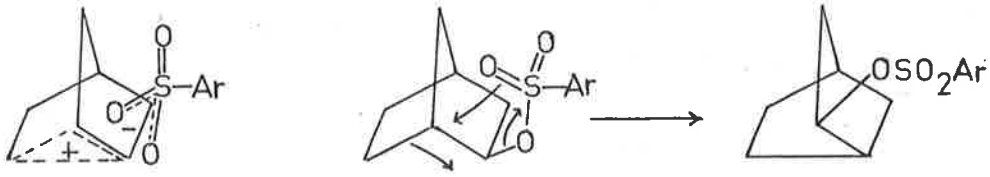


The nonclassical norbornyl cation may be described as a resonance hybrid of structures (4a) - (4c).



(4a) (4b) (4c)

In the acetolysis of (3) the rate of loss of optical activity was found to be 3.5 times greater than the rate of formation of p-bromobenzenesulphonic acid. This behaviour was attributed to the formation of an intimate ion pair (8),[8,9] which like the free bridged ion (4) is symmetrical and therefore internally compensated. Alternatively, an internal return mechanism (8a → 8b) may be written.

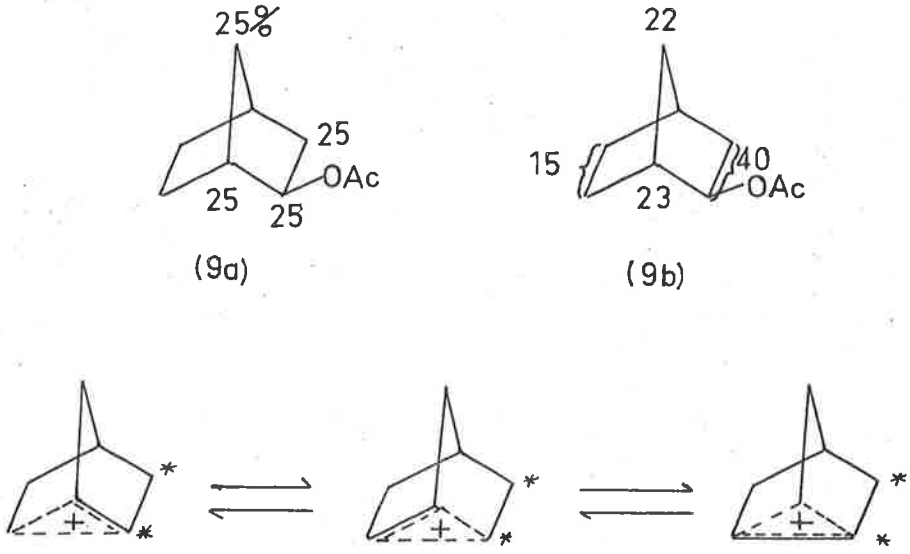


(8) (8a) (8b)

The polarimetric and titrimetric rates of solvolysis of endo-norbornyl p-bromobenzenesulphonate (5) were identical.[8b]

The solvolysis of the norbornyl p-bromobenzenesulphonates labelled equally in positions 2 and 3 with C^{14} was investigated by Roberts and co-workers.[10] The intermediate ion (4) would be expected to yield acetate labelled equally in the 1,2,3 and 7 positions (9a). The observed label distribution pattern (9b) for the acetate from the acetolysis of (3) was explained in terms of a series of hydride shifts

which are summarised in scheme 1.



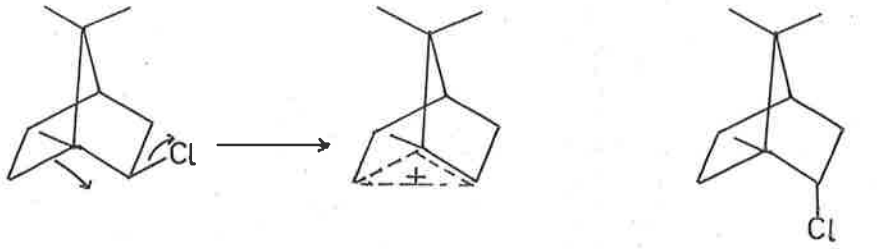
Scheme 1.

(b) Neighbouring carbon-carbon single bond participation in the isobornyl and camphenehydro series. The isobornyl-camphenehydro cation.

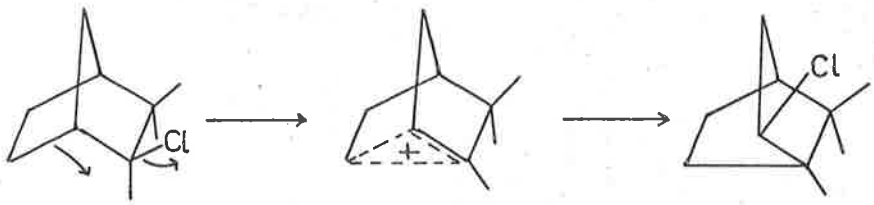
The concept of the bridged nonclassical norbornyl cation was extended by Winstein and co-workers to the isobornyl and camphenehydro series.[11] The rate of solvolysis of isobornyl chloride (10) was found to be 2.5×10^5 times that of bornyl chloride (12) in 80% ethanol, and ionisation of (10) was therefore postulated to proceed with participation of the 1,6-bond in the rate determining step, with the formation of the bridged ion (11). In bornyl chloride, the configuration of the 1,6-bond relative to the leaving group was considered to be unfavourable for participation.

The bridged or mesomeric cation (11) had earlier been suggested

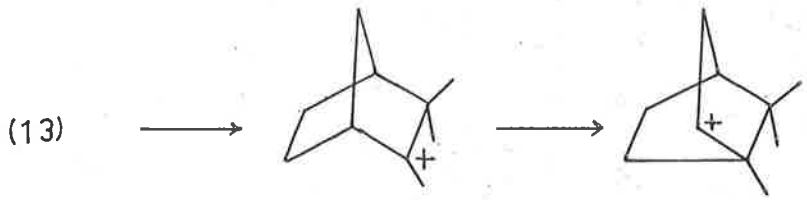
to be the intermediate in the rearrangement of camphene hydrochloride (13) to isobornyl chloride.[12] The rate of this reaction was accelerated by Lewis acids and strongly dependent on the ionising power of the solvent.[13] The classical cation (15) could not be an intermediate in the reaction since it would have produced at least some bornyl chloride (12) by attack by nucleophile from the less hindred <u>endo</u> side of (15), whereas the product appeared to be exclusively the <u>exo</u> isomer. The abnormally high rate of solvolysis of camphene hydrochloride was taken to signify participation by the 1,6-bond in the rate determining steps by Ingold and co-workers.[14] This participation by a β-substituent was termed synartetic acceleration by these authors.



(10) (11) (12)



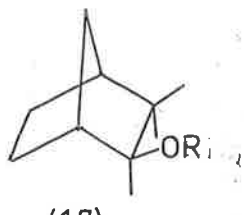
(13) (11) (10)



(13) (14) (15)

A study of the kinetics and products of the solvolysis of camphene hydrochloride, isobornyl chloride and bornyl chloride in aqueous and alcoholic solvents has recently been made by Bunton and co-workers.[15] They found that in alkaline or neutral solution only camphene (16) and camphene hydrate or its ether (17, R=H or CH_3) were formed, and that the product composition was independent of the substrate. The amount of elimination (i.e. amount of camphene) was found to increase with increasing concentration of lyate ion, increasing temperature, and on the addition of 1,2- dimethoxyethane. It was concluded that a common carbonium ion was the intermediate, and that its structure was close to that of the tertiary ion (14), although the nonclassical structure (11) was probably a better representation. The carbonium ion appeared to have a sufficiently long lifetime to discriminate between the abundant solvent molecules which preferentially added to the tertiary centre to yield (17), and the lyate ions which preferentially abstracted a proton to yield camphene.

(16)



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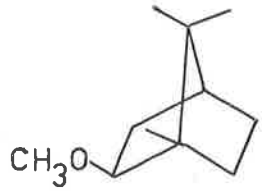
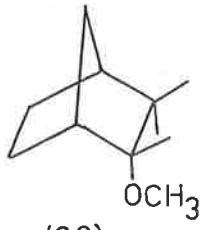


(18)

In a preliminary communication, Hückel and Heinzel[16] described the preparation of the previously unknown methylcamphenilyl chloride (19). They studied the solvolysis of (19) and of camphene hydrochloride and isobornyl chloride under conditions similar to those of Bunton and co-workers. The results of the two groups conflict markedly

in that Hückel and Heinzel claimed that methylcamphenilyl methyl ether (20) was formed in substantial quantities from camphene hydrochloride and isobornyl chloride in 0.2M sodium methoxide in methanol (cf. tables 1 and 2).

(19)



(20)

Chloride	Temp.	Ether (17)	Ether (20)	Ether (18)	Hydrocarbon (mainly camphene)
(13)	-10°	6	54	trace	40
(19)	0°	trace	10	trace	90
(10)	50°	1	24	trace	75

Table 1. Composition of the solvolysis products of some trimethyl-norbornyl chlorides in 0.2M $NaOCH_3$ in CH_3OH (Normalised peak area percentages from gas chromatographic analyses.)[16]

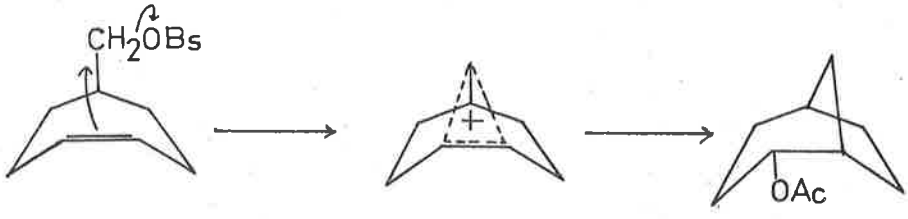
Chloride	Temp.	Ether (17)	Hydrocarbon (Camphene)
(13)	0°	80	20
	25.3°	78	22
(10)	25°	75	25
	45°	65	35

Table 2. Composition of the solvolysis products of some trimethyl-norbornyl chlorides in 0.2M $NaOCH_3$ in CH_3OH (mole percentages).[15]

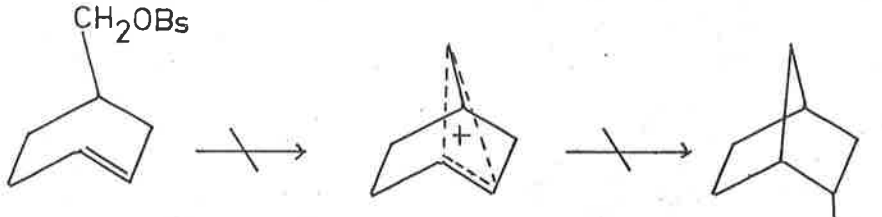
The results of Hückel and Heinzel (Table 1) cannot be interpreted in terms of the nonclassical ion (11), since the formation of the ether (20) implies nucleophilic attack from the side bearing the partially bonded bridge. It is also difficult to invoke the classical tertiary ion (14) as the intermediate, since nucleophilic attack should still occur predominantly from the less hindered exo side.

(c) Neighbouring carbon-carbon double bond participation. Ring closure to the bicyclo[2.2.1]heptyl system.

In 1960 LeNy[17] observed that the acetolysis of the unsaturated p-bromobenzenesulphonate (21) proceeded with participation of the double bond to yield the bicyclic acetate (23) in high yield, presumably via the bridgedion (22). The sulphonate (24), which by analogy might be expected to cyclise to (26) via (25), yielded however no ring closed product.



(21) (22) (23)

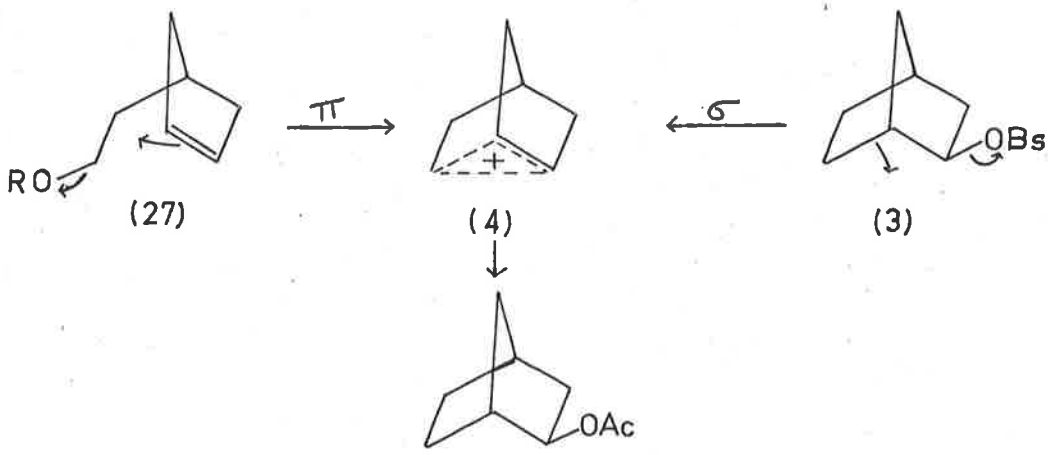


(24) (25) (26)

Wilcox and Chibber[18] also found in a study of several 3-cyclohexenylcarbinyl derivatives related to (24) that participation by the double bond and ring closure did not occur.

In 1961 Lawton[19] showed that the acetolysis of 2-(cyclopent-3-enyl)ethyl p-nitrobenzenesulphonate (27, R= p-nitrobenzenesulphonyl) proceeded 95 times faster than that of the corresponding saturated analogue, with the formation of exo-norbornyl acetate (6) as the sole product. Less than 0.5% of the monocyclic acetate (27, R=Ac) was formed. Independently Bartlett and Bank[20] showed that the tosylate (27, R = p-toluenesulphonyl) underwent anchimerically assisted ring closure to the bicyclo[2.2.1]heptyl system. The bridged norbornyl cation (4) had thus been generated from two different types of substrates. Winstein and Carter[21] proposed the general term σ-route and π-route for the anchimerically assisted ionisations of substrates in which the neighbouring group contributes σ- or π-electrons respectively. Other examples of σ- and π-routes to the same bridged cations are listed below.[21]

Solvolytic ring closures to the bicyclo[2.2.1]heptyl system via the π-route has been extensively studied by Bartlett and co-workers.[22] Anchimerically assisted ring closure was observed with the methyl substituted derivatives (28) and (29) as well as the unsubstituted 2-(cyclopent-3-enyl)ethyl arenesulphonates (27, R = SO_2Ar). The first and second methyl substituents in (28) and (29) were found to have nearly identical accelerating effects in the rate of ionisation of (28) and (29) relative to that of the unsubstituted (27, R = p-nitro-


RO
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(27)
(4)
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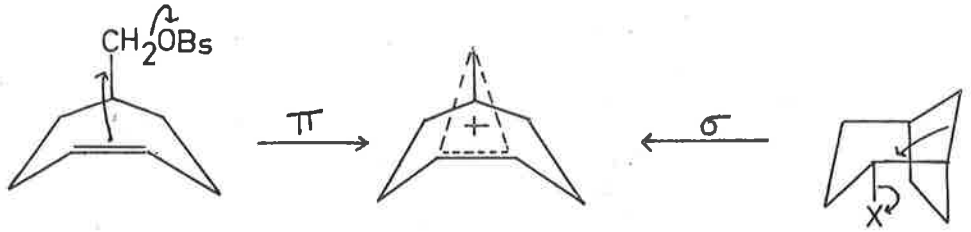
OAc
(6)


CH2OBs
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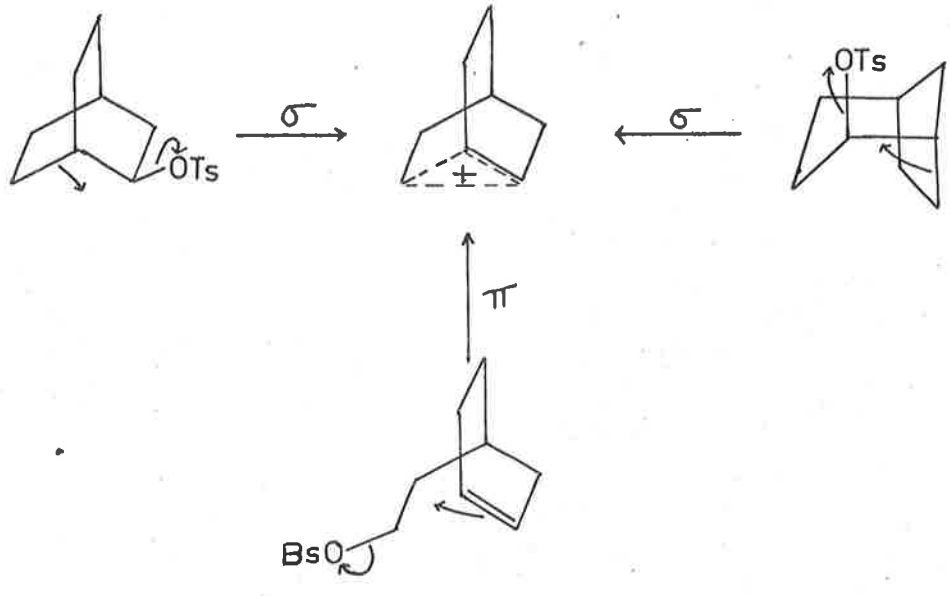
OTs
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σ
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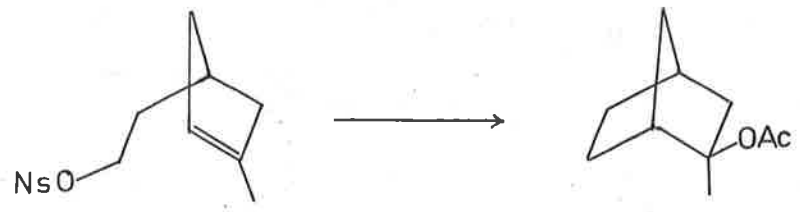
benzenesulphonyl). This strongly suggests that ionisation proceeds via a symmetrical transition state to a symmetrical (i.e. bridged) cation.



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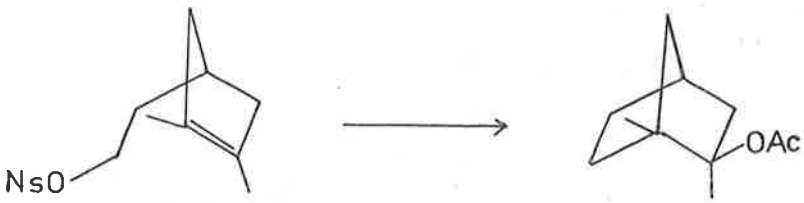


(29)

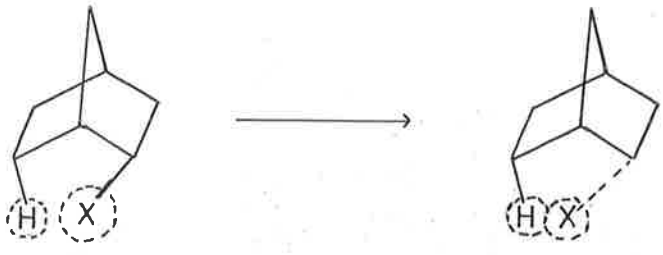
3. Nonclassical versus classical norbornyl cation.

The concept of the nonclassical norbornyl cation, and nonclassical cations in general, has been questioned by H.C. Brown.[23] He has pointed out that in many cases where anchimeric assistance and nonclassical structures have been postulated, the ground state is sterically strained, and that relief of steric strain may be responsible for the accelerated reaction rate. A brief summary of the current nonclassical versus classical carbonium ion controversy is given below, and the discussions is limited to the norbornyl and substituted norbornyl system.

The experimental evidence which led to the postulation of the nonclassical norbornyl cation can be discussed under two headings.

(a) High solvolysis rates of exo-norbornyl derivatives and high exo-endo rate ratios.

This has been interpreted by Brown to mean that the exo derivative solvolyses at a "normal" rate, while the endo derivative solvolyses at an abnormally low rate.[23,24a] The leaving group X in the endo compound (30) has to pass unusually close to the endo hydrogen atoms at C_5 and C_6 in approaching the transition state for ionisation (31). This steric inhibition to ionisation was proposed to account for the low solvolysis rates of endo- norbornyl derivatives and hence high exo-endo rate ratios. Brown has also recently shown that the rate of ethanolysis of camphene hydrochloride (13) is not abnormally high when compared with those of suitable methyl substituted cyclopentyl derivatives.[25] Thus although camphene hydrochloride solvolyses 13600 times faster than tert-butyl chloride, it solvolyses only 2.5 times faster than (32). The high solvolysis rate of (13) was therefore attributed to relief of

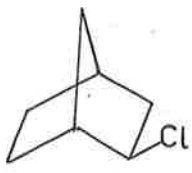


(30) (31)

(13) (32)

steric strain on ionisation, rather than 1,6-participation and non-classical carbonium ion formation. The solvolysis rates of other norbornyl derivatives were also found not to be abnormally high when compared with those of the corresponding cyclopentyl derivatives.[24b]

It has been argued by Brown[24a] that since the nonclassical norbornyl cation distributes its positive charge equally over C_1 and C_2 of the norbornyl system, a substituent in the 1 and 2 position should have an identical effect on the stability of the nonclassical ion and very similar effects on the rate of solvolysis. This is clearly not verified by the rates of ethanolysis of 1-phenyl-exo-norbornyl chloride (34) and 2-phenyl-exo-norbornyl chloride (35) relative to exo-norbornyl chloride (33). The solvolyses of (34) and (35) thus do not appear to proceed through transition states which closely resemble the nonclassical ion (36).



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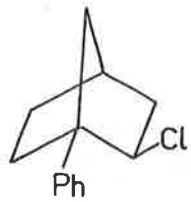

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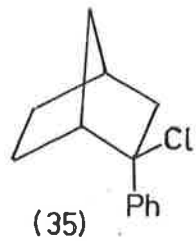
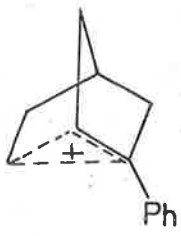
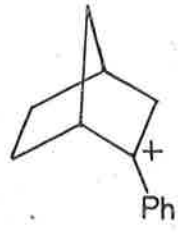


(35)

Relative rates at 25°	1.00	3.9	39,000,000

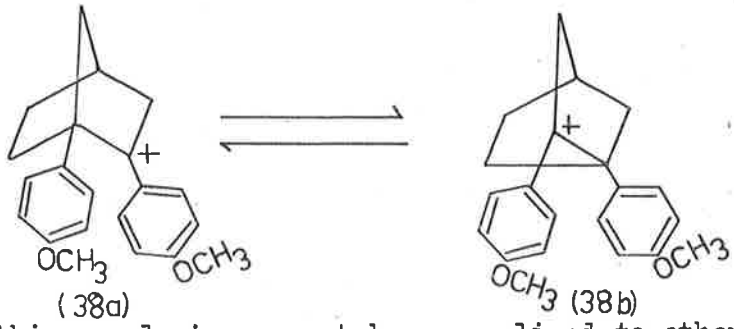


(36)



(37)

Nuclear magnetic resonance studies have indicated that the 1,2-di-p-anisyl-2-norbornyl cation exists as an equilibrating pair of classical ions in sulphuric acid solution (38a - 38b).[26]



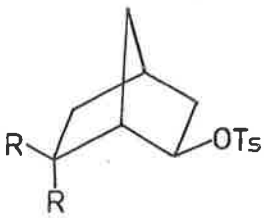
(38a) (38b)

Although this conclusion cannot be generalised to other norbornyl cations generated by solvolytic means, it has been proposed that the stabilisation provided by the adjacent p-anisyl group is so great that participation by the 1,6-bonding cloud is not required in the ionisation to yield (38).[27] This argument can also be used to explain the high solvolysis rate of 2-phenyl-exo-norbornyl chloride (35) and implies that the 2-phenylnorbornyl cation is also essentially classical, i.e. (37).

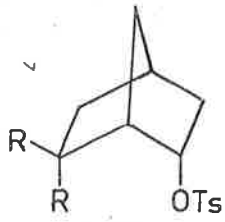
Brown has shown that the exo-endo rate ratio for various tertiary exo- and endo-2-norbornyl p-nitrobenzoates is of a similar order of magnitude as the exo-endo rate ratio for the unsubstituted 2-norbornyl arenesulphonates.[24c,28b] Since participation by the 1,6-bond should be far less significant in these stabilised tertiary ions than in the

secondary ions, he has concluded that a high exo-endo rate ratio is not a justification for the proposed existence of the nonclassical norbornyl cation.

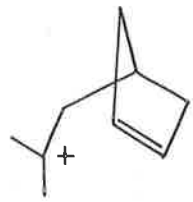
The acetolysis of 6,6-dimethyl-2-exo-norbornyl tosylate (39, R=CH_3) and of the corresponding endo tosylate (40, R=CH_3) has been studied.[29]



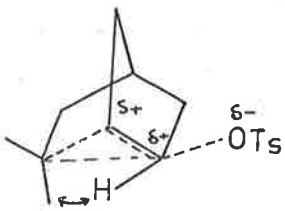
(39)



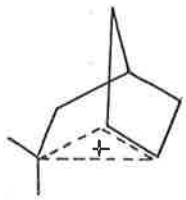
(40)



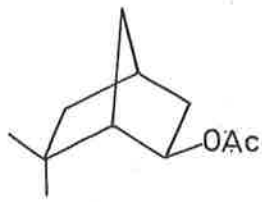
(41)



(42)



(43)



(44)

If the nonclassical ion (43) were formed, the dimethyl group should stabilise any positive charge localised at C_6, and hence increase the contribution of structure (41) to the resonance hybrid (43). This should be reflected in an increased rate of solvolysis of (39, R=CH_3) over (39, R=H). Barring some steric factor, the 6,6-dimethyl group should have little effect on the rates in the endo series (40, R=CH_3 vs. 40, R=H). The relative rates listed in table 3 are clearly contrary to these predictions.

Compound	Relative rate at 25°
(39, R=H)	1.00
(39, R=CH_3)	0.05
(40, R=H)	280
(40, R=CH_3)	11

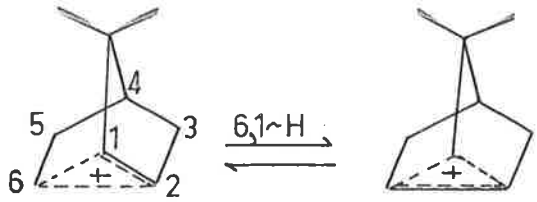
Table 3. Relative acetolysis rates of norbornyl p-toluenesulphonates.

In the exo series the 6,6-dimethyl group produced a 20-fold rate decrease. This was interpreted in terms of a transition state (42) which is strained due to steric interactions of the 6-endo methyl group, and the 2-endo hydrogen atom. In the endo series (40, R=CH_3 vs. 40, R=H) a rate decrease was also observed, and since there cannot be any participation in the ionisation of (40) this decrease was attributed to steric deceleration. In the ionisation of (40, R=CH_3) the transition state must be more crowded than the ground state. The sole product from the acetolysis of both tosylates (39, R=CH_3) and (40, R=CH_3) was the exo acetate (44), and it was concluded that the nonclassical ion (43) was the intermediate, but that (41) made little or no contribution to its structure.

(b) Exo substitution,

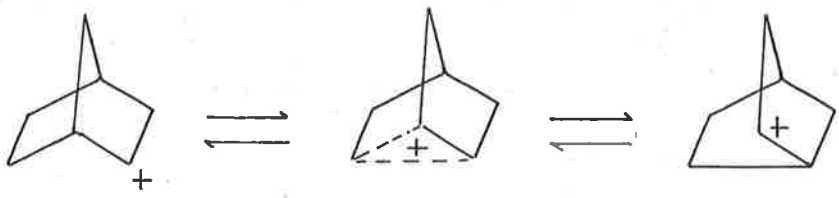
The formation of exclusively exo substituted products in the solvolysis of norbornyl derivatives is the second main basis for the postulation of the nonclassical norbornyl cation. In the norbornyl system, the exo side is the less hindered as judged by the direction of

addition of reagents to suitable model compounds.[7] This led Brown[23] to propose that the formation exo-norbornyl solvolysis products was merely the result of addition of nucleophile from the less hindered side. This argument is not valid however for norbornyl derivatives bearing substituents in the 7-position. Thus the formation of isobornyl chloride (10) from camphene hydrochloride (13) and the formation of exclusively exo substituted products from the apoisobornyl-exo-camphenilyl cation (45)[30] involves nucleophile addition from the more hindered exo side.



(45a) (45b)

Brown has proposed the pair of equilibrating cations (46a) and (46c) as an alternative to the bridged norbornyl cation.[23,28e] The rapid movement of the ethylene bridge between C_1 and C_2 was said to prevent accumulation of solvent on the endo side and thereby favour exo substitution. This proposal has in turn been questioned by Winstein,[31] who claims that the rate of such equilibration would have to be greater than $\frac{kT}{h}$ in absolute rate theory to explain the almost 100% racemic character of the exo- norbornyl acetate obtained from exo-norbornyl p-bromobenzenesulphonate.



(46a) (46b) (46c)

It can be seen that Brown's equilibrating classical cation scheme (46a⇌46c) must involve a transition state (46b) in which C_6 is partially bonded to C_1 and C_2.[32] The energy profile for this scheme is shown in figure 1. The transition state (46b) is an energy maximum, although the activation energy for the equilibration is assumed to be very low.

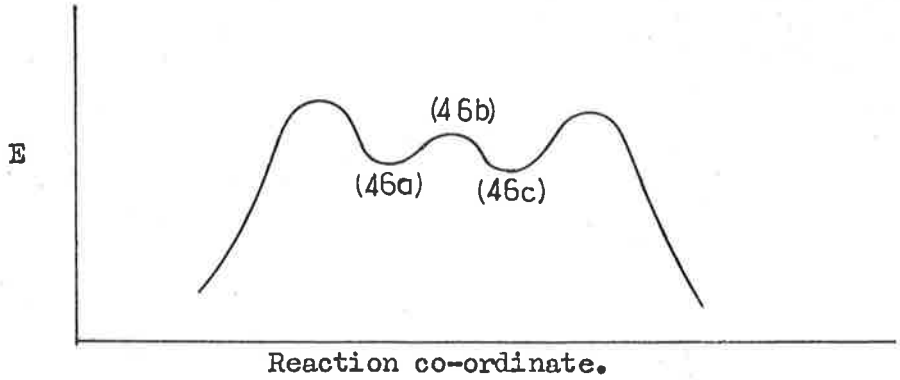
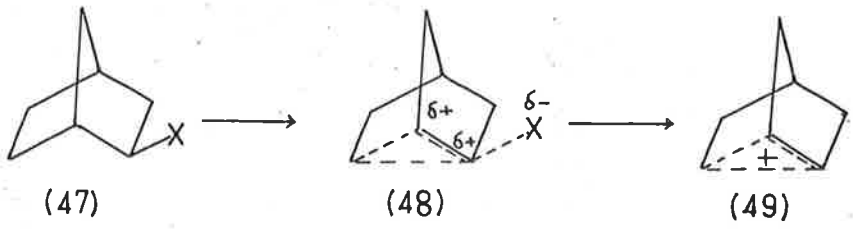


Figure 1. Energy profile for equilibrating classical norbornyl cations.

Winstein's mechanism involves participation as the group X is leaving (47), and the symmetrical bridged ion (49) is an entity of minimum energy along the reaction co-ordinate (figure 2).



(47) (48) (49)

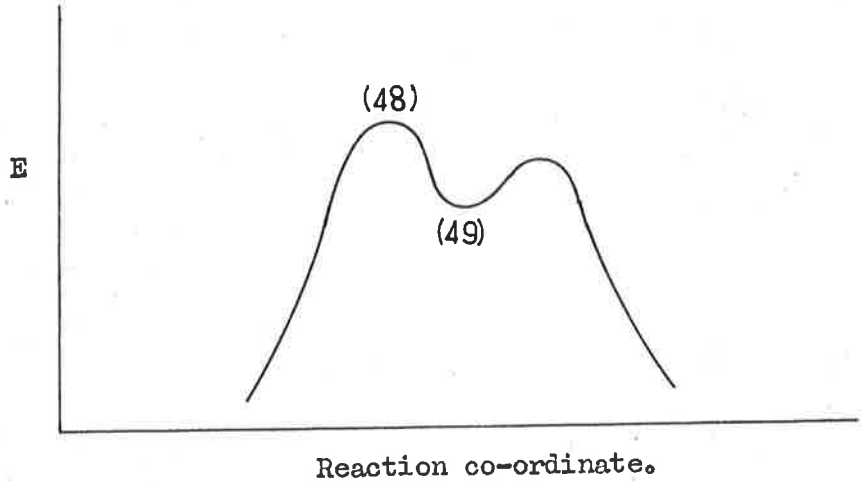
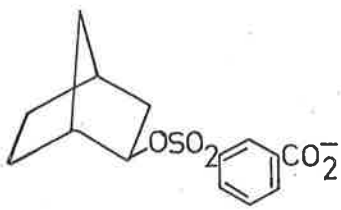


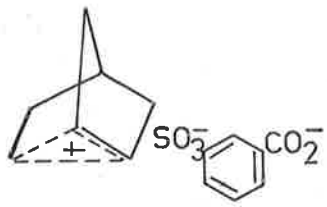
Figure 2. Energy profile for the formation of the bridged norbornyl cation.

It is clearly difficult to differentiate experimentally between the two mechanisms. In such an attempt, Corey and co-workers[33] found that the solvolysis of the optically active exo-norbornyl m-carboxybenzenesulphonate (50) yielded inactive ester (52). Since little movement by the aromatic ring is required in the formation of (52), it was concluded that the intermediate was either a bridged symmetrical cation or a pair of interconverting classical cations in which the interconversion rate was so rapid that for chemical purposes the ion could be taken as symmetrical. Similar results were obtained in the

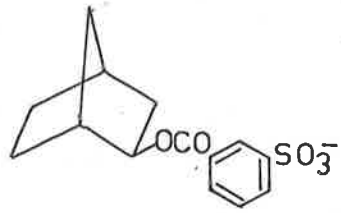
the acetolysis of optically active (53).[34] The spectrophotometric and polarimetric rates of acetolysis of (53) were found to be equal and the ester (55) isolated as a product from the reaction was found to be completely racemic. The anion in (54) requires even less reorientation for internal ion return to sulphur than the anion in (51) and provides further evidence for a symmetrical cation structure.



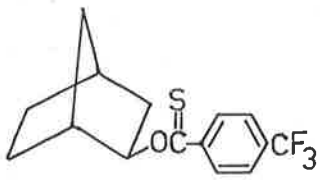
(50)



(51)



(52)



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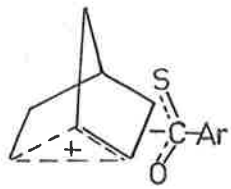

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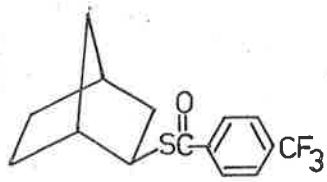
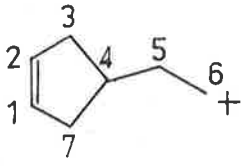


(55)

Molecular orbital calculations using an extended Hückel theory have been made for the norbornyl cation derived by closure of the open chain ion (56).[35] The geometry of the most stable form is shown in (57). Any variation from the symmetrical (i.e. nonclassical) structure led to an increase in the energy of the system. From this the argument of Brown that the bridged structure is a transition state (i.e. energy maximum) between two equilibrating classical cations appears to be ruled out. It must be noted however, that these calculations are for the

gas phase and therefore neglect solvation effects.



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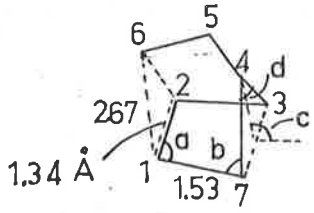


(57)

a=110.75°
b=99.4°
c=40°
d=103.8°

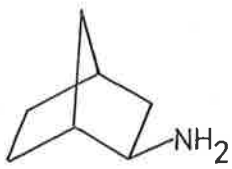
II. Some nonsolvolytic routes to carbonium ions.

1. Deamination of the norbornylamines and bornylamines.

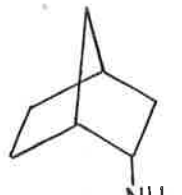
The nitrous acid deamination of an aliphatic amine, which involves departure of molecular nitrogen from the diazonium ion RN_2^+ is formally similar to the solvolysis of a halide or sulphonate, which involves departure of the halide or sulphonate ion X^-. The two processes differ in that in deamination the leaving group N_2 is uncharged and therefore charge-charge interactions in the transition state for its departure are small, and molecular nitrogen is a very stable entity and the driving force for its formation is high.

In a discussion of the structure of the norbornyl cation, it is informative to consider the products of the deamination of exo-norbornylamine (58) and endo-norbornylamine (59). In glacial acetic acid the product from optically active (58) and (59) was mainly exo-norbornyl acetate.[36,37] The composition of the acetate fractions and the calculated optical purities of the components are shown in table 4. It can be seen that there was some retention of optical activity in the deamination product, particularly in the case of the endo-acetate.

This was in contrast to the acetolysis of exo-norbornyl p-bromobenzene-sulphonate in which the sole product was completely racemic exo-acetate.



(58)



(59)

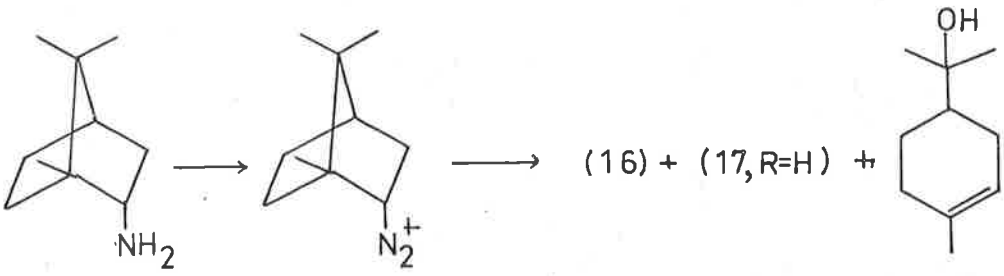
	From exo amine		From endo amine	
	Yield	Optical purity %	Yield	Optical purity %
endo acetate	2	100	47	85 ± 12
exo acetate	98	11 ± 2	95.3	18 ± 0.6

Table 4. Norbornyl acetates from the deamination of exo - and endo-norbornylamine.[37]

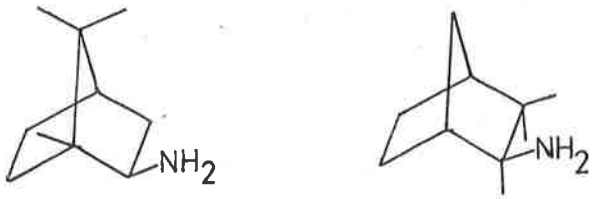
The deamination is believed to involve a "hot" carbonium ion, which is formed by departure of N_2 from the diazonium ion without 1,6-bond participation.[36] This ion requires less activation energy for reaction with an external nucleophile than the normal ion generated solvolytically, and thus reacts partly to give optically active exo and endo substitution product before rearranging to a symmetrical structure.

The nitrous acid deamination of bornylamine (60) in aqueous solution is interesting in that α-terpineol (62) was formed as well as the expected carbonium ion products camphene (16) and camphene

hydrate (17, R=H).[38] Since ∝-terpineol was not formed in the solvolysis of bornyl chloride[15] it was presumably formed directly from the diazonium ion (61) or from the highly reactive carbonium ion derived from (61). The deamination of isobornylamine (63)[38,39] and the tertiary amine (64)[40] yielded only camphene and camphene hydrate.



(60) (61) (62)

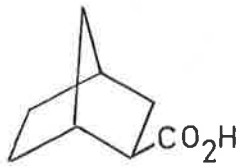


(63) (64)

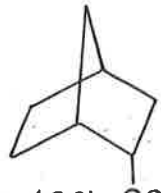
2. Oxidative decarboxylation of the norbornyl carboxylic acids.

Corey and Casanova[41] found that both exo- and endo-norbornane-2-carboxylic acids, (65) and (66), underwent conversion to predominantly exo-norbornyl acetate upon treatment with lead tetraacetate and pyridine in a suitable solvent. The acetate from the exo acid was essentially the pure exo isomer, while that from the endo acid contained ca.3% endo acetate. The exo acetate from both (65) and (66) was found to be formed with 43% net retention of optical activity with benzene as the solvent, and with 33% net retention of optical activity with the more

polar acetonitrile as the solvent.



(65)



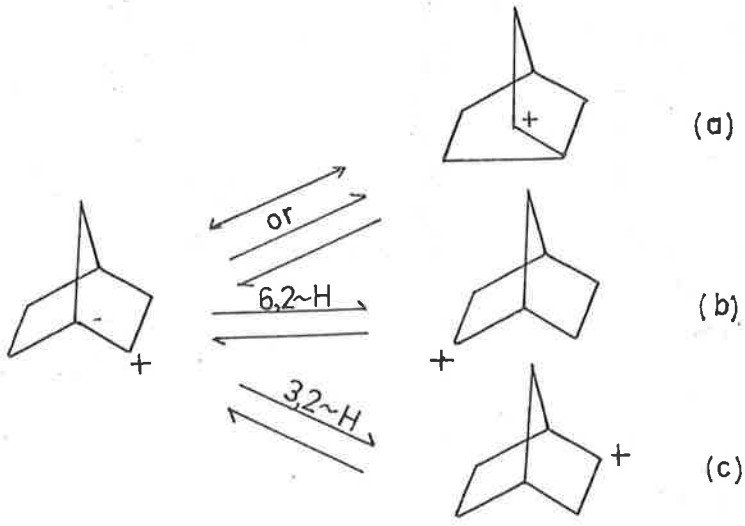
(66)

Although a decision between an initial heterolytic or homolytic decarboxylation step could not be made, it was concluded that the acetate was derived from a carbonium ion intermediate. Because of the observed partial retention of optical activity, the initially formed ion must be largely unsymmetrical (i.e. classical) in structure. The retention of optical activity was greater than that observed for the exo acetate from deamination. This was presumably due to the cation from decarboxylation being paired with an anion in a solvent which is less polar than acetic acid, the medium for deamination. Consequently one would expect a shorter lifetime, and hence less rearrangement, for the ion from decarboxylation.

3. Miscellaneous.

In the work outlined so far, carbonium ions have been transient intermediates, postulated to explain the results of kinetic and product studies. In recent years it has been possible to observe certain carbonium ions directly by nuclear magnetic resonance spectroscopy.[42] The 2-norbornyl cation has been generated as the SbF_6^- salt by dissolving 2-exo-norbornyl chloride or fluoride in SbF_5 or SbF_5— liquid

SO_2.[43] The observed n.m.r. spectrum was temperature variable, and was interpreted in terms of the rearrangements outlined below.



The low temperature spectrum was consistent with the assumption that (a) and (b) were proceeding rapidly, and (c) slowly. At higher temperatures, all rearrangements were assumed to occur rapidly to render all the protons in the ion equivalent.

Caution must be exercised before applying the conclusions reached from such direct observations to carbonium ions postulated as intermediates in solvolytic and related reactions. Thus the statement by Deno[42] that direct observation of the norbornyl cation "should render obsolete the past voluminous work" has been criticised by Winstein[30b] since the solvation and reaction possibilities in the typical solvolysing solvents are quite different to those in the nonsolvolysing solvents.

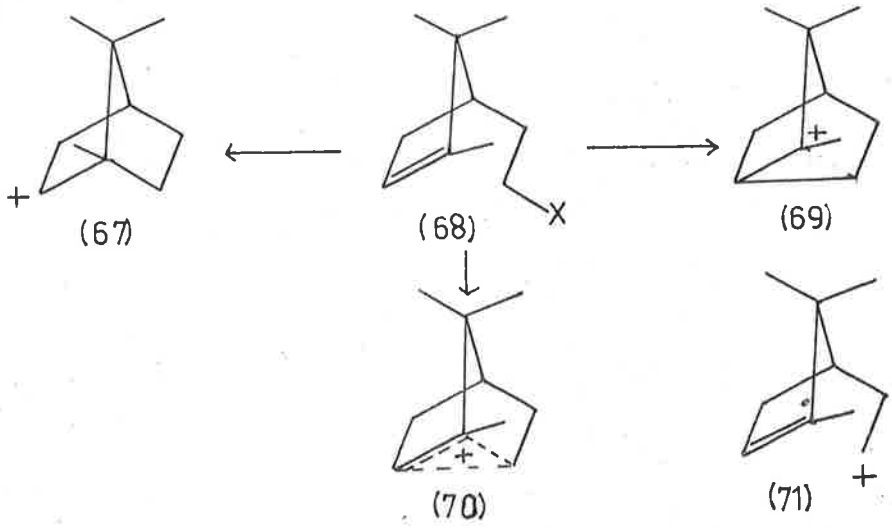
RESULTS AND DISCUSSION

I. SOLVOLYTIC ROUTES TO THE ISOBORNYL-CAMPHENEHYDRO CATION.

1. The π-route to the isobornyl-camphenehydro cation.

(a) General.

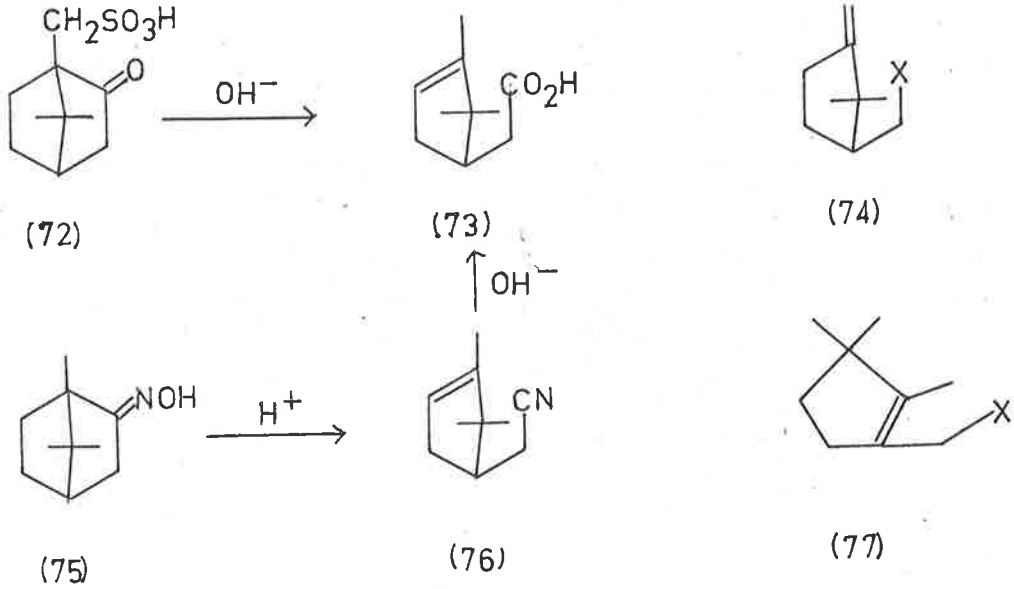
Ring closure to the isobornyl-camphenehydro cation is in principle possible if double bond participation occurs in the ionisation of a suitable derivative of α-campholenol, β-(2,2,3-trimethylcyclopent-3-enyl) ethanol (68, X=OH). Scheme 2 summarises the ways in which ring closure is theoretically possible. If the double participates directly in the ionisation step, the classical ions (67) and (69) can arise, but the formation of the latter would be expected to be favoured because it is tertiary. Alternatively, ionisation to the bridged ion (70) could occur directly. A third possibility is that unassisted ionisation to the monocyclic cation (71) can occur, and that subsequent participation by the double bond can then lead to ring closure via ions (67), (69) or (70). To test this hypothesis, the solvolyses of a number of derivatives of α-campholenol were studied.



Scheme 2.

(b) Preparation of ∝-campholenyl derivatives.

(+)-∝-Campholenic acid (73) was prepared by the alkaline fusion of (+)-camphor-10-sulphonic acid (72),[44] and by the hydrolysis of ∝-campholenonitrile (76) which was obtained by heating (+)-camphor oxime (75) with dilute sulphuric acid.[45]



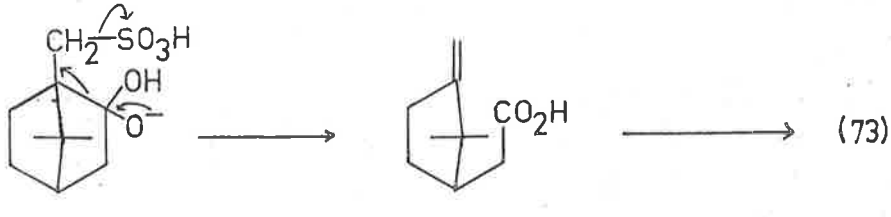
(72) (73) (74)

(75) (76) (77)

Because of the known tendency of ∝-campholenyl derivatives to rearrange to β-campholenyl derivatives (77) in the presence of strong acid,[46] the purity of the ∝-campholenic acid obtained from camphor oxime was regarded as doubtful. Vapour phase chromatography of the methyl ester of the acid prepared in this way showed the presence of 20% of the methyl ester of β-campholenic acid (77, X=CO_2CH_3), while the methyl ester of ∝-campholenic acid obtained from camphor-10-sulphonic acid was homogeneous. The nitrile (76) was also shown by v.p.c. to contain an impurity (20%), which presumably was β-campholе-

nonitrile (77, X=CN).

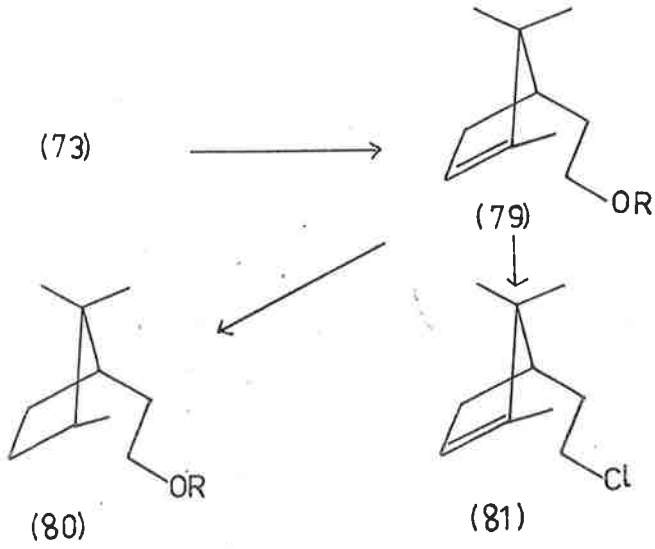
It was thought of interest to examine the dehydration of camphor oxime under nonacidic conditions, which should prevent the formation of the β-nitrile (77, X=CN). When camphor oxime was treated with one equivalent of p-toluenesulphonyl chloride in pyridine at 0°, the product (77%) was shown by v.p.c. to consist of the desired α-nitrile (76, 55%) and a second component (45%), while the β-nitrile was not present. The second component appeared to be the nitrile (74, X=CN), since the infrared and nuclear magnetic resonance spectra of the mixture (see Experimental) revealed the present of a $\geq C=CH_2$ group as well as the $\geq C=CH-$ system of α-campholenonitrile. The formation of this nitrile mixture is probably the result of kinetic control, rather than thermodynamic control, which operates under acidic conditions to give only the isomer (76) with the endocylic double bond. It may be noted that the reaction of lead tetraacetate with isoborneol yielded α-campholenaldehyde (68, CH_2X=CHO) and the isomeric aldehyde (64, X=CHO) with the endocylic double bond.[47] The formation of α-campholenic acid (73) from camphor-10-sulphonic acid also apparently involves the initial formation of the acid with the exocyclic double bond (78), which then rearranges under the reaction conditions (Scheme 3).[44a]



(78)

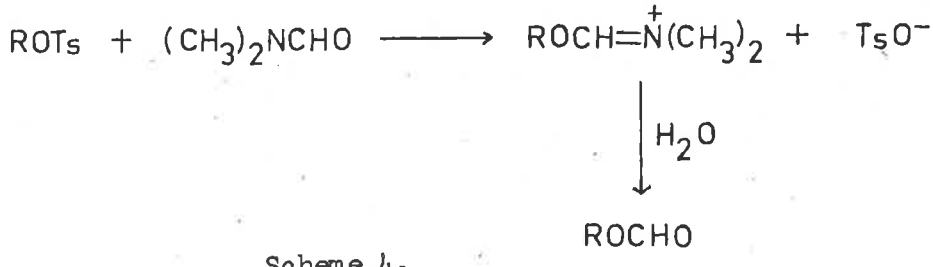
Scheme 3.

Because ∝-campholenic acid prepared from the nitrile was not homogeneous, only the acid obtained from camphor-10-sulphonic acid was used in the present study. Reduction of methyl ∝-campholenate with lithium aluminium hydride gave (+)-∝-campholenol (79, R=H), which was converted to the crystalline p-nitrobenzenesulphonate (79, R=p-nitrobenzenesulphonyl). Hydrogenation of ∝-campholenol gave the saturated alcohol (80, R=H) from which was obtained the corresponding p-nitrobenzenesulphonate (80, R=p-nitrobenzenesulphonyl).



∝-Campholenyl chloride (81) could be prepared only in low yield from ∝-campholenol by the conventional thionyl chloride-pyridine method since extensive tar formation occurred during the reaction. The chloride (81) was conveniently prepared by treating ∝-campholenyl p-nitrobenzenesulphonate with an excess of pyridine hydrochloride in dimethylformamide.[48] An attempt was also made to prepare the chloride by a

one step reaction by treating a solution of ∝-campholenol and pyridine in dimethylformamide with one equivalent of p-toluenesulphonyl chloride. The chloride (31) was formed in low yield, but the main product in this reaction was ∝-campholenyl formate (79, R=CHO), which was presumably formed by a displacement reaction in which dimethylformamide competed as a nucleophile with chloride ion (Scheme 4, R= ∝-campholenyl). The formation of formates from alkyl halides and sulphonates in dimethylformamide has been observed previously.[49]



Scheme 4.

(c) Solvolytic studies.

The products of the solvolysis of (+)- ∝-campholenyl p-nitrobenzenesulphonate in acetic acid containing an excess of sodium acetate are listed in table 5. The products were identified by comparing their vapour phase chromatographic retention times with those of authentic samples and by a comparison of infrared spectra where the components were formed in amounts sufficient to be isolated by column chromatography. It can be seen that most of the product is ring closed material derived from the isobornyl-camphenehydro cation (70) or its classical counterparts (67) and (69). The camphene obtained in this reaction had

$[\alpha]_D$-98 (lit.[50] $[\alpha]_D$-117.5°).

Tricyclene	2%
Camphene	73
Isobornyl acetate	14
-Campholenyl acetate	8
Unknown	3

Table 5. Products from the acetolysis of α-campholenyl p-nitrobenzenesulphonate in the presence of an excess of sodium acetate (100°, 5 hr).

The major product of the solvolysis of α-campholenyl p-nitrobenzenesulphonate in aqueous acetone containing calcium carbonate was camphene hydrate. Less than 10% of the total product consisted of a mixture of isoborneol, α-campholenol, and an unknown component (Table 6). This component was isolated in small amount as a ca. 1:1 mixture with α-campholenol, and the infrared spectrum of this mixture was identical with α-campholenol except for a band at 880 cm^{-1} ($C=CH_2$). The other component has therefore been tentatively assigned structure (74, $X=CH_2OH$). The mode of formation of this compound is not clear. It is possible that the α-campholenol used to prepare the p-nitrobenzenesulphonate contained a small amount of the isomeric alcohol (74, $X=CH_2OH$) which could not be detected by v.p.c. because of "tailing" by the peak due to α-campholenol, but it is felt that such impurity could not have amounted to more than 4-5% and should have been removed upon recrystallisation of the sulphonate. A second possibility is that both the α-

campholenol and the isomeric alcohol (74, K=CH_2OH) arose from the solvolysis of an intermediate formed by internal return (see p.37).

Camphene hydrate	91%
Isoborneol	3
∝-Campholenol	4
Unknown	2

Table 6. Products from the solvolysis of ∝-campholenyl p-nitrobenzenesulphonate in aqueous acetone containing an excess of calcium carbonate.

The rate of acetolysis of ∝-campholenyl p-nitrobenzenesulphonate was determined at several temperatures, and the results are summarised in Table 7.

T	Conc., M	NaOAc ,M	$k_1 \times 10^5$, sec^{-1}
30.0	0.0246	0.0473	1.61
40.7	0.0288	0.0473	5.94
40.7	0.0199	0.0473	6.02
40.7	0.0210	none	5.89
49.6	0.0238	0.0473	13.5
60.0	0.0265	0.0473	40.8
100.0			1260 (extrapolated).

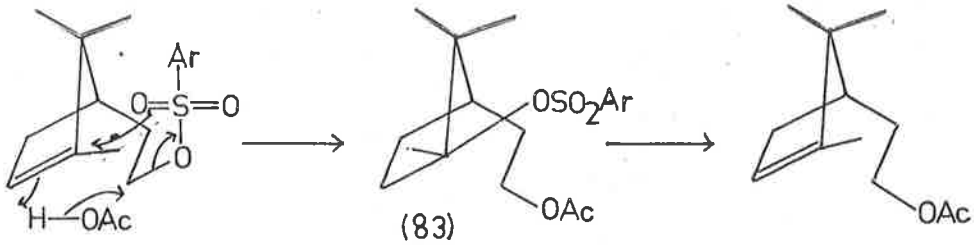
Table 7. Acetolysis rates of ∝-campholenyl p-nitrobenzenesulphonate. Solutions which were 0.0473M in sodium acetate were also 0.0473M in water.

Good first order kinetics were observed for ca. 85% of the reaction, but deviations were observed in those cases where the reaction was followed beyond this point. A comparison of the acetolysis rates listed in Table 7 with those of the saturated compound (80, R=p-nitrobenzenesulphonyl) (Table 8) reveals that the double bond provided a considerable amount of anchimeric assistance in the ionisation of the unsaturated sulphonate. Thus at 60° the ratio $\frac{k \text{ unsaturated}}{k \text{ saturated}}$ is 203, while at 100° the ratio is 153. The ionisation of ∝-campholenyl p-nitrobenzenesulphonate therefore proceeded by a concerted process which led to the bridged isobornyl-camphenehydro cation (70) or its classical counterparts (67) and (69), and the monocyclic cation (71) need not be considered on the basis of the kinetic evidence. The ∝-campholenyl acetate (79, R=$COCH_3$) formed in the acetolysis of the sulphonate thus was not derived from a reaction which involved the primary carbonium ion (71), or which involved S_N2 displacement of the p-nitrobenzenesulphonate anion by acetate ion in ∝-campholenyl p-nitrobenzenesulphonate.

T	Conc.,M	NaOAc ,M	$k_1 \times 10^5$, sec^{-1}
60.0	0.0224	0.0446	0.201
100	0.0200	0.0446	8.34
100	0.0231	0.0482	8.25

Table 8. Acetolysis rates of dihydro- ∝-campholenyl p-nitrobenzenesulphonate. Solutions were 0.0446 and 0.0482M in water as well as sodium acetate.

It is therefore tentatively proposed that the ∝-campholenyl acetate may have been derived by the reaction outlined (Scheme 5) competing with the intramolecular nucleophilic displacement of the p-nitrobenzene-sulphonate anion by the double bond. In (82) the electron shifts are intended to show intervention by acetic acid from the solvent shell in an internal return mechanism to yield the tertiary sulphonate (83), or its equivalent ion pair, which could then give rise to the unsaturated acetate. Analogous internal return mechanisms involving ring closure

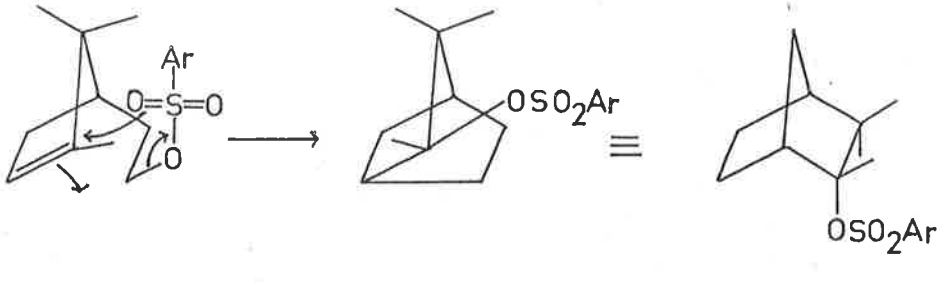


(82) (83)

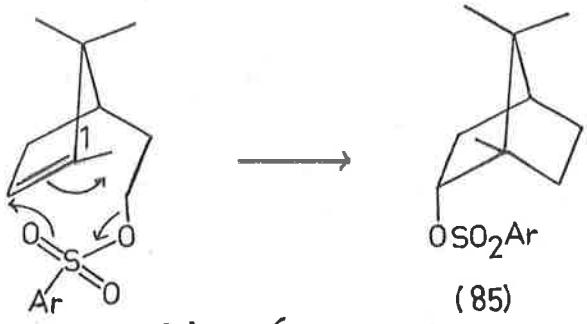
Scheme 5.

are shown in Scheme 6. Of these possible mechanisms, internal return to bornyl p-nitrobenzenesulphonate (85) is less likely since the transition state would require polarisation of the double bond in the direction opposite to that favoured by the methyl group at C_1. It may be noted that the formation of (86) and (87) by an intramolecular nitrone - olefin addition[51] is similar to the rearrangements postulated in Scheme 6.

Barlett and his co-workers[22a] concluded that internal return did not occur in the acetolysis of 2-(cyclopent-3-enyl)ethyl p-nitro-benzenesulphonate, and there is no definite evidence that the internal return mechanisms outlined in Schemes 5 and 6 operated in the solvolysis of ∝-campholenyl p-nitrobenzenesulphonate in the present work. It

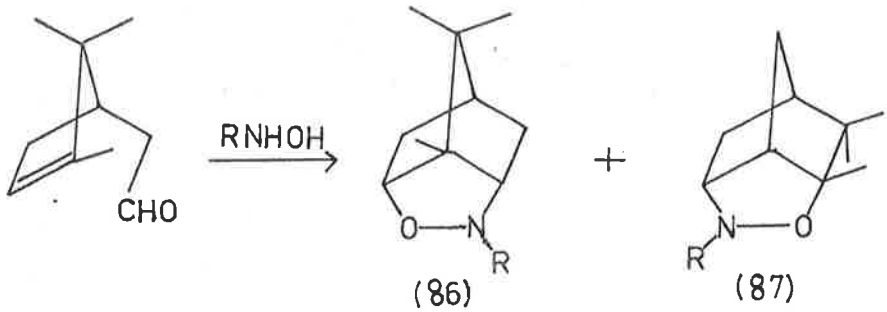


(84)



(85)

Scheme 6.



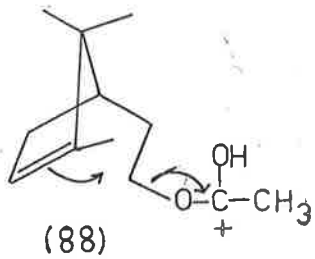
(86) (87)

may be noted however that the apparent formation of the alcohol (74, X=CH_2OH) together with ∝-campholenol from ∝-campholenyl p-nitrobenzenesulphonate in aqueous acetone could be explained in terms of the intermediate (83, Ac=H). Further work is required to settle this point. Thus a comparison of polarimetric and titrimetric solvolysis rates would be useful.

The acetolysis rate of ∝-campholenyl p-nitrobenzenesulphonate was 3.7 times that reported for the unsubstituted 2-(cyclopent-3-

enyl)ethyl p-nitrobenzenesulphonate[19] (27, R=p-nitrobenzenesulphonyl) at 60°. This increase undoubtedly was due to the electron donating methyl group at C_1 of ∝-campholenyl p-nitrobenzenesulphonate, which stabilised the positive charge in the transition state leading to the bridged isobornyl-camphenehydro cation (70). The bridged ion is a better representation of the intermediate than the classical ions (67) and (69) since no endo substitution was observed in the solvolysis of ∝-campholenyl p-nitrobenzenesulphonate. Furthermore Bartlett and co-workers have concluded that the ionisation of 2-(cyclopent-3-enyl) ethyl sulphonates proceeds by a symmetrical transition state to a symmetrical ion since the first and second methyl substituents in the sulphonates (28) and (29) have nearly identical accelerating effects (see p. 13).

It is significant to note that the acetolysis product of ∝-campholenyl chloride (81) did not contain ∝-campholenyl acetate (Table 9). Although kinetic evidence for participation by the double bond was not obtained, the exclusive formation of cyclised material in the acetolysis indicated that participation had occurred. The possibility that ∝-campholenyl acetate was initially formed and that it then cyclised, e.g. via (88), was eliminated since the unsaturated acetate was found to be stable under the reaction conditions. The absence of the acetate from the acetolysis product of the chloride may mean that an internal return mechanism such as that postulated for the solvolysis of ∝-campholenyl p-nitrobenzenesulphonate does not operate when chloride ion is the leaving group.



(88)

Tricyclene	4%
Camphene	29
Isobornyl Acetate	65
Unknown	2

Table 9. Products from the acetolysis (100°, 115 hr) of ∝-campholenyl chloride in the presence of sodium acetate.

The high proportion of isobornyl acetate in the acetolysis product of ∝-campholenyl chloride was due to a secondary reaction. Camphene was found to be slowly converted to isobornyl acetate when heated in acetic acid containing sodium acetate (Table 10).

Time (hr)	Tricyclene (%)	Camphene (%)	Isob. Acetate (%)	Unknown (%)
6	3	88	7	2
10	4	81	12	3
25	5	65	27	3
50	6	53	39	2
98	7	38	53	2

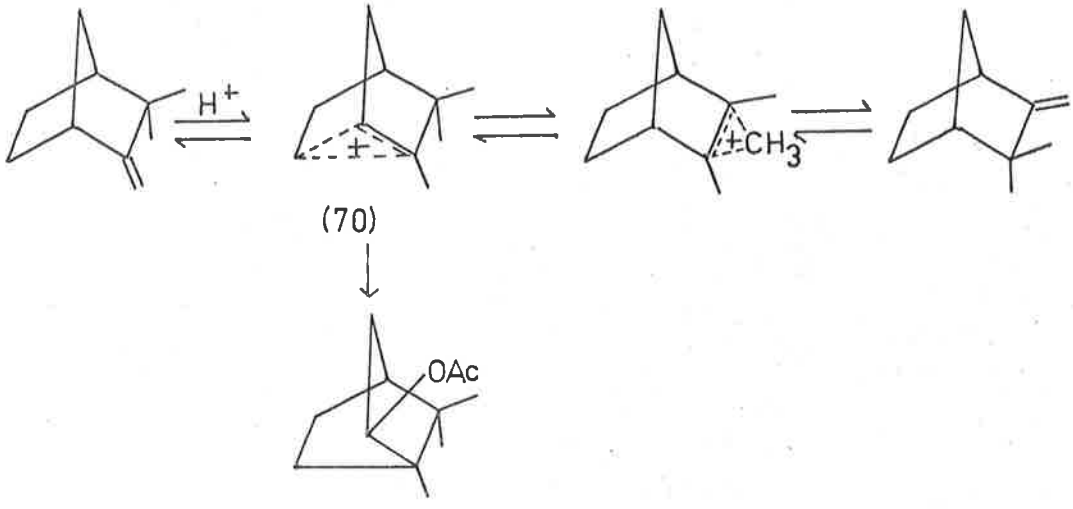
Table 10. Products from the reaction of camphene with acetic acid and sodium acetate at 100°.

Acetic acid appears to be a sufficiently strong acid to protonate camphene and the resulting carbonium ion can then be irreversibly removed as isobornyl acetate by reaction with acetate ion. The isobornyl acetate formed in this manner was found to be free from the epimeric bornyl acetate. The exclusive formation of exo substituted product in this reaction provides strong evidence that the bridged ion (70) is the intermediate. If the classical 2-bornyl cation (15) were the intermediate in the rearrangement, bornyl acetate would be expected to be the major product, since its formation would involve nucleophilic attack from the less hindered endo side.

This reaction is similar to the Bertram-Walbaum reaction[52] in which camphene is treated with a catalytic quantity of strong acid in a suitable solvent and an isobornyl derivative is the product. The homogeneity of the isobornyl derivatives produced in this way has never been clearly demonstrated, largely due to the lack of an analytical technique which permitted the detection of relatively small amounts of bornyl derivatives in the presence of the isobornyl derivatives. The development of vapour phase chromatography has overcome this problem in recent years, and there is good reason to suspect that isobornyl derivatives are not exclusively formed in the Bertram-Walbaum reaction. For example, Ermann[53] found that treatment of camphene with boron trifluoride etherate in acetic acid gave a mixture containing isobornyl acetate (52.5%) together with bornyl acetate (15.4%) and other unidentified acetates. It is possible that isobornyl acetate was the kinetically controlled product in this reaction and that it then rearranged to bornyl acetate in the presence of the strong acid. The

formation of isobornyl acetate from camphene in acetic acid in the present work involved no such rearrangement of the initial product.

The acetolysis of (+)-α-campholenyl p-nitrobenzenesulphonate gave camphene of high optical purity (p.33). The camphene isolated from the acetolysis of α-campholenyl chloride had an optical purity of only ca. 4%, while the isobornyl acetate formed in this reaction was ca. 27% optically pure. Extensive racemisation had thus occurred. Camphene is known to be racemised in the presence of acids by a series of carbonium ion reactions involving hydride ion and methyl group shifts.[54] The racemising reaction involving a 1,2-methyl group shift is shown in Scheme 7, and racemisation clearly competed with rearrangement to isobornyl acetate during the acetolysis of α-campholenyl chloride. The degree of racemisation of camphene was greater than that of the isobornyl acetate because the latter compound was continually being formed irreversibly, and was therefore to a greater degree derived from optically active intermediate carbonium ion (70).



Scheme 7.

The solvolysis of ∝-campholenyl p-nitrobenzenesulphonate in acetic acid without added sodium acetate was accompanied by a considerable amount of tar formation, which was apparently caused by the p-nitrobenzenesulphonic acid liberated during the reaction. The composition of the product as determined by capillary vapour phase chromatography is shown in Table 11. The main product was isobornyl acetate and of the minor components only ∝-campholenyl acetate could be identified by a comparison of retention times. The predominant formation of isobornyl acetate was the result of the rearrangement of camphene catalysed by the strong p-nitrobenzenesulphonic acid. The isoborneol obtained from this acetate was found to be optically inactive.

Compound	Retention time	%
1	8 min. 20 sec.	4
2	8 45	6
Isobornyl acetate	9 8	70
3	9 40	5
∝-Campholenyl acetate	10 25	4
5	10 47	11

Table 11. Products of the solvolysis of (+)-∝-campholenyl p-nitrobenzenesulphonate in glacial acetic acid (100°, 5 hr).

The acetolysis of ∝-campholenyl trifluoroacetate (79, R= $COCF_3$) yielded only ∝-campholenyl acetate, presumably by an acyl oxygen fission process (see later).

2. The σ- route to the isobornyl-camphenehydro cation.

It is clear from the work outlined in the introduction that the main evidence for the postulation of the nonclassical norbornyl cation is the high solvolysis rate of exo-norbornyl derivatives, high exo: endo rate ratios, and the formation of exo substituted products. Although the kinetic evidence for the formation of the isobornyl-camphenehydro cation (70) with neighbouring carbon participation was considered to be strong,[11,14] the recent work of H.C. Brown and co-workers[23-25,28] suggests that much of the driving force may be steric rather than electronic in origin. Little work has been reported on the examination of the products derived from the ion (70), and accordingly the solvolyses of a number of trimethylbicyclo[2.2.1]heptyl derivatives which should in principle proceed via the cation (70) were studied in the present work.

It was hoped to compare the solvolysis products of isobornyl and bornyl p-nitrobenzenesulphonates with those of α-campholenyl p-nitrobenzenesulphonate. All attempts to prepare sulphonic acid esters of isoborneol, however, were unsuccessful. When isoborneol was treated with p-toluenesulphonyl, p-nitrobenzenesulphonyl, or methanesulphonyl chloride in pyridine, only camphene and unchanged isoborneol could be isolated. Esterification was very slow, apparently due to the hindered nature of the hydroxyl group of isoborneol, and once formed, the sulphonates underwent rapid elimination to yield camphene.

It was found to be possible to utilise this reaction for the preparation of camphene of very high optical purity. When (-)-isoborneol

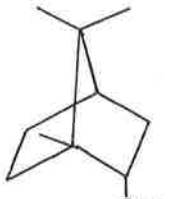
(prepared by the lithium aluminium hydride reduction of (+)-camphor, and containing 10% of (+)-borneol) was treated with p-toluenesulphonyl chloride in pyridine at 100°, camphene showing $[\alpha]_D$ +115 was obtained in 60-70% yield. This rotation appears to be the second to highest recorded for camphene. Bain and co-workers[50] obtained camphene showing $[\alpha]_D$ -117.5 by a synthetic sequence starting with optically pure β-pinene. Assuming that this camphene was optically pure, that obtained in the present work had an optical purity of 98%. Thus the dehydration of isoborneol with p-toluenesulphonyl chloride in pyridine provides a convenient method of preparing camphene which has an optical purity higher than that prepared by the pyrolysis of isobornylphenylurethane,[54] a procedure previously considered to give optically pure camphene ($[\alpha]_D$ + 107).

The preparation of isobornyl p-toluenesulphonate has been reported by Hückel.[55] The remarkable lack of reactivity reported for this compound (it was recovered unchanged after being refluxed in methanol for 3 hours) makes it extremely doubtful that it was the isobornyl derivative. From the data of Bunton and co-workers[15] it is possible to calculate that the half life for the methanolysis of isobornyl chloride at 60° is approximately 25 minutes, and since the solvolysis rates of sulphonates are greater than those of the corresponding chlorides, the reactivity observed by Hückel is not in accord with that expected for isobornyl p-toluenesulphonate. The compound reported by Hückel was presumably bornyl p-toluenesulphonate, formed from borneol present as an impurity in the isoborneol.

The preparation of sulphonic acid esters of borneol was accomplished without difficulty. The composition of the product of the acetolysis of (+)-bornyl p-nitrobenzenesulphonate is given in Table 12. Bornyl acetate was shown to be absent from the product by capillary vapour phase chromatography. These products can thus be considered to be derived from the bridged ion (70). Initial ionisation presumably produces the classical ion (67), since the rate of acetolysis of bornyl p-toluenesulphonate is only 1.4 times that of cyclohexyl p-toluenesulphonate[11] and anchimeric assistance by the 1,6-bond is therefore not involved. The secondary ion (67) must rearrange rapidly to the bridged ion (70) since attack of acetate ion or acetic acid should occur predominantly from the less hindered endo side of (67) and should yield mainly bornyl acetate. The exclusive formation of exo secondary substitution product in the acetolysis of bornyl p-nitrobenzenesulphonate is therefore stronger evidence for a bridged cation intermediate than is the formation of exo-norbornyl acetate in the acetolysis of endo-norbornyl p-bromobenzenesulphonate,[8] since the latter example involves addition of nucleophile from the less hindered exo side of the norbornyl system.

Tricyclene	5%
Camphene	64
Isobornyl acetate	25
Unknown	6

Table 12. Product of the acetolysis of bornyl p-nitrobenzenesulphonate in the presence of sodium acetate (100°, 13 hr).



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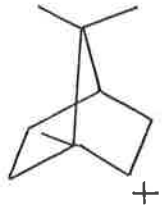

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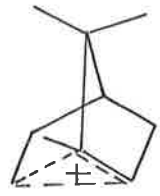


(70)

Cope and co-workers[56] studied the solvolyses of trifluoroacetates of alcohols where the corresponding sulphonates were too reactive to be prepared. In the present work it was found that isobornyl trifluoroacetate could be readily prepared, and the composition of the product of its acetolysis is given in Table 13. With the exception of the unreacted bornyl trifluoroacetate, the products were again those derived from the bridged ion (70). The camphene obtained from this reaction showed $[\alpha]_D$ + 103.

Tricyclene	4%
Camphene	76
Bornyl trifluoroacetate	5
Isobornyl acetate	12
Unknown	3

Table 13. Products from the acetolysis (100°, 5 hr) of (-)-isobornyl trifluoroacetate (containing 4% of bornyl trifluoroacetate) in the presence of sodium acetate.

The acetolysis of bornyl trifluoroacetate was interesting in that it did not proceed through a carbonium ion intermediate. The reaction

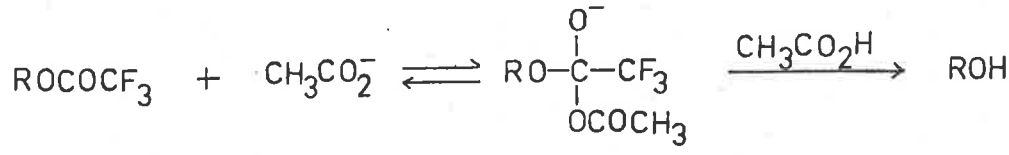
was qualitatively slower than the acetolysis of isobornyl trifluoroacetate, and analysis of the reaction mixture at various intervals indicated that initially considerable quantities of borneol were present in the product (Table 14).

Time (hr)	Bornyl trifluoroacetate (%)	Borneol (%)	Bornyl acetate (%)
6	41	31	28
12	24	19	57
18	9	13	78
26	3	4	93

Table 14. Product of the acetolysis of (+)-bornyl trifluoroacetate in the presence of sodium acetate (100°).

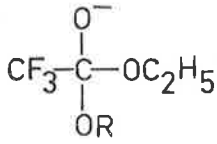
With increasing reaction time, the amount of trifluoroacetate and borneol decreased, and the amount of bornyl acetate increased. The final product was shown to be free from isobornyl acetate since on reduction it gave borneol having an optical rotation identical within experimental error with that of the borneol used to prepare the trifluoroacetate. Bornyl trifluoroacetate, unlike isobornyl trifluoroacetate, thus solvolysed by an acyl oxygen fission mechanism (Scheme 8). Bender[57] has shown that esters of trifluoroacetic acid have a strong tendency to form adducts such as (89). Thus adducts of ethyl trifluoroacetate and alkoxide ions (90) were found to be stable in inert solvents, and on the addition of acetic acid they yielded the alcohol ROH. Kinetic studies have indicated that unactivated trifluoroacetates

solvolyse by an acyl oxygen fission process[58] but that sufficiently reactive tertiary and secondary trifluoroacetates solvolyse by an alkyl oxygen fission mechanism.[59]



(89)

Scheme 8. R=bornyl.

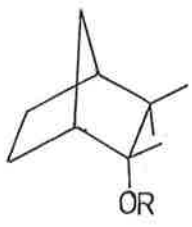


(90)

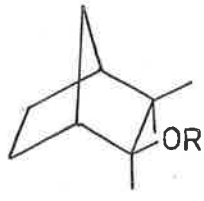
Since the acetolysis of bornyl trifluoroacetate was found qualitatively to be slower than that of isobornyl trifluoroacetate, the former reaction must require a higher activation energy. The activation energy for the hydrolysis of isobornyl acetate is higher than that for the hydrolysis of bornyl acetate, and both esters hydrolyse by an acyl oxygen fission process.[60,61] Thus if isobornyl trifluoroacetate were to solvolyse by an acyl oxygen fission mechanism, this reaction would be expected to be slower than that of bornyl trifluoroacetate. The observed rapid alkyl oxygen fission solvolysis of isobornyl trifluoroacetate may be attributed either to anchimeric assistance by the 1,6-carbon bond, or to relief of steric strain on

ionisation.

The products of the acetolyses of methylcamphenilyl trifluoroacetate (91, R= $COCF_3$) and of the trifluoroacetate of camphene hydrate (92, R= $COCF_3$) (Table 15) are in agreement with those expected from the bridged ion (70), since bornyl acetate was found to be absent.



(91)



(92)

	Methylcamphenilyl trifluoroacetate.	Trifluoroacetate of camphene hydrate.
Tricyclene	5%	4%
Camphene	79	82
Isobornyl acetate	13	12
Unknown	2	2

Table 15. Products of the acetolysis of the tertiary trifluoroacetates (91) and (92) in the presence of sodium acetate (100°, 5 hr).

The tertiary acetates (91, R= $COCH_3$) and (92, R= $COCH_3$) were prepared in good yield by the acetyl chloride - dimethylaniline procedure of Nevitt and Hammond.[62] Methylcamphenilyl acetate was found to be stable in acetic acid containing sodium acetate at 100°, and it could not be detected in the acetolysis product of the trifluoroacetates. Addition of nucleophile from the endo side to the tertiary centre of the

intermediate carbonium ion thus did not occur in these solvolyses. The acetate of camphene hydrate yielded camphene under the conditions of the acetolyses, and it is therefore not possible to say whether or not the tertiary exo acetate is an initial product of the reaction. Solvolysis of isobornyl chloride, bornyl chloride and camphene hydrochloride in methanol and aqueous methanol yielded predominantly the tertiary substitution products (92, R=H or CH_3)[15] because of the highly nucleophilic character of these solvents. In the less nucleophilic acetic acid, proton abstraction to yield camphene would be expected to occur preferentially.

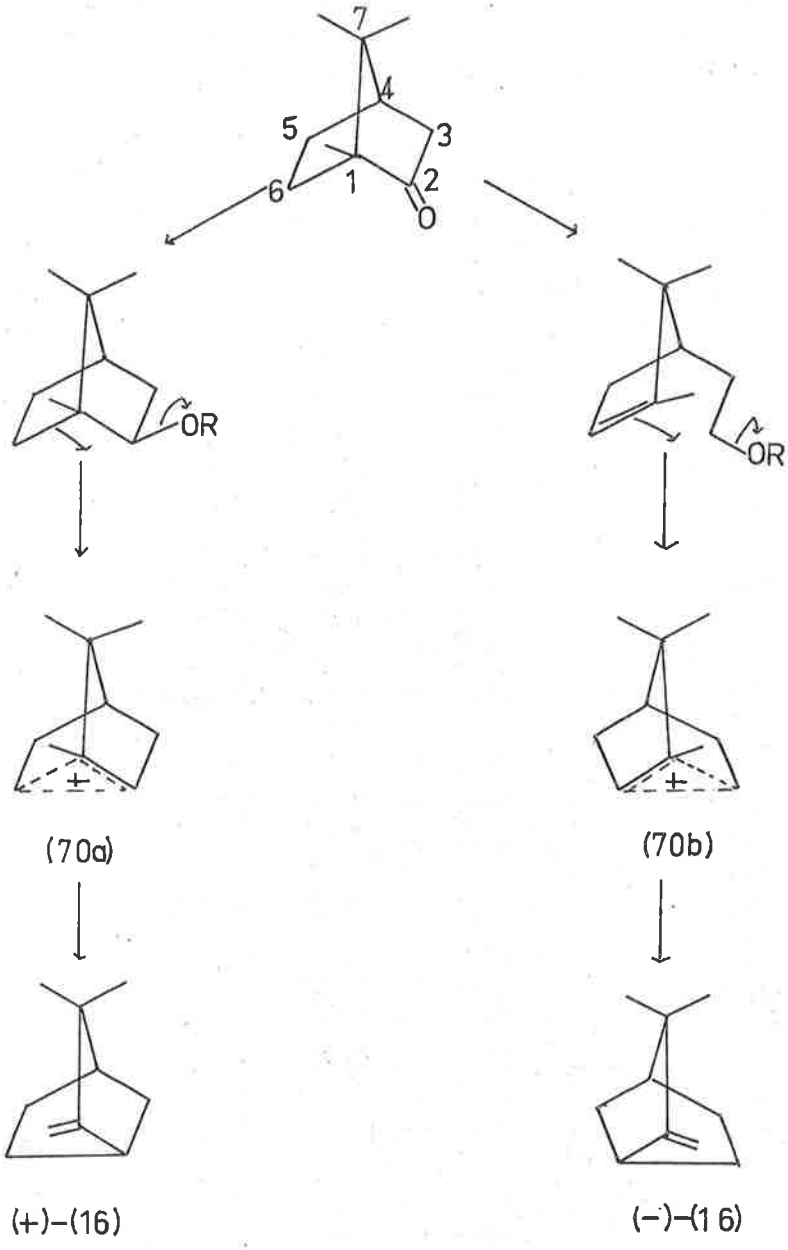
The report by Hückel and Heinzel[16] that methylcamphenilyl methyl ether (91, R=CH_3) is formed in substantial quantities in the methanolysis of camphene hydrochloride and of isobornyl and methylcamphenilyl chlorides (p. 8) prompted an examination of the solvolysis products of isobornyl chloride and methylcamphenilyl trifluoroacetate in aqueous acetone, a solvent in which products derived by nucleophilic addition to the tertiary centre of the intermediate cation would be expected. The composition of these products is shown in Table 16. Unfortunately, vapour chromatographic separations of methylcamphenilol and camphene hydrate could not be achieved. The absence of bands characteristic of methylcamphenilol from the infrared spectra of the solvolysis products indicated however that the alcohol was camphene hydrate, although less than 10% of methylcamphenilol could not have been detected in this way. The reaction products were therefore acetylated with acetyl chloride - dimethylaniline and then analysed by capillary vapour phase chromatography. Under the conditions of the analysis, the acetate of camphene

hydrate underwent pyrolytic decomposition while methylcamphenilyl acetate was stable. No peak due to methylcamphenilyl acetate was observed in the chromatogram of either solvolysis product under conditions where 1-2% could have been detected, and endo substitution therefore did not occur in these reactions.

	Camphene	Camphene hydrate	Isoborneol
Isobornyl chloride	32%	67%	1%
Methylcamphenilyl trifluoroacetate	28	72	<1

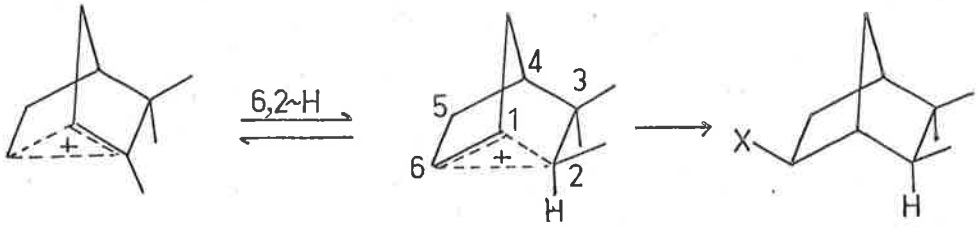
Table 16. Products of the solvolyses of isobornyl chloride and methylcamphenilyl trifluoroacetate in aqueous acetone containing an excess of calcium carbonate.

Of special interest is the fact that the isobornyl-camphenehydro cations generated by the σ- and π-routes of solvolysis are non-superimposable mirror images (Scheme 9). In the cation generated by the σ-route (70a), the 1,6- bonding electrons are delocalised between C_1 and C_2. In the formation of α-campholenol, the C_1-C_2 bond initially present in camphor is broken, and in the cation generated by the π-route (70b), the 1,2-bonding electrons are therefore delocalised between C_1 and C_6. Because of the symmetry properties of the bornane system, (70a) and (70b) and non-superimposable mirror images, and thus it was possible to obtain both (+)-camphene and (-)-camphene of high optical purity from (+)-camphor by the two routes.



Scheme 9.

The formation of a small amount (3-6%) of unidentified material with a retention time greater than that of isobornyl and ∝-campholenyl acetate was observed in all the acetolyses described in this section. As this material was also formed by the action of acetic acid and sodium acetate on camphene (table 10), it was hoped that it would be possible to isolate it from this source. V.p.c. examination of the high boiling fraction of the product obtained by refluxing camphene with acetic acid for 117 hr however revealed only trace amounts of the unknown material, and it was therefore not deemed worthwhile to attempt the isolation from this product. The unknown compound is probably 6-exo-acetoxy-exo-isocamphane (94) derived from the carbonium ion (93), which in turn is derived from the isobornyl-camphenehydro cation (70) by a 6,2-hydride shift. The acetate (94, x = $OCOCH_3$) has recently



(70) (93) (94)

been isolated from the higher boiling fraction of commercial isobornyl acetate, and its structure has been determined unequivocally.[63] An attempt by Erman[53] to prepare this acetate by treating camphene with boron trifluoride etherate in acetic acid at 100° was unsuccessful,

and isobornyl and bornyl acetates were the main products (p.40). The boron trifluoride catalysed reaction of camphene with phenol at 100° however yielded o- and p-6-exo-hydroxyphenyl-exo-isocamphane (94, x = o- and p- C_6H_4OH) as the main products.[53] These results were explained by visualising a rapid equilibrium between ions (70) and (93). The formation of the 6-substituted isomers in the phenol reaction was considered to be due to increased alkylation at the C_6 site of (93) as a result of retarded alkylation (for steric reasons) at the C_1 and C_2 positions of (70), and the stability of the 6-substituted products under the reaction conditions. In the acetic acid reaction, the acetate (94, x = $OCOCH_3$) was considered to be unstable and was considered to be rapidly converted to stable products derived from the ion (70). Such an argument can also be used to explain the absence of significant quantities of the acetate (94, x = $OCOCH_3$) from the product obtained by refluxing camphene with acetic acid-sodium acetate in the present work. These reaction conditions were somewhat more vigorous than those under which a small amount of the acetate was formed (table 10), and further work is required to determine conditions under which an optimum yield of (94, x = $OCOCH_3$) is obtained.

The acetolyses described here which proceeded via the isobornyl-camphenehydro cation all gave rise to predominantly tertiary elimination product (camphene). Much of the secondary substitution product (isobornyl acetate) appears to result from the subsequent reaction of camphene with acetic acid (table 10). It is not possible to estimate exactly how much isobornyl acetate is initially formed by attack of

nucleophile at C_1 of the bridged ion (70) without a knowledge of the solvolysis rate of the substrate and the rate of acid catalysed rearrangement of camphene. The amount of secondary substitution product formed under alkaline or neutral conditions in more nucleophilic solvents (aqueous acetone in the present work, and methanol and aqueous methanol in other studies[15,16]) is very low (2% or less) as camphene is stable under these conditions. In the rearrangement of camphene hydrochloride to isobornyl chloride in nitrobenzene, isotopic dilution experiments have indicated that the carbonium ion intermediate is initially partitioned to give camphene hydrochloride and isobornyl chloride in the ratio of ca. 40:1,[79] and similar partitioning apparently operates during nucleophilic capture of the carbonium ion in solvolytic reactions.

From the recent work of H.C. Brown and co-workers, the kinetic evidence for the formation of the isobornyl-camphenehydro cation must be regarded as doubtful because of the unknown magnitude of the steric factors which contribute to the reactivities of the substrates. The formation of exclusively exo substituted products in the solvolyses, however, are most simply explained on the basis of the bridged carbonium ion intermediate, or at least by a bridged transition state for carbonium ion capture. The only authenticated example* of significant

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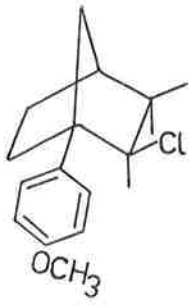
* The reported formation of methylcamphenilyl methyl ether in the methanolyses of camphene hydrochloride, isobornyl chloride and methylcamphenilyl chloride has already been mentioned (p.9). These results are in contradiction with existing concepts of carbonium ion theory and their independent verification is desirable. Further discussion of this matter cannot be made until the full experimental details are available.

(> 1%) endo substitution in a norbornyl or substituted norbornyl



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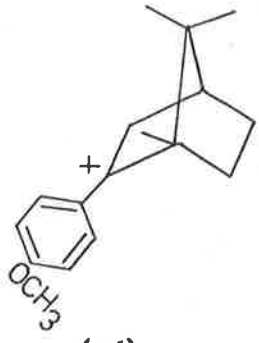

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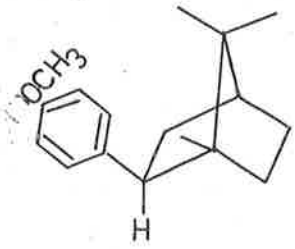


(97)

cation under kinetically controlled conditions is the formation of 10% of p-isobornylanisole (97) in the solvolysis of 1-(p-anisyl)camphene hydrochloride (95) in the presence of borohydride.[28d] The stabilised carbonium ion (96) here has presumably the classical structure.

***

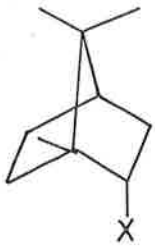
II. The oxidative decarboxylation of 2-exo- and 2-endo-carboxybornane with lead tetraacetate.

1. General.

The oxidative decarboxylation of exo- and endo-norbornane-2-carboxylic acid with lead tetraacetate is believed to proceed via an unsymmetrical 2-norbornyl cation, as the major product, exo-norbornyl acetate, is formed with partial retention of optical activity, and some endo-norbornyl acetate is also formed (p.25).[41] It was therefore thought of interest to study the oxidative decarboxylation of 2-exo- and 2-endo-carboxybornane, (105) and (107), with lead tetraacetate since the reaction possibilities are more varied in the bornane than in the norbornane system.

2. Preparation of the acids.

The preparation of optically pure 2-exo- and 2-endo-carboxybornane has been described by de Botton.[80] He found that carbonation of the Grignard reagent of optically pure bornyl chloride gave an acidic product containing ca. 96% of the endo acid, and ca. 4% of the exo acid, and he was able to separate the acids by a long procedure which involved the fractional precipitation of their bornylamine salts. Although the carbonation of bornylmagnesium chloride provides a convenient route to the endo acid (107), a more suitable method for the preparation of the exo acid is desirable. Accordingly other possible means of preparing (105) were investigated in the present work.



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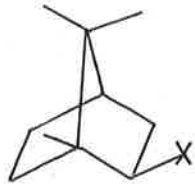

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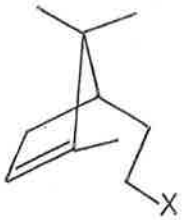

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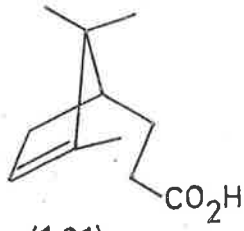


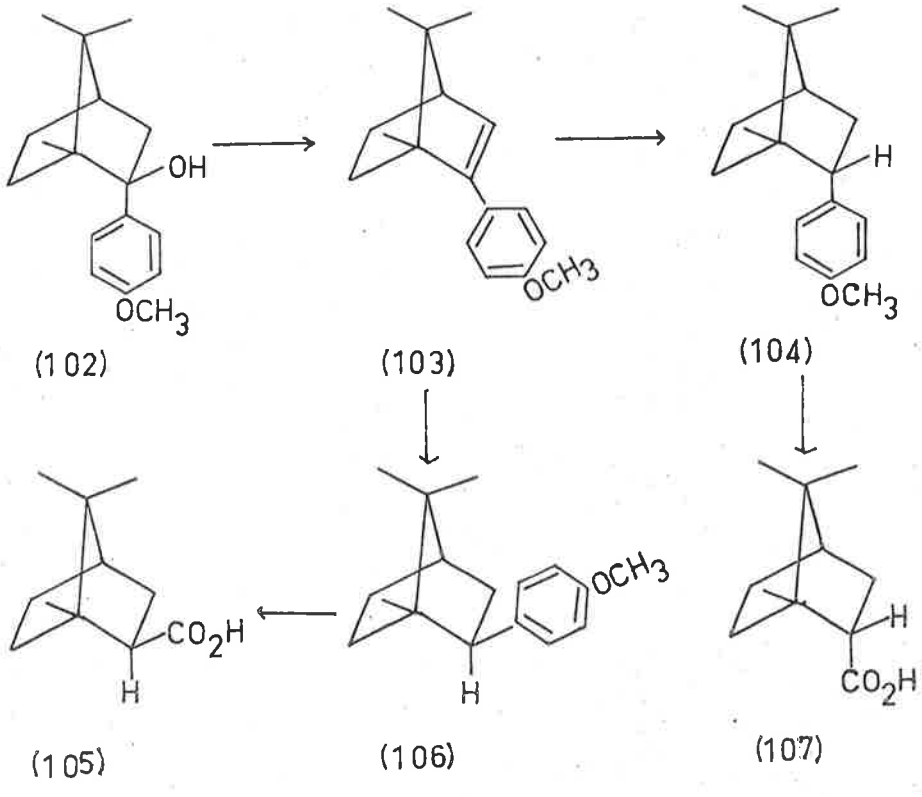
(101)

An attempt was made to effect an S_N2 displacement of tosylate by cyanide ion in bornyl tosylate (98, x = OTs), since such a reaction should yield the exo nitrile (99, x = CN) which could be converted into the exo acid by hydrolysis. Bornyl tosylate was found to be unreactive towards cyanide ion in dimethylformamide under mild conditions, and under vigorous conditions elimination occurred and camphene was formed. Similarly isobornyl chloride (99, x = Cl), which would be expected to yield the endo nitrile (98, x = CN) did not react with cyanide ion in dimethylformamide. Under these conditions, however, ∝-campholenyl p-nitrobenzenesulphonate (100, x = ONs) was readily converted into the corresponding nitrile (100, x = CN). The latter compound on hydrolysis gave the acid (101).

The lack of reactivity of the bicyclic substrates (98, x = OTs)

and (99, x = Cl) in S_N2 displacements is probably due to two factors. The initial approach of the nucleophile to both the <u>exo</u> and <u>endo</u> side of the bornane system is rather hindered, and if such approach did occur, the transition state for the displacement would require the incoming nucleophile, C_2 and the leaving group to be essentially linear. This would be expected to result in steric interactions, particularly between the entering and leaving groups and the <u>endo</u> hydrogen atom at C_6 and the methyl group at C_7. These factors would not be expected to be as great in the norbornyl system, and examples of S_N2 displacements in that system are known.[81]

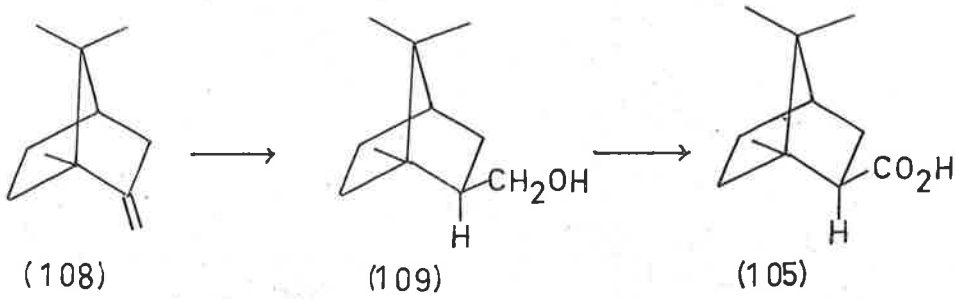
Optically active 2-<u>endo</u>-carboxybornane (107) was prepared by a procedure used by Flautt and Erman[82,83] to prepare inactive (107).



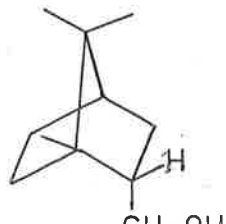
(+)-Camphor was converted into the tertiary alcohol (102) by treatment with p-anisylmagnesium bromide, and (102) was dehydrated to (103) with boron trifluoride etherate in ether. Sodium-liquid ammonia reduction of (103) gave p-bornylanisole (104), which on ozonolysis and oxidation gave (+)-2-endo-carboxybornane (107). The optical rotations of this acid determined at several wavelengths were in good agreement with those given by de Botton[80] for enantiomorphic (107) prepared from bornylmagnesium chloride.

Flautt and Erman[82] prepared p-isobornylanisole (106) by the hydrogenation of (103) with a sponge-nickel catalyst. As (106) should give the exo acid (105) on ozonolysis-oxidation, the hydrogenation of (103) was carried out in the present study, but nickel boride[84] was used as the catalyst. The resulting product was a low-melting solid which could not be purified by recrystallisation, and which was judged to be a 60:40 mixture of (106):(104) from its n.m.r. spectrum. Ozonolysis and oxidation of this mixture gave only a low yield of crystalline acid which was judged to be a 35:65 exo (105):endo (107) mixture from its rotation. A considerable amount of oily acidic material was formed in the reaction, and this appeared to be due to further degradation of the isobornylanisole or the exo acid during the reaction. This scheme was therefore unsuitable for the preparation of 2-exo-carboxybornane.

Pure 2-exo-carboxybornane was prepared by the sequence outlined in scheme 10. (+)-Camphor was converted into 2-methylenebornane (108) via a Wittig reaction. Hydroboration of (108) with disiamylborane[85]



(108) (109) (105)



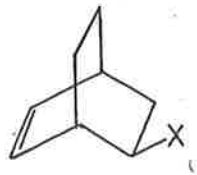
(110)

Scheme 10.

followed by alkaline peroxide oxidation gave a 90:10 mixture of the carbinols (109) and (110) in 59% yield. The predominant formation of 2-exo-hydroxymethylbornane (109) was the result of the addition of the hydroborating agent to the less hindered endo side of (108). Oxidation of the carbinol mixture with Jones' reagent[86] yielded an acid mixture containing 75% of the desired exo acid (105) and 25% of the endo acid (107). The additional 15% of (107) in this mixture was presumably formed by epimerisation of (105) or the intermediate aldehyde during the oxidation of (109). Pure (-)-2-exo-carboxybornane was isolated from this mixture via its (+)-bornylamine salt. The optical rotations of this acid were in good agreement with those given by de Botton[80] for the enantiomorphic (105) obtained from bornylmagnesium chloride.

3. Oxidative decarboxylations.

It was initially hoped to carry out the oxidative decarboxylation of 2-exo and 2-endo-carboxybornane in acetic acid, and to compare the products obtained in this way with those obtained from the acetolyses described in Part I. Such a comparison of solvolysis and oxidative decarboxylation products has been described by LeBel and Huber[91] for the bicyclo[2.2.2]oct-2-enyl derivatives (111, X = OTS) and (111, X = CO_2H). These workers found that the acid (111, X = CO_2H) gave an



(111)

acetate mixture (30-38%) on being heated with lead tetraacetate in acetic acid containing potassium acetate. In the present work it was found that 2-endo-carboxybornane did not undergo oxidative decarboxylation to a significant extent under conditions identical to those of LeBel and Huber, except that sodium acetate was used instead of potassium acetate. (Sodium acetate was used since it was also used in the acetolyses described in Part I). Although all of the lead tetraacetate was consumed in this reaction, the endo acid was recovered unchanged (60%), and only a low yield of neutral product was obtained. A crystalline compound $C_{12}H_{18}O_2$, m.p. 101-103°, the structure of which is discussed in Part III, was isolated from this product.

The products expected from a carbonium ion intermediate were not detected, although the formation of the compound $C_{12}H_{18}O_2$ implies that oxidative decarboxylation occurred and that some camphene was formed (see Part III). The oxidative decarboxylations of the acids (105) and (107) were therefore carried out under conditions similar to those described by Corey and Casanova[41] for the norbornane-2-carboxylic acids.

After this work had been completed, it was learnt that lead tetraacetate is unstable in acetic acid containing sodium acetate.[92] Halide, cyanide, and thiocyanate anions as well as acetate anions have been reported to initiate rapid decomposition of lead (IV) esters.[94] It may, therefore, be possible to carry out the oxidative decarboxylations in acetic acid not containing added salts.

Treatment of (±)-2-*endo*-carboxybornane with 1.5 equivalents of lead tetraacetate in benzene-pyridine at reflux temperature for 4½ hr led to essentially complete conversion of the acid into neutral material. The composition of the product is given in Table 17. 8-Methylcamphene, and acetates A, B and C were found to be also formed when camphene was heated with lead tetraacetate in benzene, and were therefore due to secondary reactions. These products will be discussed later. Because of these secondary reactions, some unchanged acid was recovered even when more than one equivalent of lead tetraacetate was used. The relative amounts of byproducts were reduced by decreasing the amount of lead tetraacetate (*e.g.* in the oxidative decarboxylation of 2-*exo*-carboxybornane, Table 17).

	(±)-endo *	(-)-exo ≠
Tricyclene	2%	2%
Camphene	59	77
trans-8-Methylcamphene	14	3
cis-8-Methylcamphene	2	trace
Bornyl acetate	5	4
Isobornyl acetate	12	9
Acetate A	trace	trace
Acetate B	3	2.5
Acetate C	3	2.5

Table 17. Composition of the products of the oxidative decarboxylation of (±)-2-endo and (-)-2-exo-carboxybornane in benzene-pyridine. (Analysed on a 150' Apiezon capillary column, 130°).

* 1.48 mole $Pb(OAc)_4$/mole acid; 4% acid recovered.

≠ 1.04 mole $Pb(OAc)_4$/mole acid; 13% acid recovered.

It will be shown in the discussion following below that the products listed in Table 17 (excluding those due to the secondary reactions of camphene with lead tetraacetate) are those expected from a carbonium ion intermediate, rather than a free radical intermediate, but that the formation of some endo substitution product, bornyl acetate, indicates that the isobornyl-camphenehydro cation is not uniquely required as the intermediate. The camphene obtained from the oxidative decarboxylation

of optically active 2-exo and 2-endo-carboxybornane had a high optical purity; that obtained from the exo acid showed $[\alpha]_D$ + 109 and that obtained from the endo acid showed $[\alpha]_D$ + 112.

Although the products formed in the oxidative decarboxylation of aliphatic monocarboxylic acids are usually those expected from carbonium ion intermediates,[41,93] the recent work of Kochi[94] suggests that the initial decarboxylation step is homolytic in nature. Kochi found that the reaction is catalysed by pyridine and copper (II) acetate, and on the basis of extensive product and rate studies, he proposed the free radical chain process outlined in Scheme 11. The

$$Pb(OAc)_4 + 4\ RCO_2H \rightleftharpoons Pb(RCO_2)_4 + 4\ AcOH$$

Initiation: $Pb(RCO_2)_4 \longrightarrow Pb(RCO_2)_3 + R\cdot + CO_2$

Propagation: $Pb(RCO_2)_3 \longrightarrow Pb(RCO_2)_2 + R\cdot + CO_2$

$R\cdot + Pb(RCO_2)_4 \longrightarrow Pb(RCO_2)_3 + R^+$

Termination: $R\cdot + Pb(RCO_2)_3 \longrightarrow Pb(RCO_2)_2 + R^+$

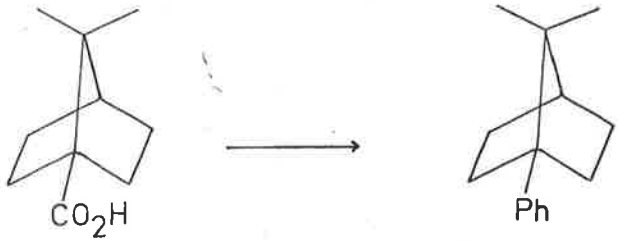
$R\cdot + HS \longrightarrow RH + S\cdot$

Scheme 11 (HS = hydrogen donor)

intermediate radical R. can be oxidised to the carbonium ion R^+ by the lead (IV) species in the propagation step, and by the lead (III) species in the termination step. This electron transfer appears to occur very readily, and in some instances it does not appear to be possible to distinguish between direct carbonium ion formation and indirect carbonium ion formation via a $R\cdot\cdot Pb(OAc)_3$ radical pair.[41]

The formation of (113) from (112) by the action of lead tetra-

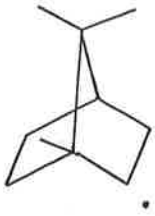
acetate in benzene provides good evidence for the initial formation of a radical in the decarboxylation step.[95] In this example, oxidation to the bridgehead carbonium ion is unfavourable, and radical abstraction occurs preferentially.



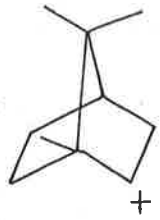
(112) (113)

The 2-bornyl radical (114) has been generated by the decarbonylation of 2-formylbornane[96] at 138° and by the thermal decomposition of 2-azobornane[97] at temperatures above 250°. The main product in these reactions was the hydrocarbon bornane (115) formed as a result of hydrogen abstraction by the bornyl radical. Although small amounts of tricyclene were formed in these reactions, camphene was not present, and the formation of the latter hydrocarbon therefore appears to be characteristic of a carbonium ion precursor.

Bornane (115) could not be detected in the products of the oxidative decarboxylation of 2-exo and 2-endo-carboxybornane, and the free 2-bornyl radical (114) is therefore not involved in these reactions. Since the bornyl radical does not rearrange at low temperatures,[96] the first intermediate in the oxidative decarboxylation is presumably the classical 2-bornyl cation (67), formed either directly by a heterolytic decarboxylation step, or by a homolytic decarboxylation step



(114)



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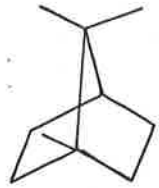

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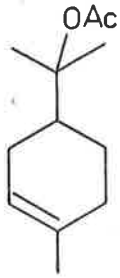


(116)

(117)

followed by a rapid electron transfer from the radical to the lead (III) intermediate. It is significant that the fragmentation products α-terpinyl acetate (116) and limonene (117) which might be expected from a "hot" 2-bornyl cation (cf. the deamination of bornylamine (p.25) which gives rise to significant quantities of α-terpineol), were not present in the decarboxylation product.

During the v.p.c. analysis of the oxidative decarboxylation products on conventional packed columns, some baseline instability, indicative of decomposition of a component of the mixture, was observed. When the decarboxylation products were examined by v.p.c. on a 300' Ukon capillary column, an additional acetate peak, not observed on the 150' Apiezon capillary column, was recorded. This additional peak was found to be due to the acetate of camphene hydrate (92, R = $COCH_3$). Although this acetate underwent decomposition to camphene

on the 150' Apiezon column, it was eluted as a sharp peak on the Ukon column. The compositions of the decarboxylation products of the endo acid, and of a 57:43 exo:endo acid mixture determined under conditions where the acetate of camphene hydrate was stable, are listed in Table 18.

	endo	57:43 exo:endo mixture.
Tricyclene	2%	2%
Camphene	53	57
trans-8-Methylcamphene	3	4
Bornyl acetate	6	5
Isobornyl acetate	13	11
Acetate of camphene hydrate	9	9
Acetate A	2	2
Acetate B	6	5
Acetate C	6	5

Table 18. Composition of oxidative decarboxylation products. (Analysed on a 300' Ukon capillary column, 140°).

The composition of the acetate fractions of various decarboxylation products is shown in Table 19.

It can be seen that the relative amounts of bornyl and isobornyl acetate, and of the acetate of camphene hydrate, are similar in the products from both the exo and the endo acid. In particular, the ratio of exo:endo secondary substitution product, isobornyl : bornyl acetate, is always ca. 68:32. Both acids therefore appear to give

rise to the same product-determining intermediate during the oxidative decarboxylation. The bornyl acetate may be considered to be derived

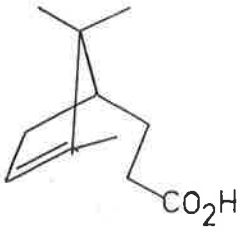
Acid	Bornyl acetate	Isobornyl acetate	Acetate of camphene hydrate	exo:endo
(-)-exo	20	41	39	67:33
(+)-endo	19	40	41	68:32
(+)-endo and (-)-exo (43:57)	21	44	35	68:32
(±)-endo	21	44	35	68:32

Table 19. Composition of the acetate fractions of the oxidative decarboxylation products (300' Ukon capillary column, 140°).

from the classical bornyl cation - AcO^- (or $Pb(OAc)_3^-$) ion pair by addition of nucleophile, or transfer of ligand, to the less hindered endo side of the cation. If this ion pair were the only intermediate giving rise to secondary substitution product, the amount of bornyl acetate should exceed the amount of isobornyl acetate formed for steric reasons. The observed predominant formation of isobornyl acetate suggests that rearrangement of the 2-bornyl cation to the bridged isobornylcamphenehydro cation (70) may compete with nucleophilic capture of the 2-bornyl cation. Addition of nucleophile to the secondary centre of the bridged ion (70) would then give rise to isobornyl acetate. In support of this hypothesis is the observed formation of tertiary exo substitution product, the acetate of camphene hydrate (92, R = $COCH_3$), and the complete absence of tertiary endo substitution product, methyl-

camphenilyl acetate (91, R = $COCH_3$).

The reaction of β-(2,2,3-trimethylcyclopent-3-enyl)propionic acid (101) with lead tetraacetate in benzene-pyridine was also examined. Ring closure to the bicyclo[2.2.1] heptyl system is here theoretically



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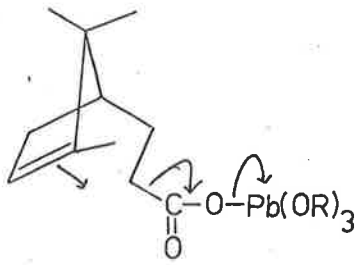

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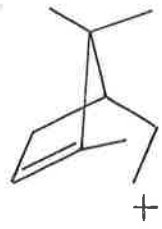


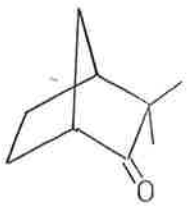
(71)

possible by a concerted displacement of the carboxyl group, as in (118) or by cyclisation of the monocyclic cation (71). Treatment of the acid (101) with 1.2 equivalents of lead tetraacetate in refluxing benzene-pyridine gave a small yield of low boiling product which contained tricyclene, camphene, 8-methylcamphene and bicyclic acetates. Significantly, α-campholenyl acetate (79, R = $COCH_3$) was not present in the product, and the monocyclic cation (71) is therefore unlikely to be an intermediate. Several unidentified high boiling neutral products were also formed, and ca. 50% of acidic material was recovered. The latter appeared to concist mainly of starting acid (101), but some acetoxylated material appeared also to be present. The high proportion of by-products formed during the oxidative decarboxylation of (101) was probably the result of the low reactivity of primary carboxyl group towards lead tetraacetate.[94] It may be possible to increase the yield

of decarboxylation product by the addition of copper (II) acetate, which increases the efficiency of oxidation of alkyl radicals to carbonium ions in the propagation step of Kochi's reaction scheme (p.64), but time did not permit a study of this point in the present work.

4. Reaction of camphene with lead tetraacetate.

The acetates A, B and C, and the hydrocarbon 8-methylcamphene (121) formed during the oxidative decarboxylation of 2-exo and 2-endo-carboxybornane (Tables 17 and 18) were also found to be formed by the action of lead tetraacetate on camphene in benzene. 8-Methylcamphene was isolated by careful chromatography of the oxidative decarboxylation



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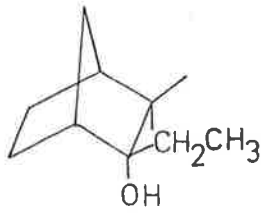

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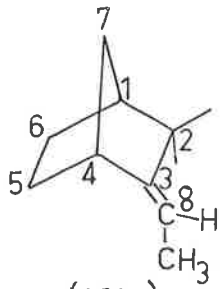
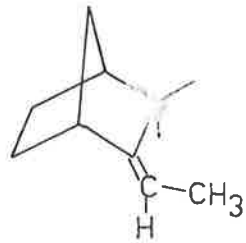


(121a)



(121b)

product of (±)-2-endo-carboxybornane on silver nitrate impregnated silica gel. Its n.m.r. spectrum clearly supports the assigned structure (Table 20a). 8-Methylcamphene, identical with the product obtained from the oxidative decarboxylation, was also formed by the action of lead tetraacetate on camphene in benzene, but was not formed by the action of lead tetraacetate on camphene in acetic acid.

τ	Multiplicity	Proton count	Assignment.
9.03	singlet	6	gem-dimethyl
8.90–8.10	complex	10	$-CH_2-$ and saturated $-CH-$
8.43	doublet, J=7		$=CH-CH_3$
7.10	broad singlet	1	bridgehead* $-CH-C=$
5.10	quartet, J=7	1	$C=CH-CH_3$

Table 20a. N.m.r. spectrum of 8-methylcamphene.

* Bridgehead proton at C_4 of camphene absorbs at τ 7.33.

Treatment of camphenilone (119) with ethylmagnesium bromide unexpectedly gave the reduction product camphenilol. A small quantity of the addition product (120) was however obtained pure, and dehydration of this alcohol with phosphorus oxychloride in pyridine gave 8-methylcamphene identical with the samples obtained from the lead tetraacetate reactions.

In an alternative synthesis of 8-methylcamphene, camphenilone was treated with ethylidenetriphenylphosphorane. The hydrocarbon fraction of this reaction product consisted of two components in the ratio of 77:23, and the v.p.c. retention time of the minor component was identical with that of 8-methylcamphene obtained from the lead tetraacetate and phosphorus oxychloride reactions. This component was therefore assigned structure (121a) in which the methyl group is trans to the ring carbon bearing the gem-dimethyl group. The formation of the trans isomer (121a) would be expected in the phosphorus oxychloride-

pyridine reaction since the methyl group would be expected to be remote from the gem-dimethyl group in the transition state for the dehydration step. The major product of the Wittig reaction was therefore apparently the cis isomer (121b), although the trans isomer would also be expected on steric grounds. The trans:cis olefin ratio in Wittig reactions however appears to depend on other factors such as temperature, solvent, and the nature of the base used in preparing the alkylidene-phosphorane,[98] and one of these factors may be responsible for the observed predominant formation of (121b) in the present reaction.

The formation of 8-methylcamphene from camphene and lead tetraacetate in benzene apparently involves free methyl radicals, since nuclear methylation of aromatic compounds with lead tetraacetate are known.[99] A free radical addition of the elements of methyl acetate to the double bond of camphene, analogous to that observed when styrene is treated with lead tetraacetate in benzene,[100] followed by elimination of acetic acid, would give 8-methylcamphene. Camphene appears to be susceptible to substitution in the 8- position, and other groups which have introduced into that position include bromo,[101] nitro,[102] acetyl,[103] and trichloromethyl.[104]

The unidentified acetates A, B and C formed during the oxidative decarboxylations (Tables 17 and 18) were also formed by the action of lead tetraacetate on camphene in benzene (Table 20b). The reaction of camphene with lead tetraacetate in acetic acid has been studied by several workers,[105,106] and the major product of this reaction appears to be the ring-expanded enol-acetate (122). This compound is therefore

Component	Solvent		Retention time
	Acetic acid	Benzene	
1	28%	4%	11 min 45 sec
2	4	-	12 25
3	-	4	14 25
4(acetate A)	56	12	15 20
5(acetate B)	4	39	16 20
6(acetate C)	8	41	16 45

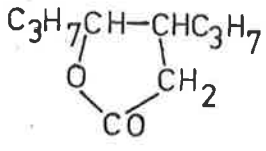
Table 20b. Composition of the products from the reaction of lead tetraacetate with camphene in acetic acid, and in benzene (150' Apiezon capillary column, 130°).

(122)

presumably acetate A, but the structures of acetates B and C are unknown. It may be noted that the compositions of the products obtained with acetic acid and benzene as solvents differ considerably (Table 20b). Because of the complex nature of these mixtures, they were not further investigated in the present work.

III. Exo and endo lactones of β-(2-hydroxy-3,3-dimethyl-2-norbornyl) propionic acid.

During an attempt to effect the oxidative decarboxylation of (±)-2-endo-carboxybornane with lead tetraacetate in acetic acid - sodium acetate, the formation (in a low yield) of a product $C_{12}H_{18}O_2$, m.p. 101-3°, was observed. The infrared spectrum of this compound showed the presence of a γ-lactone (1777 cm^{-1}) and a gem-dimethyl group (1386 and 1366 cm^{-1}), while its n.m.r. spectrum revealed the presence of two tertiary methyl groups (overlapping singlets at τ 9.02). The absence of signals at lower field than 140 c/s showed that the ether oxygen of the lactone group must be attached to a carbon devoid of hydrogen atoms. As camphene has been shown to be the major product from the action of lead tetraacetate on 2-endo-carboxybornane in benzene, the above product (later shown to be a mixture of epimers) was considered to have arisen from the addition of a $.CH_2COO.$ moiety (with no mechanistic implications) to the double bond of camphene. Such a hypothesis seemed reasonable as Criegee[110] has observed the formation of the γ-lactone (123) by the addition of a $.CH_2COO.$ moiety to the



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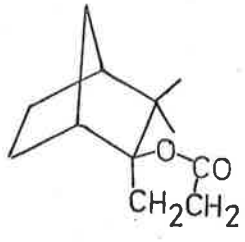

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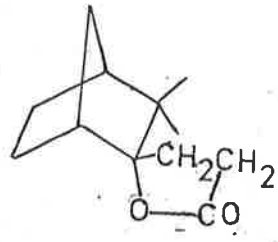

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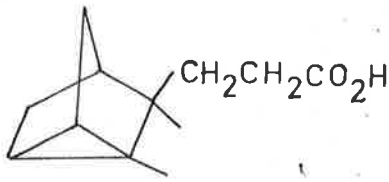


(126)

double bond of oct-4-ene by the action of lead tetraacetate.

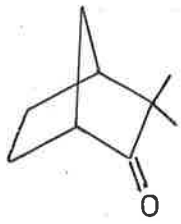
In a study of the action of lead tetraacetate on camphene in acetic acid, Hückel and Hartmann[105a] isolated a byproduct $C_{12}H_{18}O_2$, m.p. 101°, to which they were unable to assign a structure. Repetition of their work revealed that their product was identical with that obtained from 2-endo-carboxybornane.

Working on the hypothesis that the $\cdot CH_2COO\cdot$ moiety would be added to the double bond of camphene from the less hindered exo side,[7,111] the unknown lactone was considered to be β-(2-exo-hydroxy-3,3-dimethyl-2-norbornyl)propionic acid lactone (124) rather than the epimeric endo lactone (125). Structure (125) was recently assigned by Bhati[112] to the lactone, m.p. 103-104°, obtained from tricycloekasantalic acid (126) by the action of strong acids.[113] The assignment was based on an unambiguous synthesis of (125), m.p. 103-104°, and a comparison of the infrared spectra, m.p. and mixed m.p. of the synthetic lactone (125) and the lactone from the acid (126).

The formation of the lactone from tricycloekasantalic acid appeared to involve certain interesting mechanistic features. In order to correlate this lactone with that from camphene, a new unambiguous synthesis of the endo lactone (125) was carried out, and some aspects of the

formation of the lactone from tricycloekasantalic acid were re-examined.

The synthesis of the endo lactone (125) was achieved by the following route. Treatment of (±)-camphenilone (119) with allylmagnesium chloride yielded the tertiary alcohol (127) which was homogeneous as



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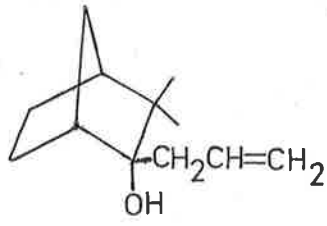

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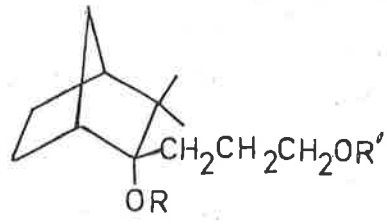

(128)

judged by capillary vapour phase chromatography, and in which the hydroxyl group must have the endo configuration.* Hydroboration-oxidation[114] gave the crystalline diol (128, R=R'=H), m.p. 68-9°, which was oxidised with Jones' reagent to give the endo lactone (125), m.p. 102-103°. Although capillary v.p.c. showed that this lactone was homogeneous, its infrared spectrum showed distinct differences in the

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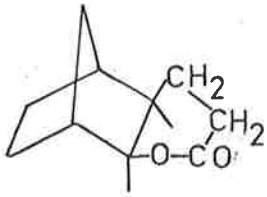
* Although the Grignard product was homogenous on two capillary columns, the presence of some epimeric exo alcohol was possible, since the tertiary alcohol pair methylcamphenilol and camphene hydrate could also not be separated on these columns. Contamination by the exo alcohol could have been only slight, since the addition of reagents to norbornan-2-ones unsubstituted in the 7-position is highly stereospecific, and occurs from the exo side.[111]

"fingerprint" region when compared with the spectra of the lactones from 2-endo-carboxybornane and camphene. Examination of these lactones by v.p.c. revealed that they were in fact 4:1 mixtures of two components. In both cases, the minor component had a retention time identical with that of the authentic endo lactone (125).

The lactone from tricycloekasantalic acid (126) was generated with sulphuric acid (15 and 25%), and formic acid. In each case, the "pure" product was shown by v.p.c. to be a mixture of the same lactones as from 2-endo-carboxybornane and camphene (Table 21), with the endo lactone (125) again being the minor component. When tricycloekasantalic acid was treated with 98% sulphuric acid at -10° for 25 mins, the resulting lactone mixture contained a third component (56%). As the infrared spectrum of this mixture showed carbonyl absorption of similar intensity at 1780 (γ-lactone) and 1745 cm^{-1} (δ-lactone), the third component is believed to be the δ-lactone (129). The latter structure, and not the alternative endo structure (130) is assigned to the δ-lactone since the carboxyl group would be expected to attack the intermediate carbonium ion (135) from the exo side. In support of structure (129) was the fact that the n.m.r. spectrum of the mixture was similar to that of the lactone mixture from camphene, except for a sharp singlet at τ 8.76 which was assigned to the tertiary methyl group attached to the carbon bearing the ether oxygen atom of the lactone group in (129). The alternative structures (132) (which can be derived formally from tricycloekasantalic acid by a Wagner-Meerwein change in the ions (137) and (138)), and (133) were excluded due to the absence of signals at lower field than 140 c/s in the n.m.r.

Starting material	Reagent	Purity	Composition (%) exo	endo	δ
2-endo-Carboxy-bornane	$Pb(OAc)_4$ in AcOH-NaOAc	Recrystallised twice, m.p. 101-103°	79	21	-
Camphene	$Pb(OAc)_4$ in AcOH-NaOAc	Recrystallised twice, m.p. 101-103°	83	17	-
Tricycloekasantalic acid	98% H_2SO_4, -10°, 25 min	Recrystallised once, m.p. 65-75°	32	12	56
Tricycloekasantalic acid	15% H_2SO_4, reflux, 45 min	Crude, m.p. 75-100°	47	39	14
		Recrystallised twice, m.p. 100-104°	73	27	-
Tricycloekasantalic acid	25% H_2SO_4, reflux 15 min	Crude, m.p. 85-95°	54	33	13
		Recrystallised 3 times, m.p. 101-103°	69	31	-
Tricycloekasantalic acid	98% HCO_2H, reflux 30 min	Crude, m.p. 94-97°	62	38	-
		Recrystallised 4 times, m.p. 101-103°	73	27	-
Unsaturated acid (134)	25% H_2SO_4, reflux, 10 min	Recrystallised once, m.p. 97-99°	68	32	-

Table 21. Composition of the lactone mixtures.



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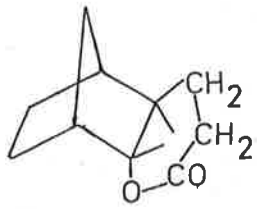

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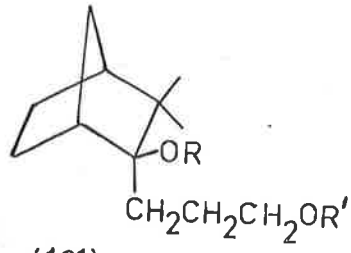

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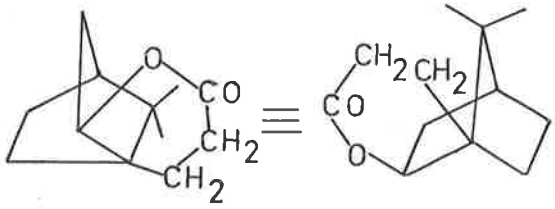

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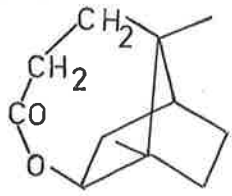
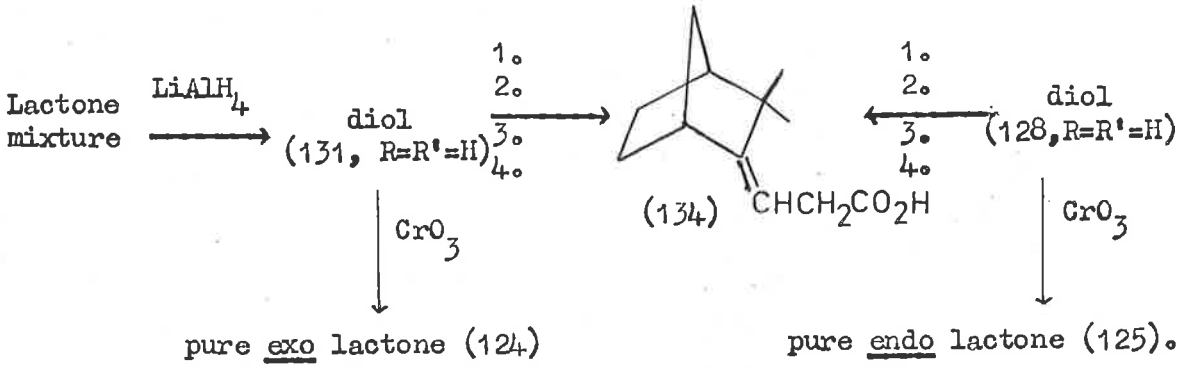


(133)

spectrum of the mixture. The lactone (129) was also present in small amounts (Table 21) in the crude products obtained from the action of hot dilute sulphuric acid on tricycloekasantalic acid, but was readily removed during subsequent recrystallisations. Three or four recrystallisations of the crude products gave "pure" compounds which were in fact mixtures (ca. 7:3) of the two γ-lactones, the minor component being still the endo lactone (125).

Having established that the major component of these lactone mixtures is not the endo lactone (125), the epimeric exo structure (124) can be assigned to it on the basis of the conversions summarised

in Scheme 12.* The lactone mixture (ca. 70:30) from tricycloekasantalic acid was reduced with lithium aluminium hydride to give a crystalline diol (131, R=R'=H), m.p. 133-134°, $[\alpha]_D$ + 25. Significantly, this diol could be oxidised by Jones' reagent to the exo lactone (124) m.p. 119-120°, $[\alpha]_D$ + 40, which was homogeneous as judged by capillary v.p.c.



Scheme 12.

and whose retention time was identical with that of the major component in the lactone mixture from tricycloekasantalic acid, 2-endo-carboxybornane, and camphene.

It is therefore clear that the lactone from tricycloekasantalic acid is a mixture of the exo lactone (124), $[\alpha]_D$ + 40, and the endo

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* The series of transformations of the lactone mixture described by Bhattacharyya and co-workers[115] to give a very poor yield of camphenilone (119) is rendered ambiguous since their intermediate diol was a ca. 1:1 mixture of (131, R=R'=H) and (128, R=R'=H) (based on the reported optical activity of their diol).

lactone (125) and that the latter must possess a negative specific rotation to account for the low and contradictory rotations reported in the literature.[112,115] The incorrect assignment of stereochemistry to the major component of the lactone mixture by Bhati[112] can be explained by the fact that the melting point of the lactone mixture is not depressed in admixture with the (±)-*endo* lactone (125). Contrary to Bhati's findings, however, the infrared spectral differences between the two are distinct (Fig. 3).

The unsaturated acid (134) which was obtained by Bhati[112] from both his synthetic *endo* lactone (125) and the lactone from tricycloekasantalic acid, and which he claimed was converted back to the lactone (125) by treatment with dilute sulphuric acid, has been synthesised in the present work (Scheme 12). Successive treatments of the diol (128, R=R'=H) with acetic anhydride in pyridine, phosphorus oxychloride in pyridine, lithium aluminium hydride, and Jones' reagent, yielded (134). Its n.m.r. spectrum confirmed the structure assigned (see Experimental). In sulphuric acid (25%), this acid lactonised to give a 68:32 mixture of *exo* and *endo* lactones, (124) and (125), respectively.

Since the mixtures of lactones were always formed in the acid catalysed reactions with tricycloekasantalic acid and the unsaturated acid (134), each of the pure lactones (125) and (124) were subjected to acid treatment and the results are summarised in Table 22. In all cases, it was found that the lactones underwent equilibration to give mixtures (*ca.* 60:40) of the lactones with the *exo* lactone predominating.

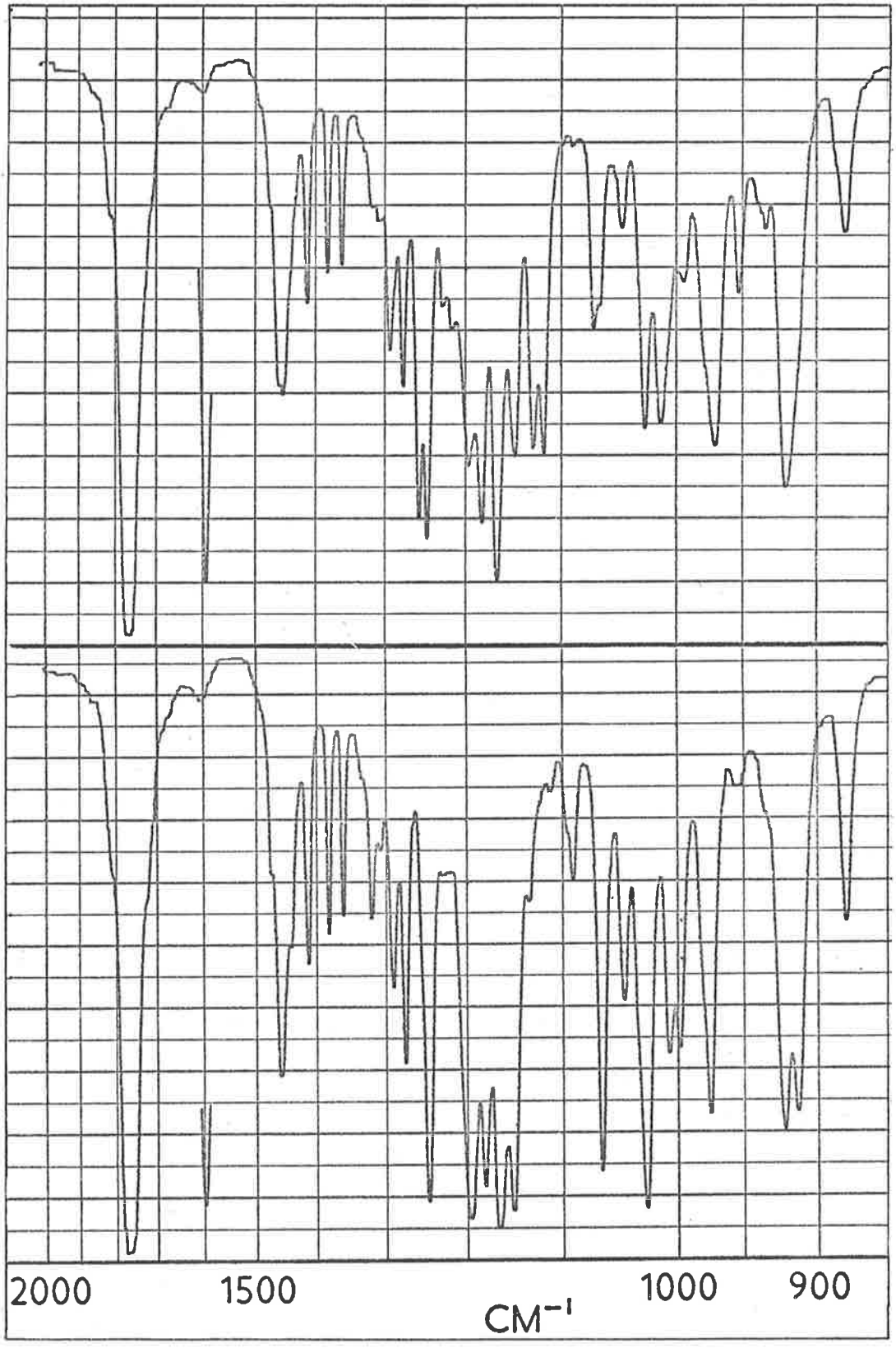

Figure 3. Top: Lactone from tricycloekasantalic acid, m.p. 101-103°.

Lower: (±)-endo-Lactone (125), m.p. 102-103°.

Lactone	Reagent	Composition	
		% exo	% endo
(±)-endo	25% H_2SO_4, 15 min reflux	60	40
(±)-endo	25% H_2SO_4, 45 min reflux	57	43
(+)-endo	98% HCO_2H, 90 min reflux	60	40
(+)-exo	15% H_2SO_4, 45 min reflux	66	34

Table 22. Composition of the lactone mixtures from the acid catalysed equilibration of the pure exo and endo lactones, (124) and (125), respectively.

For the formation of the lactone mixture from tricycloekasantalic acid (126), two pathways can be envisaged (Scheme 13). Protonation and opening of the cyclopropane ring in (126) can yield either the tertiary carbonium ions (135) or (136). The cations (137) and (138) can be derived by the migration of an endo methyl group in (135), and of an exo methyl group in (136), respectively. Cyclisation would then yield the exo lactones (124a) and (124b), or their corresponding endo counterparts. It may be noted that the pairs of structures (137) and (138), and (124a) and (124b) are non-superimposable mirror images. From the rotation studies of Ourisson[116] and the synthetic work of Corey and co-workers[117] the absolute configuration of tricycloekasantalic acid is represented by (126) and hence (124a)* and (124b)* represent the absolute configurations of the exo lactones derived

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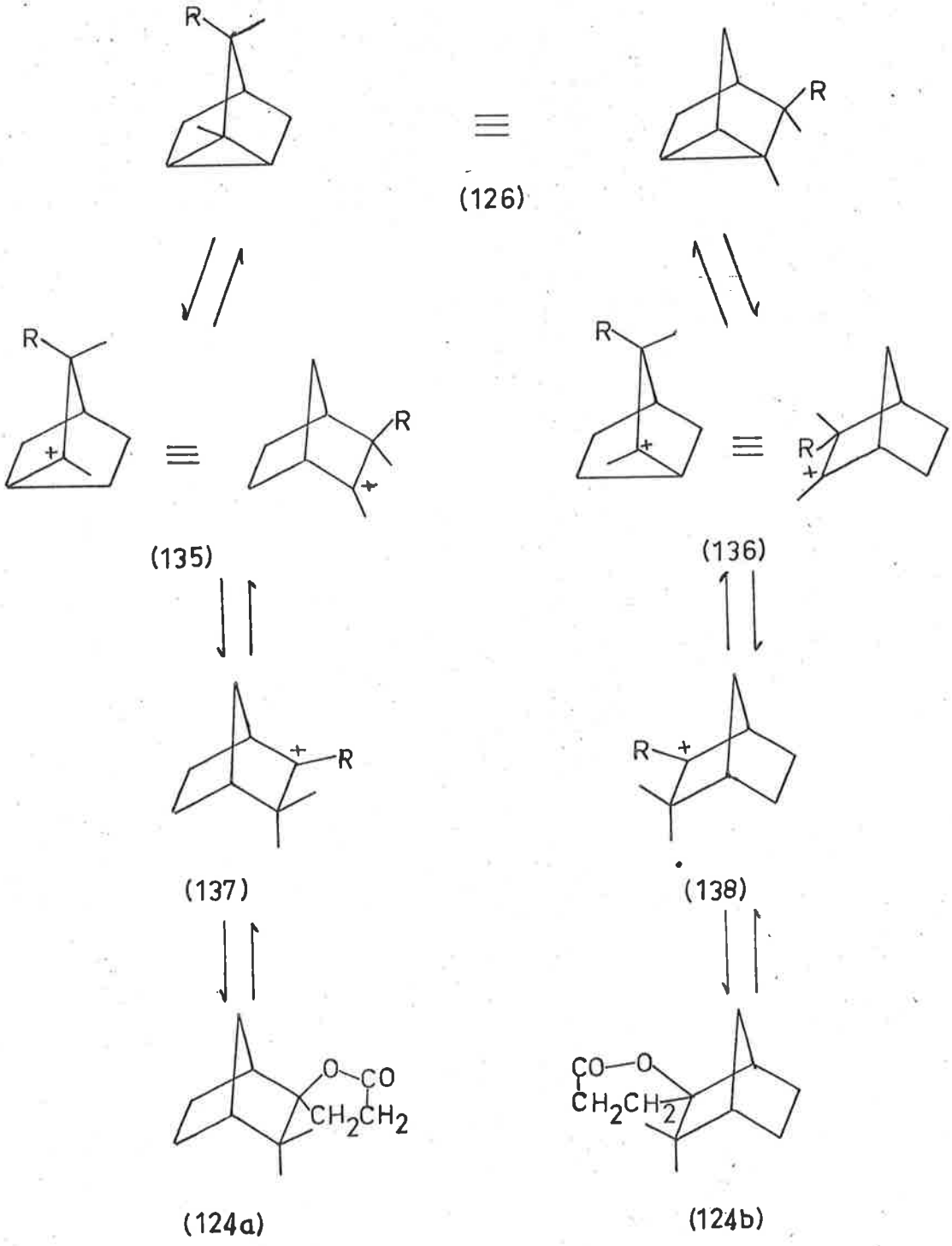
* Lactone (124a) is formally derived from (+)-camphenilone while lactone (124b) is derived from (-)-camphenilone.

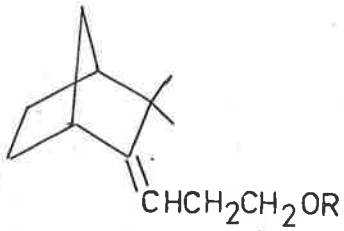


Scheme 13.

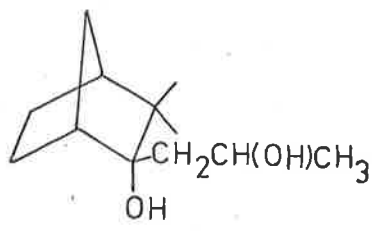
(R= $CH_2CH_2CO_2H$)

by endo and exo methyl group migration, respectively. Hence, a configurational correlation of the exo lactone (124) from tricycloekasantalic acid with camphenilone should allow a distinction to be made between the two pathways outlined in Scheme 13.

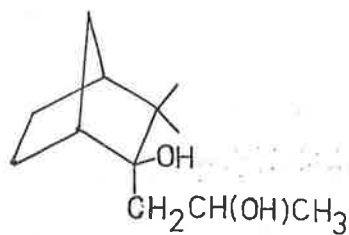
For the configurational studies, syntheses of the optically active lactones (124) and (125) from optically active camphenilone were desired. (+)-Camphenilone (80% optically pure) was converted into the (+)-endo lactone (125), m.p. 114-115°, $[\alpha]_D$ + 32, by the sequence already outlined for the synthesis of (±)-(125).* As the solvolysis of methylcamphenilyl trifluoroacetate in aqueous acetone containing calcium carbonate yielded camphene (28%) and camphene hydrate (72%) (p.51), it was thought that a similar solvolysis of the optically active ditrifluoroacetate (128, R=R'=$COCF_3$) would yield optically active exo diol (131, R=R'=H) which could then be oxidised to the optically active exo lactone. The product of the solvolysis, however, was the unsaturated alcohol (139, R=H).



(139)



(140)



(141)

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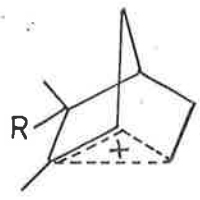
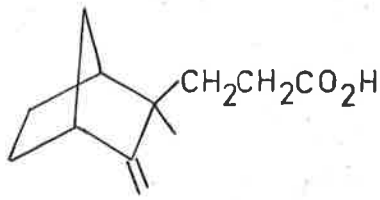
* As well as the desired diol (128, R=R'=H), two other diols were isolated from the hydroboration product of the (+)-tertiary alcohol (127). These have been assigned structures (140) and (141) on the basis of their n.m.r. spectra. The formation of (141) indicates that the tertiary alcohol (127) was contaminated by some exo alcohol.

At this stage, attempts to synthesise optically active exo lactone were abandoned, as the unsaturated alcohol (139) was readily oxidised by Jones' reagent to the unsaturated acid (134), m.p. 100-102°, $[\alpha]_D$ + 95, which served as a very satisfactory reference compound for the configurational correlations.

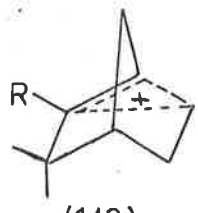
By the sequence of steps already described for the preparation of the unsaturated acid (134) from the (±)-endo diol (128, R=R'=H), the (+)-exo diol (131, R=R'=H) from the lactone from tricycloekasantalic acid was converted into (134), m.p. 95-96°, $[\alpha]_D$ - 118. The calculated rotation of optically pure (134) is + 119 from the observed value of $[\alpha]_D$ + 95 for (134) synthesised from (+)-camphenilone of 80% optical purity. The sign and magnitude of the rotation of the acid (134) obtained from the exo lactone therefore indicates that the latter is derived by the exclusive migration of the exo methyl group in (136a), the nonclassical counterpart of the classical ion (136). This finding is in accord with the general observation that 3,2-hydrogen or alkyl shifts in norbornyl or substituted norbornyl cations appear to occur only when the migrating group is exo.[118,119] The highly stereospecific nature of 3,2-shifts has been rationalised in terms of nonclassical cationic intermediates in which attack by nucleophile (in this case the migrating group) can only occur from the exo direction.



(136a)

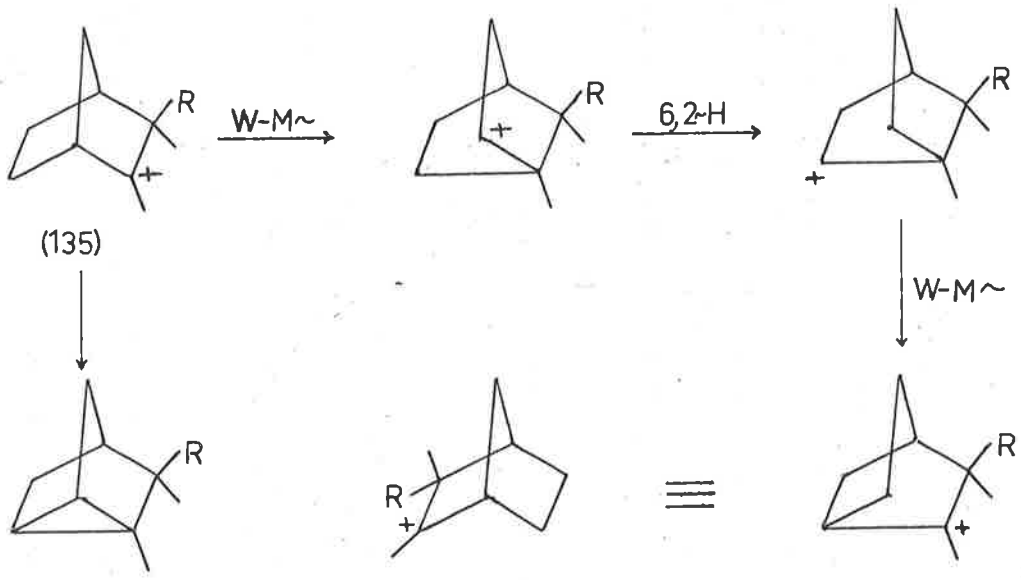


(142)



(143)

It is interesting to note that the action of formic acid on bicycloekasantalic acid (142) has been reported to give the same lactone as does tricycloekasantalic acid.[113b] Protonation of (142) would yield the carbonium ion (135) in which the methyl group at the migration origin has the endo configuration, and its migration is



(136)

Scheme 14.

therefore prohibited. Before migration can occur, therefore, rearrangement to the ion (136) must occur either via tricyloekasantalic acid (as in Scheme 13) or via the Wagner-Meerwein rearrangements and 6,2-hydride shift outlined in Scheme 14. Of these pathways, the latter seems more likely even though the conversion of a tertiary ⟶ secondary carbonium ion is involved, since the formation of tricyclene deriva-

tives from 2-norbornyl cations in acid media has been shown to be unlikely by labelling experiments.[118,120]

Although nonclassical structures for carbonium ions of the substituted 2-norbornyl series require that vicinal 3,2-shifts occur only when the migrating group is exo,[119] the formation of the endo lactone (125) from tricycloekasantalic acid and from the acid catalysed equilibration of the pure exo lactone (124) involves addition of the carboxyl group to the endo side of the intermediate carbonium ion. Clearly the bridged ion (143) cannot be the intermediate and recourse must be made to the classical tertiary ion (138). The acid catalysed equilibration of 2-norbornyl derivatives has received scant attention in the literature, although a study of the equilibration of the 2-norbornyl acetates was recently reported.[121] The formation of endo substituted norbornyl derivatives under these conditions presumably involves the classical norbornyl cation, for which the energy barrier for capture by nucleophile is likely to be less than that for capture of the more stable nonclassical ion.[121] In the case of the lactones, the ca. 60:40 exo:endo composition observed is presumably that of the equilibrium mixture.

EXPERIMENTAL

General.

Melting points were determined on a Reichert micro-hot stage, and in sealed capillaries in a stirred paraffin bath for substances which sublimed, and are uncorrected.

Infrared spectra were determined with Perkin-Elmer 137 and 237 spectrophotometers.

Nuclear magnetic resonance spectra were recorded by Dr. T.M. Spotswood and Mr. L. Paltridge with a Varian D.P.60 spectrometer operated at 60 Mc/s, using tetramethylsilane as internal standard, and CCl_4 or $CDCl_3$ as solvent.

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

Vapour phase chromatography was carried out with two instruments. For the early work a Griffin and George Mk.II apparatus (referred to as instrument 1 throughout this section) fitted with a thermal conductivity detector was used. The carrier gas was nitrogen, and the flow rate was 1.0 l/hr. Most analyses were carried out with a Perkin-Elmer 800 gas chromatograph equipped with a flame ionisation detector and accessories to allow the fitting of Golay (capillary) columns. The carrier gas (nitrogen) flow rate was 40 ml/min for the conventional columns, and 2ml/min for the capillary columns. For quantitative analyses, peaks were approximated to triangles, and the areas were determined from (peak height) x (peak width at $\frac{1}{2}$ peak height). The normalised peak areas were multiplied by detector response factors, which were determined by running standard mixtures of the components

under the conditions of the analysis. These standard mixtures were made up gravimetrically, and hence the compositions reported are normalised weight percentages. Each product analysis was the average of 3 determinations, which were generally in agreement to $\pm 1\%$. Qualitative identifications were made by comparing the retention times of the components with those of the authentic samples, and by peak enhancement. It was generally necessary to use capillary columns to separate a given exo-endo isomer pair.

Acetic acid was A.R. grade which had been dried by distillation from triacetyl borate.[64]

All organic solvent extracts were dried over anhydrous magnesium sulphate.

***

I. Work described in part I.

(±)-Isoborneol m.p. 211-212° (sealed capillary, lit.[72] m.p. 212°) was prepared by the hydrolysis of commercial (Fluka) isobornyl acetate, which had been shown to be free of bornyl acetate by capillary vapour phase chromatography.

(-)-Isoborneol.

(a) Reduction of (+)-camphor with lithium aluminium hydride in ether[65] yielded a 90 : 10 isoborneol : borneol mixture, m.p. 210-212° (sealed capillary), $[\alpha]_D^{20}$ -25.0 (c 2.47, ethanol).

(b) A suspension of lithium aluminium hydride (8.0 g, 0.21 mole) in anhydrous tetrahydrofuran (100 ml) was cooled in an icebath and dry tert-butanol (50.0 g, 0.68 mole) in tetrahydrofuran (50 ml) was added over a period of 20 min. The resulting solution of lithium tri-tert-butoxy-aluminohydride[66] was stirred at room temperature for 10 min, and was then cooled, and a solution of (+)-camphor (24.0 g, 0.16 mole) in tetrahydrofuran (50 ml) was added over a period of 15 min. The mixture was stirred at room temperature overnight, after which sufficient water was added to decompose the excess of hydride and the metal complex. The tetrahydrofuran was removed by decantation, and the inorganic residue was well washed with ether. The combined tetrahydrofuran-ether solution was washed with water and dried. The solvent was removed through a short fractionating column and the residue was recrystallised from light petroleum to yield 17.0 g (71%) of colourless crystals, m.p. 211-212° (sealed capillary), $[\alpha]_D^{20}$ -31.0 (c 2.00, ethanol). This rotation corresponded to that of a 96:4 isoborneol : borneol

mixture, using values of -34.0 and +37.0 for the specific rotations of pure isoborneol and borneol respectively.[67] Isobornyl acetate was prepared from this product by the usual acetic anhydride-pyridine method.

(+)-Borneol.

(+)-Camphor was reduced with sodium in ethanol as described by Wallach.[68] The resulting product, after recrystallisation from light petroleum, showed $[\alpha]_D$+21 (ethanol) and was thus a 78:22 borneol: isoborneol mixture. This product was purified by a procedure similar to that described by Pickard and Littlebury.[67] The mixture (30 g) and fused zinc chloride (50 g) were refluxed in benzene (100 ml) for 2 hr. The cooled solution was poured into water, and the benzene layer was separated. The aqueous layer was extracted with ether and the combined organic layers were washed with water and dried. The solvent was removed through a fractionating column, and the residue was diluted with light petroleum and cooled. The precipitated product was collected, washed with a small volume of light petroleum and then recrystallised from that solvent to yield pure borneol (10 g), m.p. 208-209° (sealed capillary), $[\alpha]_D^{26}$+37.0 (c 2.90, ethanol) (lit.[67] $[\alpha]_D$+37.0). Bornyl acetate, prepared from this product by the usual acetic anhydride-pyridine method, was vapour chromatographically homogeneous (150' Apiezon capillary column).

(±)-Camphene hydrate.

The following procedure was based on that of Ashan.[69] A solution of (±)-camphene (25 g) in dry ether (200 ml) was saturated with dry HCl below 0°. The ether was removed *in vacuo* and the residue was stirred with calcium carbonate (50 g) in a mixture of acetone (400 ml) amd water (100 ml) at room temperature for 2 hr and on a water bath under reflux for a further 6 hr. Most of the acetone was removed by distillation and the cooled residue was extracted with light petroleum. The organic extract was washed with water, dried and concentrated in volume to *ca.* 50 ml. The solution was cooled in a dry ice - ethanol mixture and the colourless crystals which separated were quickly collected (17.5 g, m.p. 140-142°). Recrystallisation from a small volume of light petroleum gave (±)-camphene hydrate (12.0 g), m.p. 150-152° (sealed capillary) (lit.[69] m.p. 150-151°).

Acetylation of (±)-camphene hydrate.

A cold solution of camphene hydrate (0.50 g) in dimethylaniline (20 ml) was treated dropwise with acetyl chloride (5 ml). The mixture was kept at room temperature for 1 hr and was then warmed on a water bath for 2 hr. The cooled mixture was poured into water and worked up by ether extraction. Distillation of the product afforded 0.52 g (80%) of the tertiary acetate b.p. 50° (bath)/0.5 mm, infrared maxima 1735 and 1250 cm^{-1}. For analysis a sample was redistilled.

(Found: C, 73.7; H, 10.2. $C_{12}H_{20}O_2$ requires C, 73.4; H, 10.3%).
Decomposition occurred on attempted analysis by v.p.c.

(±)-Methylcamphenilol.

This was prepared by the addition of methylmagnesium iodide to (±)-camphenilone[70,71] and was purified by low temperature recrystallisation from light petroleum. It had m.p. 118-119° (lit.[71] m.p. 118-119°) and was vapour chromatographically homogeneous (3' Apiezon and 300' Ukon capillary columns).

(±)-Methylcamphenilyl acetate.

Methylcamphenilol was acetylated by a procedure similar to that described for camphene hydrate. The acetate, obtained in 75% yield had b.p. 50° (bath)/0.4 mm, and was vapour chromatographically homogeneous (3' Apiezon and 150' Apiezon capillary columns).

(Found: C, 73.1; H, 10.0. $C_{12}H_{20}O_2$ requires C, 73.4; H, 10.3%).

(±)-Camphene, prepared by the dehydration of (±)-isoborneol with zinc chloride in benzene,[72] and tricyclene, prepared by the oxidation of camphor hydrazone with mercuric oxide,[73] had physical constants in agreement with the literature values.

Attempted preparations of isobornyl sulphonates.

(a) p-Toluenesulphonyl chloride (2.1 g, 0.012 mole) was added to a cold solution of (±)-isoborneol (1.54 g, 0.01 mole) in anhydrous pyridine (20 ml), and the mixture was kept at 0° for 2 weeks. The mixture was poured into water, extracted with ether and the ether was washed with dilute hydrochloric acid and water. Removal of the ether from the dried extract left a semi-solid residue (1.0 g) which showed

infrared maxima ($CHCl_3$) at 3640 and 3450 (O-H), 1650 (C=C), 1065, 1000, and 883 ($C=CH_2$) cm^{-1}, and which appeared to be a mixture of isoborneol and camphene.

(b) Methanesulphonyl chloride (0.40 g) was added to a cold solution of (±)-isoborneol (0.50 g) in dry pyridine (5 ml) and the mixture was allowed to stand at 0° for 5 days. Work-up by ether extraction yielded a semi-solid product (0.31 g), the infrared spectrum of which was identical with that of camphene. Under identical conditions, borneol (0.50 g) yielded a crystalline methanesulphonate (0.55 g) which after one recrystallisation from light petroleum had m.p. 92-94°. The infrared spectrum (nujol) lacked O-H absorption and showed strong bands at 1335, 1170, 965 and 895 cm^{-1}. This material was not further characterised.

(c) A cold solution of (-)-isoborneol (containing 4% of (+)-borneol) (1.50 g) in dry pyridine (10 ml) was treated with p-nitrobenzenesulphonyl chloride (2.30 g), and the mixture was kept at room temperature for 10 days. The mixture was poured into water and worked up by ether extraction to yield an oil (1.2 g), which showed infrared maxima (film) at 3500 (O-H) 1650 (C=C), 1535 (NO_2) and 885 ($C=CH_2$) cm^{-1}. This oil was diluted with petroleum ether (10 ml) and the precipitated solid was collected (0.075 g). This had m.p. 94-96° (dec.), and its infrared spectrum was identical with that of authentic bornyl p-nitrobenzenesulphonate. The petroleum ether soluble portion of the product was chromatographed on active alumina (60 g). Elution with petroleum ether yielded camphene (0.53 g), the infrared spectrum of which was identical with that of an authentic sample. After distillation

the camphene showed $[\alpha]_D^{27}$+ 110 (c 0.746, benzene). Elution with 50% ether-petroleum ether gave colourless crystals of isoborneol (0.295 g) which after sublimation showed m.p. 210-212° (sealed capillary), $[\alpha]_D^{27}$+ 33.0 (c 1.03, ethanol).

(d) The procedure was that employed for benzyl tosylates by Kochi and Hammond.[74] (±)-Isoborneol (2.0 g, 0.013 mole) and sodium hydride (0.80 g, 0.016 mole) (as a 50% suspension in oil) were refluxed in anhydrous ether (50 ml) with stirring for 7 hr (nitrogen atmosphere). The suspension was cooled to -10° and a solution of p-toluenesulphonyl chloride (2.9 g, 0.015 mole) in ether was added. The mixture was stirred at 0° for 18 hr, and then the insoluble material was collected by filtration. This still contained sodium hydride since it reacted vigorously on being added to water. The clear filtrate was evaporated to dryness in vacuo to give a colourless solid residue (5.1 g), which showed infrared maxima (nujol) at 3450, 1585, 1183, 1175, 1070, and 835 cm^{-1}. These bands were a combination of those present in the spectra of p-toluenesulphonyl chloride and isoborneol, and it was concluded that the product was a mixture of starting materials. Similar results were obtained when isoborneol was refluxed with sodium hydride for 20 hr, and stirring was carried out at room temperature for 60 hr after the addition of the tosyl chloride.

(±)-Camphene.

A solution of (-)-isoborneol (containing 10% of (+)-borneol) (15.4 g) and p-toluenesulphonyl chloride (21.0 g) in dry pyridine (100 ml) was heated on a boiling water bath for 6 hr with exclusion

of moisture. The cooled solution was poured into water and extracted with ether. The ether extract was washed with dilute hydrochloric acid and water and was dried. The ether was removed by distillation through a short fractionating column and the residue was chromatographed on active neutral alumina (100 g) in light petroleum. The first 100 ml fraction which was eluted was concentrated and distilled to yield camphene (8.5 g, 63%), b.p. 158-160°, m.p. 49-50°, $[\alpha]_D^{20}$ + 115, (c 2.30, benzene).

(+)-Bornyl p-nitrobenzenesulphonate.

This was prepared from borneol having $[\alpha]_D$+ 37 by the conventional pyridine method. The sulphonate crystallised from light petroleum as colourless needles, m.p. 94-95° (dec., variable with rate of heating), $[\alpha]_D^{20}$ + 14.9 (c 1.58, chloroform).

(Found: C, 56.9; H, 6.1; N, 4.05. $C_{16}H_{21}NO_5S$ requires C, 56.6; H, 6.2; N, 4.1%).

(+)-Bornyl p-toluenesulphonate prepared by the pyridine method had m.p. 68-69° (lit.[75] m.p. 67°), $[\alpha]_D^{21}$ + 20.0 (c 2.0, chloroform).

Bornyl chloride, m.p. 130-131° (lit.[76] m.p. 130-131°) was prepared by the addition of dry hydrogen chloride to α-pinene in chloroform.[76]

Isobornyl chloride m.p. 160-162° (lit.[13b] m.p. 161.5°) was prepared by the addition of hydrogen chloride to camphene in ethyl bromide, and

heating the resulting solution under reflux for 6 days.[13b]

(+)-α-Campholenic acid.

(a) This acid, prepared by the alkaline fusion of (+)-camphor-10-sulphonic acid,[44] was obtained as a colourless oil, b.p. 156-158°/20mm (lit.[44b] b.p. 147-148°/16)mm., α_D+10.2 (pure liquid) (lit.[44b] α_D+ 10.66). The methyl ester, prepared by treating the acid with an excess of ethereal diazomethane, was vapour chromatographically homogeneous, (instrument 1,6' squalene-Celite and 6'dinonyl phthalate-Celite columns).

(b) (+)-Camphor oxime m.p. 118-119° (lit.[77] m.p. 115°), $[\alpha]_D^{20}$-41 (c 2.00, ethanol) was converted to α-campholenonitrile b.p. 103-106°/14 mm in 87% yield by the method of Tiemann.[45] V.p.c. analysis (3' Apiezon column) revealed the presence of 20% of impurity, eluted ahead of the main peak. Alkaline hydrolysis of the nitrile yielded α-campholenic acid, b.p. 149-150°/15 mm, α_D+ 8.80° (pure liquid) (lit.[44b] α_D+ 8.0), infrared spectrum identical with that of the acid from (+)-camphor-10-sulphonic acid. V.p.c. analysis of the methyl ester (instrument 1, 6' squalene-Celite column) indicated the presence of 20% of the methyl ester of β-campholenic acid.*

Dehydration of camphor oxime with pyridine-p-toluenesulphonyl chloride.

A solution of (+)-camphor oxime (42 g, 0.25 mole) in pyridine (ca. 200 ml) was cooled and p-toluenesulphonyl chloride (50 g, 0.26

* An authentic sample of β-campholenic acid, prepared by the method of Tiemann,[46] was kindly supplied by Dr. G.E. Gream.

mole) was added in small portions. The mixture was kept at 0° for 20 hr, and was then poured into water and thoroughly extracted with ether. The ether extract was washed with dilute hydrochloric acid, water and was dried. The residue obtained on removal of the ether was distilled to yield 29 g (77%) of colourless oil, b.p. 104-106°/14 mm. V.p.c. analysis (12' BDS column, 190°) revealed the presence of α-campholenonitrile (55%) and a second component (45%), apparently the isomeric nitrile (74, X=CN). The infrared spectrum of this product was identical with that of α-campholenonitrile prepared by Tiemann's procedure[45] except for a band at 880 cm^{-1} ($C=CH_2$). The n.m.r. spectrum of the mixture showed absorption at τ 4.79 (>C=CH-) and 5.20 ($C=CH_2$).

(+)-α-Campholenol.

The vapour chromatographically homogeneous methyl ester of α-campholenic acid was reduced with lithium aluminium hydride in tetrahydrofuran[44a] to give the alcohol, b.p. 119-121°/21 mm, $[\alpha]_D^{20}$ + 5.4 (c 2.06, chloroform) in 89% yield. The acetate, prepared by the conventional pyridine-acetic anhydride method, had b.p. 120-122°/19 mm. (Found: C, 73.4; H, 10.4. $C_{12}H_{20}O_2$ requires C, 73.4; H, 10.3%).

(+)-α-Campholenyl p-nitrobenzenesulphonate.

p-Nitrobenzenesulphonyl chloride (1.80 g, 0.008 mole) was added to an ice-cold solution of α-campholenol (1.00 g, 0.0065 mole) in dry pyridine (10 ml). The mixture was kept at 0° for 2 hr, diluted with cold water, and the precipitated product was collected and dried

(2.1 g, 95%). Recrystallisation from light petroleum b.p. 60-80° with minimal heating yielded the sulphonate as pale yellow needles, m.p. 86-87° (dec., dependent on rate of heating), $[\alpha]_D^{22}$ + 3.42 (c 7.45, chloroform).

(Found: C, 56.7; H, 6.2; N, 4.3. $C_{16}H_{21}NO_5S$ requires C, 56.6; H, 6.2; N, 4.1%). In larger scale reactions the yield of sulphonate, after 2 recrystallisations, was generally 50-60%.

Dihydro-α-campholenyl p-nitrobenzenesulphonate (80, R=p-nitrobenzenesulphonyl).

A solution of (+)-α-campholenol (2.0 g) in ethanol (25 ml) was hydrogenated over platinum oxide catalyst (0.1 g) at atmospheric pressure for 10 hr. The catalyst was removed by filtration and the filtrate was concentrated under reduced pressure. The residue (2.0 g) was dissolved in ether and the ether solution was washed with water and dried. Removal of the ether and distillation of the residue yielded the alcohol (80, R=H) as a colourless oil, b.p. 121-123°/27 mm. A cold solution of the alcohol (0.50 g, 0.0032 mole) in dry pyridine (10 ml) was treated with p-nitrobenzenesulphonyl chloride (0.85 g, 0.0038 mole) and was kept at 0° for 1½ hr. Cold water was added dropwise, and the precipitated product was collected (0.80 g, 77%). Recrystallisation from light petroleum afforded the sulphonate as colourless plates, m.p. 64-65°.

(Found: C, 56.7; H, 6.9; N, 4.1. $C_{16}H_{23}NO_5S$ requires: C, 56.3; H, 6.8; N, 4.1%).

Acetolysis (+)-α-campholenyl p-nitrobenzenesulphonate.

The sulphonate (5.5, 0.016 mole) and fused sodium acetate (3.0 g, 0.037 mole) were heated in glacial acetic acid (100 ml) at 100° for 5 hr. The cooled solution was poured into water and extracted with ether and the ether extract was washed with sodium carbonate solution and water. Removal of the ether from dried extract through a short fractioning column yielded an oil (1.90 g) which showed infrared maxima (film) at 1740 (m) and 1240 (m) (acetate), and 1650 (w) and 885 (s) cm^{-1} ($C=CH_2$). Quantitative v.p.c. analysis (3' Apiezon column) indicated that the product consisted of tricyclene (2%), camphene (73%), isobornyl acetate (14%), α-campholenyl acetate (8%) and an unidentified compound (3%). The acetolysis product (1.7 g) was chromatographed on silica gel (30 g). Elution with light petroleum gave camphene (1.07 g), m.p. 47-49°, $[\alpha]_D^{21}$ - 98 (c 0.44, benzene). Elution with 10% ether-light petroleum gave an acetate fraction (0.19 g). This was reduced with lithium aluminium hydride in ether and the product obtained upon work-up was chromatographed on neutral alumina (15 g). Elution with 5% ether-hexane yielded isoborneol (0.030 g), identified by its infrared spectrum. Elution with 15% ether-hexane gave α-campholenol (0.020 g), the infrared spectrum of which was identical with that of an authentic sample.

Solvolysis of (+)-α-campholenyl p-nitrobenzenesulphonate in aqueous acetone.

The p-nitrobenzenesulphonate (4.0 g, 0.012 mole) and calcium

carbonate (1.50 g, 0.015 mole) were refluxed in 50% aqueous acetone (100 ml) for 5 hr. The inorganic residue was removed from the cooled solution by filtration, and the filtrate was thoroughly extracted with ether. The ether extract was washed with water, dried and the ether was removed through a short fractioning column to yield a semi-solid residue (1.30 g). V.p.c. analysis (instrument 1, 9' Carbowax-Embacel column, 167°) indicated that this consisted almost wholly of camphene hydrate. Less than 10% of the mixture consisted of isoborneol, α-campholenol and an unknown component having a retention time higher than that of α-campholenol (table 6). The product was chromatographed on neutral alumina (30 g) in hexane. Elution with hexane yielded solid material (0.95 g), m.p. 130-145°, which was sublimed to yield camphene hydrate, m.p. 149-151°; mixed m.p. with an authentic sample m.p. 150-152° was 149-151°. The infrared spectra of the two samples were also identical. The camphene hydrate obtained in the reaction showed $[\alpha]_D^{25}$ + 27.5 (c 2.55, ethanol), (lit.[71] $[\alpha]_D$ - 26.0). Elution with 25% ether hexane yielded a liquid fraction (0.065 g), the infrared spectrum of which was identical with that of authentic α-campholenol, except for the presence of a band at 880 cm^{-1}. V.p.c. examination of this fraction showed that it was a mixture of α-campholenol and the previously observed unknown component (presumably (74, X=CH_2OH)).

Unbuffered acetolysis of α-campholenyl p-nitrobenzenesulphonate.

A solution of the sulphonate (1.0 g) in glacial acetic acid (50 ml) was heated at 100° for 5 hr. The dark solution was poured into water, and was extracted with ether. The ether extract was washed with sodium

carbonate solution, water, and was dried. Removal of the ether left a dark oil (0.45 g), the infrared spectrum of which was virtually identical with that of isobornyl acetate. Distillation yielded 0.30 g of colourless oil, b.p. 115-125° (bath)/15 mm. This was analysed by capillary v.p.c. (150' Apiezon column, 140°) and its composition (normalised peak areas only) is given in table 11, p.42. The solvolysis product (0.25 g) was reduced with lithium aluminium hydride in ether, and the semi-solid product obtained on work-up (0.20 g) was chromatographed on active neutral alumina (20 g). Elution with ether yielded solid material (0.10 g), which was sublimed to give colourless crystals of isoborneol (0.60 g) $[\alpha]_D^{20}$ 0 (c 1.00, ethanol). The infrared spectrum was identical with that of authentic material. Elution with 2% methanol-ether gave 0.090 g of semi-solid material, which was not further investigated.

α-Campholenyl chloride.

(a) A mixture of (+)-α-campholenol (1.5 g, 0.01 mole) and pyridine 0.80 g, 0.01 mole) was cooled in an icebath and thionyl chloride (1.20 g, 0.01 mole) was added dropwise. The mixture was kept at 0° for 15 min. and was then heated with stirring at 60-80° for 2½ hr. Evolution of SO_2 from the mixture was accompanied by extensive tar formation. (Earlier trial experiments had indicated that chlorination did not proceed at lower temperatures.) The cooled mixture was poured into water, and work-up by ether extraction yielded a dark brown product (1.4 g) which on distillation yielded a colourless oil (0.80 g, 47%), b.p. 100° (bath)/16 mm, which lacked hydroxyl absorption in its

infrared spectrum. V.p.c. analysis (3' Apiezon column) revealed the presence of ca. 10% of impurity eluted ahead of the main peak. For analysis a sample was redistilled.

(Found: C, 69.1; H, 10.0. $C_{10}H_{17}Cl$ requires: C, 69.5; H, 9.9%.)

(b) A solution of (+)-α-campholenyl p-nitrobenzenesulphonate (3.5 g, 0.010 mole) and pyridine hydrochloride (2.5 g, 0.022 mole) in dimethylformamide (25 ml) was kept at room temperature for 20 hr. The mixture was poured into water, extracted with ether, and the ether was thoroughly washed with water and dried. Distillation of the residue obtained on removal of the ether yielded α-campholenyl chloride (1.60 g, 90%) b.p. 100° (bath)/15 mm, which was vapour chromatographically homogeneous. The infrared spectrum of this product was identical with that of the impure product obtained in (a).

(Found: C, 69.2; H, 9.8. Calc for $C_{10}H_{17}Cl$: C, 69.5; H, 9.9%).

(c) A solution of α-campholenol (1.50 g, 0.01 mole), pyridine (1.60 g, 0.02 mole) and p-toluenesulphonyl chloride (1.90 g, 0.01 mole) in dimethylformamide (10 ml) was kept at 0° for 18 hr. The mixture was poured into water and work-up by ether extraction yielded an oil (1.65 g), which showed strong carbonyl absorption at 1730 cm^{-1}. The oil was chromatographed on silica gel (20 g) and elution with hexane yielded α-campholenyl chloride (0.11 g), identified by its infrared spectrum. Elution with 10% ether-hexane yielded α-campholenyl formate (1.15 g), $\nu_{max.}$ 1730, 1160, and 803 cm^{-1}. For analysis a sample was distilled.

(Found: C, 73.0; H, 10.1. $C_{11}H_{18}O_2$ requires: C, 72.5; H, 10.0%).

Acetolysis of (+)-α-campholenyl chloride.

A solution of the pure chloride (0.59 g, 0.0034 mole) and fused sodium acetate (0.60 g, 0.0073 mole) in acetic acid (15ml) was heated at 100° for 115 hr. Work-up by ether extraction yielded 0.51 g of liquid product, the infrared spectrum of which showed strong absorption at 1740 and 1240 cm^{-1} (acetate), and only weak absorption due to camphene at 1650 and 880 cm^{-1}. Quantitative v.p.c. analysis (3' Apiezon column) showed that the product was a mixture of tricyclene (4%), camphene (29%), isobornyl acetate (65%) and an unidentified component (2%). Starting material and α-campholenyl acetate were not present in the solvolysis product. Part of the product (0.35 g) was chromatographed on neutral alumina (20 g). Elution with petroleum ether yielded camphene (0.075 g), which after distillation showed $[\alpha]_D^{20}$ - 5.0 (c 0.80, benzene). Elution with 2% ether-petroleum ether gave isobornyl acetate (0.225 g). The acetate (0.17 g) was reduced with lithium aluminium hydride in ether to yield white crystals of isoborneol (0.090 g), m.p. 208-210° (sealed capillary), $[\alpha]_D^{27}$ + 9.1 (c 1.092, ethanol). The isoborneol was found to be free from borneol by v.p.c. analysis (300' Ukon capillary column) under conditions where 1% of borneol could have been detected.

Reaction of camphene with acetic acid-sodium acetate.

(a) A solution of camphene (1.0 g) and sodium acetate (0.65 g) in acetic acid was sealed in ampoules in 5 equal portions. The ampoules were heated in a bath at 100° and were withdrawn at known intervals. The contents were worked up by the usual procedure and the

product was analysed by v.p.c. (12' BDS column). The compositions are summarised in table 10.

(b) (+)-Camphene (27 g) and sodium acetate (17 g) were refluxed in glacial acetic acid (250 ml) for 173 hr. The neutral product obtained by ether extraction was fractionated under reduced pressure. After a forerun, consisting mainly of camphene and tricyclene, a main fraction (21.2 g), b.p. 110-111°/18 mm was collected. The infrared spectrum of this material was identical with that of authentic isobornyl acetate. Bornyl acetate was shown to be absent by v.p.c. analysis (150' Apiezon capillary column, 135°) under conditions where 1% could have been detected. The distillation residue was distilled in a smaller flask to yield 1.8 g of liquid, which was shown by v.p.c. to consist of isobornyl acetate together with the unknown compound (ca. 10%) previously observed in the acetolysis products and in the reaction described in (a). Because of the small amount of this compound present in the mixture, attempts to isolate it were not thought to be worthwhile.

Preparation of the trifluoroacetates.

The following general procedure was used.[56] A cold solution of the alcohol in anhydrous ether was treated dropwise with an excess of trifluoroacetic anhydride, and the stoppered mixture was kept at room temperature overnight. The mixture was then poured into cold sodium carbonate solution and the ether layer was separated, washed with water and was dried. The product was distilled after removal of the ether.

(a) Isobornyl trifluoroacetate, obtained from isoborneol having $[\alpha]_D$-31 in 87% yield, had b.p. 97-98°/28mm, $[\alpha]_D^{19}$-32.5 (c 2.00, chloroform).

(Found: C, 57.6; H, 6.9. $C_{12}H_{17}F_3O_2$ requires: C, 57.6; H, 6.9%).

(b) Bornyl trifluoroacetate, obtained from borneol having $[\alpha]_D$ + 37 in 74% yield, had b.p. 97-98°/28 mm, $[\alpha]_D^{20}$+32.5 (c 2.52, chloroform).

(Found: C, 57.9; H, 6.9. $C_{12}H_{17}F_3O_2$ requires: C, 57.6; H, 6.9%).

(c) α-Campholenyl trifluoroacetate, obtained from α-campholenol having $[\alpha]_D$+ 5.4 in 67% yield, had b.p. 92-93°/13 mm, $[\alpha]_D^{20}$0 (chloroform).

(Found: C, 57.3; H, 6.7. $C_{12}H_{17}F_3O_2$ requires: C, 57.6; H, 6.9%).

(d) Methylcamphenilyl trifluoroacetate, obtained from (±)-methylcamphenilol in 88% yield, had b.p. 95-97°(bath)/13 mm.

(Found: C, 58.4; H, 6.9. $C_{12}H_{17}F_3O_2$ requires: C, 57.6; H, 6.9%).

(e) (±)-Camphene hydrate was converted to its trifluoroacetate in quantitative yield. The trifluoroacetate was not sufficiently stable to be distilled, and was therefore not analysed.

The trifluoroacetates all showed strong absorption at 1775, 1210, and 1150 cm^{-1}.

Acetolysis of (+)-bornyl trifluoroacetate.

(a) The trifluoroacetate (0.50 g) and fused sodium acetate

(0.35 g) were dissolved in acetic acid (16 ml). The solution was divided into 4 equal portions, and these were sealed in ampoules and heated at 100°. Ampoules were removed from the heating bath at intervals, and were cooled and opened. The contents were poured into water, neutralised by the addition of sodium carbonate and the mixture was extracted with ether. The ether extract was washed with water and dried, and the residue obtained after removal of the ether through a short fractionating column was analysed by v.p.c. (instrument 1, 6' squalene-Celite column, 158°). The composition of the product at various intervals is shown in the table below.

Time (hr)	Bornyl trifluoro-acetate (%)	Borneol (%)	Bornyl acetate (%)
6	41	31	28
12	24	19	57
18	9	13	78
26	3	4	93

The infrared spectrum of the product obtained after 6 hr at 100° showed strong absorption at 3450 (OH), 1780 (trifluoroacetate carbonyl) and 1740 (acetate carbonyl) cm^{-1}. With increasing reaction time the hydroxyl and the trifluoroacetate carbonyl band intensities decreased, and the acetate carbonyl intensity increased.

(b) A solution of the trifluoroacetate (1.0 g) and fused sodium acetate (0.70 g) in acetic acid (30 ml) was heated at 100° for 26 hr. The solution was worked up as in (a) to give an oil (0.67 g), the infrared spectrum of which was identical with that of bornyl acetate,

except for weak absorption at 3500 and 1780 cm^{-1}. This product was refluxed with an excess of lithium aluminium hydride in ether for 30 min, and work-up in the usual way yielded borneol (0.425 g), $[\alpha]_D^{20}$ + 36.1 (c 1.62, ethanol), the infrared spectrum of which was identical with that of an authentic sample.

Acetolysis of α-campholenyl trifluoroacetate.

The trifluoroacetate (0.10 g), fused sodium acetate (0.070 g) and acetic acid (3 ml) were heated in an ampoule at 100° for 10 hr. Work-up in the usual way yielded an oil (0.060 g), the infrared spectrum of which was identical with that of α-campholenyl acetate, except for weak trifluoroacetate carbonyl absorption at 1780 cm^{-1}. V.p.c. analysis (instrument 1, 6' squalene-Celite column, 153°) indicated that the product consisted of α-campholenyl acetate and a small amount of unchanged trifluoroacetate.

Acetolysis of (-)-isobornyl trifluoroacetate.

A solution of the trifluoroacetate (containing 4% of (+)-bornyl trifluoroacetate) (3.0 g, 0.012 mole) and fused sodium acetate (2.0 g, 0.025 mole) in acetic acid (100 ml) was heated at 100° for 5 hr. Work-up in the usual way gave an oil (1.45 g) which was shown by quantitative v.p.c. analysis (3' Apiezon column) to consist of tricyclene (4%), camphene (76%), isobornyl acetate (12%), unchanged bornyl trifluoroacetate (5%), and an unknown compound eluted after isobornyl acetate (3%). Examination by capillary v.p.c. (150' Apiezon column, 135°) revealed the presence of a small amount of bornyl acetate (2%) which

was apparently formed from the bornyl trifluoroacetate. Methylcamphenilyl acetate could not be detected. Under the conditions of the analysis the retention times were: bornyl acetate 9 min 55 sec; isobornyl acetate 10 min 20 sec; methylcamphenilyl acetate 10 min 50 sec. The acetolysis product (1.25 g) was chromatographed on neutral alumina (25 g). Elution with light petroleum yielded camphene (0.95 g), which after distillation had $[\alpha]_D^{21}$ + 103 (c 1.32, benzene). Elution with 10% ether-light petroleum gave isobornyl acetate (0.080 g), the infrared spectrum of which was identical with that of an authentic sample.

Acetolysis of methylcamphenilyl trifluoroacetate.

A solution of the trifluoroacetate (0.61 g, 0.0024 mole) and fused sodium acetate (0.50 g, 0.006 mole) in acetic acid (15 ml) was heated at 100° for 5 hr. Work-up by ether extraction gave an oil (0.28 g), which was shown by quantitative v.p.c. analysis (3' Apiezon column) to consist of tricyclene (5%), camphene (79%), isobornyl acetate (13%), and an unknown compound (3%). Capillary v.p.c. analysis showed that bornyl acetate and methylcamphenilyl acetate were not present in the product.

Acetolysis of the trifluoroacetate of camphene hydrate.

A solution of the trifluoroacetate (0.73 g, 0.0029 mole) and fused sodium acetate (0.50 g, 0.006 mole) in acetic acid (15 ml) was heated at 100° for 5 hr. The product (0.37 g) obtained by the usual work-up

procedure was shown by quantitative v.p.c. analysis to consist of tricyclene (4%) camphene (82%), isobornyl acetate (12%) and an unknown compound (2%). Bornyl and methylcamphenilyl acetates were shown to be absent by capillary v.p.c.

Acetolysis of (+)-bornyl p-nitrobenzenesulphonate.

A solution of the sulphonate (5.0 g, .015 mole) and sodium acetate (250 g, .030 mole) in acetic acid (120 ml) was heated at 100° for 13 hr. Work-up in the usual way gave 1.80 g of product, which was shown by quantitative v.p.c. to consist of tricyclene (5%), camphene (64%), isobornyl acetate (25%) and the unknown compound (6%). Capillary v.p.c. analysis showed that bornyl acetate and methylcamphenilyl acetate were absent under conditions where ca. 2% of each in the isobornyl acetate could have been detected. The acetolysis product (1.70 g) was chromatographed on silica gel (30 g). Elution with hexane gave camphene (0.72 g), which after distillation showed $[\alpha]_D^{25}$ + 56 (c 3.1, benzene). Elution with 2% ether-hexane gave 2 acetate fractions. The first of these (0.25 g) consisted of isobornyl acetate (v.p.c. and infrared spectrum) while the second (0.17 g) was shown by v.p.c. (3' Apiezon column, 190°) to consist of isobornyl acetate (70%, retention time 1 min 50 sec) and the unknown compound (30%, retention time 2 min 40 sec).

Stability of acetates in acetic acid-sodium acetate.

(a) A solution of methylcamphenilyl acetate (0.19 g) and sodium acetate (0.10 g) in acetic acid (5 ml) was kept at 100° for 6 hr.

Work-up by ether extraction gave unchanged acetate (0.16 g), identified by its infrared spectrum and retention time (150' Apiezon capillary column).

(b) The acetate of camphene hydrate (0.15 g) and sodium acetate (0.10 g) were heated in acetic acid (5 ml) at 100° for 6 hr. Work-up by ether extraction gave 0.095 g of semisolid material, the infrared spectrum of which showed strong absorption due to camphene (1650 and 880 cm^{-1}), and weak acetate bands at 1740 and 1240 cm^{-1}. V.p.c. examination (3' Apiezon column) indicated that the product consisted of camphene and ca. 5% of isobornyl acetate.

(c) A solution of α-campholenyl acetate (0.18 g) and sodium acetate (0.20 g) in acetic acid (6 ml) was kept at 100° for 96 hr. Ether extraction gave 0.15 g of slightly discoloured oil, the infrared spectrum of which was identical with that of the starting acetate. V.p.c. analysis (3' Apiezon column) showed only α-campholenyl acetate.

Solvolyses in aqueous acetone.

(a) A solution of methylcamphenilyl trifluoroacetate (0.50 g) in aqueous acetone (70% v/v, 25 ml) was heated under reflux with calcium carbonate (0.60 g) for 10 hr (bath temperature 70-75°). The mixture was diluted with water, and ether extraction gave 0.21 g of solid product. Capillary v.p.c. analysis (300' Ukon column, 140°) indicated that the product consisted of camphene (27%, retention time 8 min 50 sec), camphene hydrate (72%, 22 min) and isoborneol ($<1\%$, 26 min 20 sec). Methylcamphenilol and camphene hydrate could not however be separated. Synthetic mixtures of the two alcohols were eluted as sharp symmetrical

peaks (retention time 22 min). The infrared spectrum of the product (CCl_4) however indicated that the alcohol was camphene hydrate and not methylcamphenilol. Methylcamphenilol showed strong characteristic bands at 955 and 945 cm^{-1} which were not present in the spectra of camphene hydrate or the solvolysis product. However $< 10\%$ of methylcamphenilol in camphene hydrate could not be detected by these characteristic bands as judged by the spectra of synthetic mixtures of the two alcohols. The solvolysis product was dissolved in dimethylaniline (10 ml) and acetyl chloride (2 ml) was added. The mixture was kept at room temperature for 2 hr, and was then warmed on a water bath for 1 hr. The product obtained by addition of water and ether extraction in the usual way was analysed by v.p.c. (150' Apiezon capillary column, 150°, injector 220°). Under these conditions methylcamphenilyl acetate was stable, and was eluted as a sharp peak at 9 min 42 sec, while the acetate of camphene hydrate decomposed, and was eluted as a large peak at 4 min 30 sec and a minor peak at 9 min (apparently isobornyl acetate). The chromatogram of the acetylated solvolysis product was identical with that of the acetate of camphene hydrate. Methylcamphenilyl acetate could not be detected in the acetylated solvolysis product.

(b) A solution of isobornyl chloride (0.20 g) in aqueous acetone (70% v/v, 10 ml) was heated with calcium carbonate (0.30 g) at 55° (bath) for 17 hr. Work-up by ether extraction gave 0.14 g of colourless solid, which was shown by v.p.c. to consist of camphene (32%), camphene hydrate (67%) and isoborneol (1%). The infrared spectrum of this product (CCl_4) was identical with that obtained in (a). Acetylation with acetyl chloride-dimethylaniline and v.p.c. analysis as in (a) showed

that methylcamphenilol was not present.

Kinetic Measurements.

These were made using standard techniques.[78] Sodium acetate solution was prepared by adding the calculated quantity of A.R. sodium carbonate to a known volume of glacial acetic acid. Perchloric acid solution was similarly prepared by diluting A.R. perchloric acid with the required quantity of acetic acid. The perchloric acid was standardised against potassium hydrogen phthalate in acetic acid, and the sodium acetate was in turn standardised against the perchloric acid. Bromophenol blue in acetic acid was used as the indicator.

A 50 ml volumetric flask containing a weighed amount of sulphonate was filled to the mark with the acetic acid-sodium acetate solution. The resulting solution was divided into 8 equal portions which were sealed in ampoules. The ampoules were placed in a thermostatted bath and allowed to reach the bath temperature (15 min). Ampoules were withdrawn at known intervals, cooled in iced water (1 min) and allowed to attain room temperature (3 min). 5.0 ml of solution was withdrawn and titrated with the perchloric acid solution. The time of the first analysis was called zero time. The molarity of sodium acetate in the solvolysis solution was calculated from the volume of perchloric acid required to neutralise it. This enabled the amount of sodium acetate consumed, and hence the amount of sulphonic acid liberated to be calculated. From the latter value the concentration of sulphonate remaining was found.

If c_o = [sulphonate] at time = o, and c= [sulphonate] at time = t, then for a first order reaction

$$\ln c = \ln c_o - kt$$

or $$2.303 \log c = \ln c_o - kt$$

The slope of a plot of log c versus t is thus $-\frac{k}{2.303}$.

∝-Campholenyl p-nitrobenzenesulphonate in buffered acetic acid.

1. $T = 30.0 \pm 0.1^{\circ}C$

$HClO_4 = 0.0526M$

Initial $[NaOAc] = 0.0473M$

Initial [sulphonate] = 0.0246M

Time (hr)	Titre (ml)	c	log c
0.0	4.50	0.0245	-1.610
1.5	4.27	0.0221	-1.656
3.5	4.02	0.0195	-1.711
5.5	3.85	0.0177	-1.752
8.0	3.60	0.0150	-1.823
10.0	3.46	0.0136	-1.867
11.5	3.36	0.0125	-1.902
22.0	2.81	0.0068	-2.171

$k = 1.61 \times 10^{-5}$ sec^{-1} from slope of graph.

2. $T = 40.7 \pm 0.1^{\circ}$
$HClO_4 = 0.0507M$
Initial [NaOAc] = 0.0473M

(a) Initial [sulphonate] = 0.0288M.

Time (hr)	Titre (ml)	c	log c
0.0	4.51	0.0272	-1.566
0.5	4.24	0.0244	-1.612
1.5	3.77	0.0197	-1.707
3.0	3.24	0.0143	-1.845
4.5	2.87	0.0105	-1.977
6.0	2.57	0.0075	-2.126
8.0	2.33	0.0051	-2.296

$k = 5.94 \times 10^{-5}$ sec^{-1} from slope of graph.

(b) Initial [sulphonate] = 0.0199M

Time (hr)	Titre (ml)	c	log c
0.0	4.46	0.0178	-1.749
1.0	4.16	0.0148	-1.830
2.5	3.75	0.0106	-1.974
4.0	3.46	0.0076	-1.120
5.5	3.24	0.0054	-2.264
7.5	3.07	0.0037	-2.430
9.0	2.96	0.0026	-2.585

$k = 6.02 \times 10^{-5}$ sec^{-1} from slope of graph.

3. $T = 49.6 \pm 0.1^{\circ}$

$HClO_4 = 0.0555M$

Initial $[NaOAc] = 0.0473M$

Initial [sulphonate] = 0.0238M

Time (hr)	Titre (ml)	c	log c
0.0	4.02	0.0209	-1.681
0.5	3.58	0.0161	-1.794
1.0	3.23	0.0122	-1.914
1.5	3.04	0.0101	-1.996
2.5	2.65	0.0058	-2.234
3.0	2.56	0.0048	-2.316
4.0	2.40	0.0300	-2.523
5.5	2.31	0.0200	-2.699

$k = 1.35 \times 10^{-4}$ sec^{-1} from slope of graph.

4. $T = 60.0 \pm 0.1^{\circ}$

$HClO_4 = 0.0526M$

Initial $[NaOAc] = 0.0473M$

Initial [sulphonate] = 0.0265M

Time (hr)	Titre (ml)	c	log c
0.0	3.98	0.02210	-1.678
0.25	3.29	0.0137	-1.863
0.50	2.86	0.0092	-2.036
0.75	2.59	0.0064	-2.197
1.0	2.39	0.0043	-2.371
1.4	2.22	0.0025	-2.607
1.6	2.17	0.0020	-2.710

$k = 4.08 \times 10^{-4}$ sec^{-1} from slope of graph.

∝-Campholenyl p-nitrobenzenesulphonate in unbuffered acetic acid.

The liberated sulphonic acid was titrated with standard sodium acetate solution.

$T = 40.7 \pm 0.1^{\circ}$

NaOAc = 0.0473M

Initial [sulphonate] = 0.0210M

Time (hr)	Titre (ml)	c	log c
0.0	0.13	0.0208	-1.681
0.5	0.35	0.0176	-1.754
1.5	0.66	0.0147	-1.833
3.0	1.05	0.0110	-1.958
4.75	1.45	0.0072	-2.141
5.5	1.55	0.0063	-2.202
7.5	1.78	0.0041	-2.387

$k = 5.89 \times 10^{-5}$ sec^{-1} from slope of graph.

Dihydro-α-campholenyl p-nitrobenzenesulphonate in buffered acetic acid.

1. T = 60.0 ± 0.1°

$HClO_4$ = 0.0516M

Initial [NaOAc] = 0.0446M

Initial [sulphonate] = 0.0224M

Time (hr)	Titre (ml)	c	log c
0.0	4.30	0.0222	-1.654
9.0	4.13	0.0206	-1.686
20.0	4.02	0.0193	-1.715
32.5	3.85	0.0175	-1.756
50.0	3.65	0.0155	-1.811
74.0	3.44	0.0133	-1.876
104.5	3.23	0.0111	-1.954

$k = 2.01 \times 10^{-6}$ sec^{-1} from slope of graph.

2. T = 100°

(a) $HClO_4$ = 0.0490M

Initial [NaOAc] = 0.0482M

Initial [sulphonate] = 0.0231M

Time(hr)	Titre (ml)	c	log c
0.0	4.70	0.0202	-1.695
1.0	4.11	0.0144	-1.842
1.5	3.90	0.0124	-1.908
2.5	3.58	0.0093	-2.031
4.0	3.23	0.0058	-2.239
5.0	3.10	0.0045	-2.346
6.0	2.97	0.0032	-2.490

$k = 8.25 \times 10^{-5}$ sec^{-1} from slope of graph.

(b) $HClO_4$ = 0.0516M

Initial [NaOAc] = 0.0446M

Initial [sulphonate] = 0.0200M

Time (hr)	Titre (ml)	c	log c
0.0	4.17	0.0185	-1.734
1.0	3.66	0.0132	-1.880
2.0	3.30	0.0095	-2.023
2.75	3.15	0.0081	-2.093
3.5	2.98	0.0062	-2.210
4.5	2.80	0.0043	-2.365
5.25	2.74	0.0037	-2.432
6.0	2.67	0.0030	-2.527

$k = 8.34 \times 10^{-5}$ sec^{-1} from slope of graph.

II. Work described in part II.

Attempted preparation of 2-exo-cyanobornane (99, x = CN).

(a) A mixture of (+)-bornyl p-toluenesulphonate (0.30 g), powdered sodium cyanide (0.30 g) and dimethylformamide (5 ml) was sealed in an ampoule and heated at 55° for 45 hr. The reaction mixture was poured into water, extracted with ether, and the ether extract was thoroughly washed with water, and was dried. Removal of the ether yielded a colourless crystalline residue (0.29 g), m.p. 64-65°, whose infrared spectrum was identical with that of bornyl p-toluenesulphonate.

(b) A mixture of the toluenesulphonate (0.30 g), sodium cyanide (0.30 g) and dimethylformamide (20 ml) was heated at 110-130° for 10 hr (nitrogen atmosphere). Work-up by ether extraction gave a semi-solid product (0.10 g), the infrared spectrum of which was identical with that of camphene. Nitrile absorption was not present.

Attempted preparation of 2-endo-cyanobornane (98, x = CN).

(a) A mixture of (±)-isobornyl chloride (0.30 g), sodium cyanide (0.30 g) and dimethylformamide (5 ml) was kept at room temperature overnight. Work-up by ether extraction yielded unchanged isobornyl chloride (0.25 g), m.p. 161-162°, whose infrared spectrum was identical with that of the starting material.

(b) The same quantities of reactants as in (a) were sealed in an ampoule and maintained at 55° for 46 hr. Work-up yielded unchanged isobornyl chloride (0.26 g), identified by its infrared spectrum.

The following compounds were prepared by the method of Flautt and Erman[82] except that (+)-camphor was used as the starting material instead of (±)-camphor. Literature melting and boiling points are for the (±)-compounds:

2-(p-Anisyl)isoborneol (102), m.p. 105-107° (lit. m.p. 105-107°), $[\alpha]_D^{19}$ - 21.7 (c 1.08, chloroform).

2-(p-Anisyl)bornylene (103), m.p. 86-87° (lit. m.p. 71-72°), $[\alpha]_D^{19}$ - 177 (c 2.00, chloroform).

p-Bornylanisole (104), m.p. 37-38° (lit. b.p. 110°/ 0.1 mm), $[\alpha]_D^{20}$ - 39.3 (c 2.06, chloroform). Its n.m.r. spectrum showed singlets at τ9.30, 9.06, and 8.97 (3H each, methyl groups), a multiplet at 7.9-8.7 (7 H, methylene and bridgehead), a quartet at 7.03 (1 H, benzylic), a singlet at 6.22 (3 H, methoxyl), and a quartet at 3.10 (4 H, aromatic), in agreement with the spectrum published for the (±)-compound.[82]

p-Isobornylanisole (106).

A solution of 2-(p-anisyl)bornylene (12.0 g,) in ethanol (50 ml) was hydrogenated over nickel boride catalyst[84] (from 5.0 g of nickel acetate and 2.4 g of sodium borohydride) at 90° and 1900 lb./sq.in. for 20 hr. The catalyst was removed by filtration and the ethanol was removed under reduced pressure. The residue was dissolved in ether, washed with water and dried. Evaporation of the ether left a viscous oil (11.4 g), showing $[\alpha]_D^{18}$ - 56 (chloroform). A portion of this oil crystallised from cold methanol as colourless plates, which reverted

to oil on attaining room temperature. A sample which had been recrystallised twice in this fashion had $[\alpha]_D^{20}$ - 56. The n.m.r. spectrum showed methyl peaks at τ 9.30 and 9.20 in agreement with the literature values for (106). Contamination by p-bornylanisole (104) was indicated by methyl peaks at τ 9.08 and 9.00. From an integration the product was a 60:40 (106):(104) mixture. This product was used for the ozonolysis experiments.

Ozonolysis of p-isobornylanisole.

Ozonised oxygen was passed through a solution of p-isobornylanisole (9.5 g) in methylene chloride (250 ml) at -5° for 53 hr. Work-up as described for the bornyl compound[83] yielded a gummy acid fraction (5.3 g), which could not be induced to crystallise. The gum was chromatographed on silica gel (40 g) and elution with 5% ether-hexane afforded 2.25 g (33%) of crystalline acid, m.p. 68-70°, $[\alpha]_D^{20}$ - 23 (chloroform). Recrystallisation from aqueous methanol raised the m.p. to 71-73°, but the specific rotation was unchanged. For analysis a sample was distilled at 2 mm.

(Found: C, 72.7; H, 9.9. Calc. for $C_{11}H_{18}O_2$: C, 72.5; H, 10.0%).

Elution of the column with 10% ether-hexane yielded an oil, which was not further investigated.

In a separate experiment, ozonolysis of 1.0 g of p-isobornylanisole gave 0.60 g of gummy acid fraction, which after chromatography yielded 0.25 g of crystalline acid, m.p. 73-75°, $[\alpha]_D^{20}$ - 32 (chloroform).

(+)-2-endo-Carboxybornane.

This was prepared by the ozonolysis of (-)-bornylanisole using the procedure of Flautt and Erman.[83] The yield of crude crystalline acid was 84%. After one recrystallisation from aqueous methanol the acid showed m.p. 82-83° (lit.[80] m.p. 82-82.5°), $[\alpha]_D^{20}$ + 16.8, $[\alpha]_{578}^{24}$ + 17.2, $[\alpha]_{546}^{24}$ + 20.3, $[\alpha]_{436}^{24}$ + 38.0 (c 4.926, benzene) (lit.[80] $[\alpha]_{578}$ - 17.3, $[\alpha]_{546}$ - 19.5, $[\alpha]_{436}$ - 38.1).

2-endo-Carboxybornane, from bornyl chloride.

Bornylmagnesium chloride was prepared by the method of Rupe and Hirschmann[87] except that tetrahydrofuran was used as the solvent. Carbonation was effected by pouring the Grignard reagent onto dry ice. The acid crystallised from aqueous methanol as colourless plates, m.p. 74-75° (lit.[87] m.p. 73°), $[\alpha]_D^{21}$ 0 (c 4.26, benzene).

2-Methylenebornane.

Methyltriphenylphosphonium bromide[88] (130 g., 0.38 mole) was added portionwise to a stirred ethereal solution of n-butyllithium (320 ml of 1.2N solution, 0.38 mole) in an atmosphere of nitrogen. The mixture was stirred at room temperature for 1 hr, after which (+)-camphor (40.0 g, 0.26 mole) in ether (200 ml) was added dropwise. The solution was heated under reflux for 1 hr and was then kept at room temperature overnight. The majority of the ether was then slowly distilled from the reaction vessel, and was replaced by tetrahydrofuran (500 ml). The mixture was heated under reflux with stirring for 15 hr, after which

ca. half of the tetrahydrofuran was removed by distillation. The residue was treated with water (ca. 500 ml) and extracted with hexane (2 x 400 ml). The hexane solution was washed with water and dried, and filtered through a column of neutral alumina (700 g). Two 100 ml fractions giving positive tetranitromethane tests were collected. Removal of the hexane through a short fractionating column yielded 2-methylenebornane (25.5 g, 64%), containing ca. 5% camphor as judged by the carbonyl absorption in its infrared spectrum. Recrystallisation from methanol gave pure 2-methylenebornane (14.0 g), m.p. 68-69° (lit.[89] m.p. 68-70°), $[\alpha]_D^{26}$ - 48.5 (c 2.12, benzene).

2-exo-Hydroxymethylbornane.

A solution of disiamylborane (0.095 mole) in diglyme was prepared from 2-methylbut-2-ene (13.3 g, 0.19 mole), sodium borohydride (2.70 g, 0.071 mole) and boron trifluoride etherate (13.5 g, 0.095 mole).[85] To this stirred, cooled solution, maintained in an atmosphere of nitrogen, was added dropwise a solution of 2-methylenebornane (13.0 g, 0.087 mole) in diglyme (40 ml). Stirring was continued at 0° for 2 hr, and the mixture was then kept at room temperature overnight. The mixture was then oxidised by the addition of sodium hydroxide (3N, 30 ml) followed by hydrogen peroxide (30%, 30 ml). Work-up by ether extraction followed by fractional distillation yielded 2-exo-hydroxymethylbornane (9.5 g, 59%) b.p. 130-131°/15 mm, m.p. 106-108°, $[\alpha]_D^{23}$ - 49.3 (c 1.54, benzene). Sublimation gave an analytical sample, m.p. 107-109°, $[\alpha]_D^{20}$ - 50.8 (benzene).

(Found: C, 78.8; H, 11.8. $C_{11}H_{20}O$ requires C, 78.5; H, 12.0%).

A solution of the carbinol (0.20 g) in pyridine (10 ml) was treated with acetic anhydride (2 ml) and the mixture was kept at room temperature for 48 hr. Work-up by ether extraction and distillation yielded the acetate (0.21 g) as a colourless oil, b.p. 100°/(bath)/15 mm. V.p.c. analysis (150' Apiezon capillary column, 150°) indicated the presence of 10% of the acetate of endo-2-hydroxymethylbornane.

(-)-2-exo-Carboxybornane.

A stirred solution of (-)-2-exo-hydroxymethylbornane (4.3 g) in acetone (250 ml) was treated dropwise with Jones' reagent until the colour of the reagent persisted. The solution was stirred at room temperature for 1 hr, after which ethanol was added to remove excess of oxidising agent. The solution was diluted with water and concentrated under reduced pressure. The aqueous residue was extracted with ether, and the ether extract was washed with water and then extracted with dilute sodium hydroxide solution. The sodium hydroxide extract was acidified with dilute hydrochloric acid, and work-up by ether extraction yielded crystalline acid (3.5 g, 75%), m.p. 75-77°, α_D^{20} -62, $[\alpha]_{578}^{20}$ -70, $[\alpha]_{546}^{20}$ -82, $[\alpha]_{436}^{20}$ -136 (benzene). The rotations at the last three wavelengths correspond to those of a 75:25 exo:endo acid mixture, using the rotations for pure exo and endo acids given by de Botton.[80] This acid mixture (3.0 g, 0.016 mole) was dissolved in ethanol (30 ml) and was neutralised (phenolphthalein) by the addition of 1N sodium hydroxide solution. The volume of the solution was made

to 100 ml by the addition of water. (+)-Bornylamine hydrochloride[90] (2.3 g, 0.012 mole) was dissolved in 30% ethanol-water (120 ml), and part of this solution (60 ml) was added dropwise to the stirred solution of the sodium salt of the acid mixture. The precipitated salt was collected by filtration, suspended in dilute sodium hydroxide solution, and extracted with ether to remove the liberated bornylamine. The aqueous layer was acidified with dilute hydrochloric acid, and ether extraction yielded 1.06 g of acid, having $[\alpha]_D^{21}$ -92. The filtrate from above was treated with the remaining 60 ml of bornylamine hydrochloride solution, and work-up of the precipitated salt yielded a further 0.88 g of acid, having $[\alpha]_D^{21}$ -81. This was converted into the sodium salt and treated with bornylamine hydrochloride (0.67 g) in the manner described above to yield 0.54 g of acid having $[\alpha]_D^{20}$ -96. The acid fractions having $[\alpha]_D$ -96 and -92 were combined and recrystallised from aqueous methanol to give pure 2-exo-carboxybornane (1.16 g) as colourless plates, m.p. 81-82° (lit.[80] m.p. 81-81.5°), α_D^{18} -95, $[\alpha]_{578}^{24}$ -103, $[\alpha]_{546}^{24}$ -121, $[\alpha]_{436}^{24}$ -201 (c 2.123, benzene) (lit.[80] $[\alpha]_{578}$ -102.7, $[\alpha]_{546}$ -117.2, $[\alpha]_{436}$ -205.5).

Correlation of optical rotations.

The following acids were methylated with ethereal diazomethane: exo acid $[\alpha]_D$ -95 and $[\alpha]_D$ -62; endo acid $[\alpha]_D$ + 16.8. Synthetic mixtures of the exo and endo methyl esters could not be separated by v.p.c. on any of the following columns: 3' Apiezon, 6' Silicone, 12' B.D.S., 150' Apiezon capillary and 300' Ukon capillary. The methyl esters were reduced with lithium aluminium hydride in ether and the

products obtained by the normal work-up procedure were sublimed to yield the crystalline 2-hydroxymethylbornanes. The acetates of the exo and endo carbinols could be separated by v.p.c. (150' Apiezon capillary column). The rotations of the carbinols (in benzene) and their calculated compositions are shown below.

Source of carbinol	M.p.	$[\alpha]_D$	% exo	% endo
Reduction of endo acid $[\alpha]_D$ + 16.8	86-87°	+ 47.5	-	100 ≠
Reduction of exo acid $[\alpha]_D$ -95	113-114°	- 60	100 ≠	-
Hydroboration of 2-methyl-eneobornane	107-109°	- 50	91	9 *
Reduction of acid $[\alpha]_D$ -62	103-105°	- 33	75	25

≠ Homogeneous from v.p.c. of acetate.

* 90:10 mixture from v.p.c. of acetate.

β-(2,2,3-Trimethylcyclopent-3-enyl)propionic acid (101).

Powdered sodium cyanide (15 g) was added to a cold solution of (+)-α-campholenyl p-nitrobenzenesulphonate (12.0 g) in dimethylformamide (100 ml). The mixture was kept at room temperature overnight and then poured into water. The solution was extracted with ether and the ether extract was well washed with water and dried. The ether was removed to yield the nitrile (100, x = CN) as a pale yellow oil, which

showed infrared absorption at 2240 cm^{-1} (CN) and no sulphonate bands. The crude nitrile was refluxed with sodium hydroxide (40 g) in water (100 ml) for 1 hr. The cooled solution was washed with ether and the aqueous layer was acidified with dilute hydrochloric acid. The liberated organic acid was extracted into ether, and the ether extract was washed with water and dried. Removal of the ether afforded a crystalline residue (5.5 g), which was distilled to give 4.9 g (76% overall) of acid b.p. 112-114°/2 mm, m.p. 43-45°, $[\alpha]_D^{20}$ - 16.6, (c 5.1, benzene). For analysis a sample was redistilled.

(Found: C, 72.3; H, 9.8. $C_{11}H_{18}O_2$ requires C, 72.5; H, 10.0%).

Bornane.

A mixture of camphor hydrazone (5 g), potassium hydroxide (2 g) and diethylene glycol (30 ml) was heated under reflux for 2 hr. During this period a considerable amount of white material sublimed into the condenser. This material was washed out with ether, and the reaction vessel was set for distillation, and ca. 15 ml of diethylene glycol was distilled. The combined distillate and ether solution was washed with water and dried. Distillation from sodium of the residue obtained on removal of the ether gave a colourless solid (3.5 g), b.p. 155-170°, which appeared to contain unchanged hydrazone (from infrared spectrum). Recrystallisation from methanol gave colourless crystals of bornane (1.5 g, 36%), m.p. 155-156° (sealed capillary, lit.[107] m.p. 156-157°).

Oxidative decarboxylation of (±)-2-endo-carboxybornane in benzene-pyridine.

A stirred solution of the acid (8.0 g, 0.044 mole), pyridine (5.0 g, 0.063 mole) and lead tetraacetate (29.0 g, 0.065 mole) in dry benzene (90 ml) maintained in a nitrogen atmosphere was slowly heated to 95° (external bath temperature). At this temperature a vigorous evolution of gas commenced and continued for 2-3 min, and the solution began to deposit colourless crystals (presumably lead (II) acetate). The stirred solution was maintained at 85-90° (bath) for 4½ hr. The cooled solution was then poured into water, the benzene layer was separated, and the aqueous layer was extracted with ether. The combined organic layers were washed successively with dilute hydrochloric acid, water, diluted sodium hydroxide solution, and water. Acidification of the sodium hydroxide extract followed by ether extraction gave a gummy acid fraction (0.23 g), which was not further investigated.

The dried organic extract was concentrated through a short fractionating column, and the residue was freed of last traces of solvent *in vacuo* at room temperature. The residual oil was distilled into a receiver immersed in a dry ice-ethanol bath to yield a colourless liquid (3.95 g), b.p. 20-66°/*ca.*1 mm, $\nu_{max.}$ (film) 1740(m), 1730(s), 1650(m), 1235(s) and 880 (s) cm^{-1}. The viscous residue (0.78 g) which remained in the flask was not further investigated.

The distilled product was analysed by v.p.c. (150' Apiezon capillary column, 130°) and the composition is shown in Table 17. Detector response factors were determined from synthetic mixtures of camphene and

isobornyl acetate, and the observed peak areas of the hydrocarbons were multiplied by the factor for camphene (0.89), and the acetate peak areas were multiplied by the factor for isobornyl acetate (1.30). It was later found that the reaction product contained the acetate of camphene hydrate, and that this material decomposed to camphene on the column. The camphene content of the product shown in Table 17 is therefore high. Bornane, limonene, and α-terpinyl acetate were shown to be absent from the product by co-chromatography.

(a) Silica gel chromatography.

The decarboxylation product (0.88 g) was chromatographed on silica gel (50 g). Elution with hexane yielded a liquid fraction (0.35 g), the infrared spectrum of which was identical with that of camphene. This fraction however failed to solidify, and v.p.c. analysis showed that it was a mixture of camphene and the component later shown to be 8-methylcamphene. Elution with 5% ether-hexane gave an acetate fraction (0.17 g), $\nu_{max.}$ (film) 1740, 1730 and 1235 cm^{-1}.

(b) Silica gel-silver nitrate chromatography.

The adsorbent was prepared by shaking silica gel (100 g) with a solution of silver nitrate (32 g) in water (10 ml) for 5 hr, and drying the resulting powder at 100° overnight.[91] The decarboxylation product (1.46 g) was chromatographed on this adsorbent (75 g) in light petroleum (b.p. 40-60°). Fractions (ca. 20 ml) were collected, concentrated through a fractionating column, and analysed by v.p.c. (150' Apiezon capillary column, 130°). Fractions which had similar compositions were combined.

Fractions 1-8 contained only trace amounts of material.

Fractions 9-11 were homogeneous, and were distilled in a bulb to yield trans-8-methylcamphene (0.025 g) as a colourless liquid. The n.m.r. spectrum is described in Table 20(a). The infrared spectrum (CCl_4) showed bands at 1485(w), 1460(s), 1450(m), 1385(s), 1365(s), 1290(m), 1170(w), 1155(w), 1115(m), 1045(w), 980(m), 950(m), and 880(m) cm^{-1}.

Fraction 12 consisted of trans-8-methylcamphene, and the component later shown to be cis-8-methylcamphene.

Fraction 13 consisted of approximately equal quantities of cis and trans-8-methylcamphene and camphene.

Fractions 14-19, eluted with 1% ether-light petroleum, yielded camphene (0.44 g), m.p. 45-47°, the infrared spectrum of which was identical with that of an authentic sample.

Fraction 20 (0.17 g) consisted of acetates B and C, contaminated by camphene. Bulb to bulb distillation at 120°/15 mm gave the acetates (0.080 g) free from camphene. The infrared spectrum (film) showed peaks at 1750(s), 1460(m), 1385(m,sh), 1370(s), 1275(w), 1225(s), 1165(w), 1155(w), 1095(m), 1075(m), 1055(m), and 910(w)cm^{-1}.

Fraction 21 (0.14 g) consisted of isobornyl and bornyl acetates, contaminated by small amounts of camohene and acetates C and D. The infrared spectrum of this fraction was identical with that of isobornyl acetate except for bands at 1225 (m, sh), 1095(w) and 1030 (wmsh)cm^{-1}.

Oxidative decarboxylation of (+)-endo-2-carboxybornane.

A solution of the optically active acid (2.50 g 0.0137 mole), pyridine (1.60 g, 0.020 mole) and lead tetraacetate (6.2 g, 0.014 mole) in dry benzene (40 ml) was maintained in a nitrogen atmosphere at 85-95° with stirring for 3½ hr. The reaction mixture was worked up as described for the (±)-endo acid above. Unchanged acid (0.36 g, m.p. 79-81°) was recovered from the sodium hydroxide extract. The neutral portion of the product was distilled and the fraction (0.37 g) b.p. to 40°/1 mm was collected in a receiver cooled in a freezing mixture. V.p.c. analysis of this fraction indicated that it consisted mainly of camphene, together with small amounts of tricyclene and 8-methyl-camphene. The mixture was chromatographed on silver nitrate impregnated silica gel (20 g) in hexane, and the concentrated fractions were examined by v.p.c., and fractions containing only camphene were combined. Removal of the solvent followed by bulb to bulb distillation gave camphene (0.11 g), $[\alpha]_D^{20}$ + 112 (c. 3.92, benzene). Distillation of the remaining neutral portion of the product yielded an acetate fraction (0.34 g), b.p. 130° (bath)/15 mm, which was shown by v.p.c. (300' Ukon capillary column, 140°) to consist of bornyl acetate (17%), isobornyl acetate (34%), acetate of camphene hydrate (35%), acetate A (2%), acetate B (6%), and acetate C (6%). The relative amounts of the acetates of borneol, isoborneol, and camphene hydrate are shown in Table 19.

Oxidative decarboxylation of (-)-2-exo-carboxybornane.

A stirred solution of the acid (0.96 g, 0.0053 mole), pyridine

(0.60 g, 0.0065 mole) and lead tetraacetate (2.4 g, 0.0055 mole) in benzene (15 ml) was stirred at 90-95° (bath) in a nitrogen atmosphere for 4½ hr. The reaction mixture was worked up as described for the endo acid, and unchanged acid (0.12 g) was recovered. The neutral product was distilled into a receiver immersed in dry ice-ethanol bath to yield a colourless liquid (0.325 g), $\nu_{max.}$ (film) 1750(m), 1740(s), 1650(w), 1220(s) and 880(s)cm^{-1}. The composition of the product was determined by v.p.c. (150' Apiezon capillary column, 130°) under conditions identical with those used for the (±)-endo decarboxylation product, and the results are summarised in Table 17.

The decarboxylation product (0.20 g) was chromatographed on silver nitrate impregnated silica gel (15 g) in hexane, and the fractions were analysed by v.p.c. Fractions 4-6, which contained only camphene, were combined and distilled to yield 0.085 g, $[\alpha]_D^{19}$ + 109 (c. 1.70, benzene). Elution with 10% ether-hexane gave an acetate fraction (0.050 g) which was shown by v.p.c. (300' Ukon capillary column, 140°) to consist of bornyl acetate (16%), isobornyl acetate (34%), the acetate of camphene hydrate (33%), acetate A (3%), acetate B (7%) and acetate C (7%). The relative amounts of the acetates of borneol, isoborneol and camphene hydrate are shown in Table 19.

Complete analyses of the oxidative decarboxylation products on the 300' Ukon capillary column.

(a) (±)-2-endo-Carboxybornane.

A solution of the acid (2.0 g, 0.011 mole) and pyridine (1.20 g,

0.015 mole) in dry benzene (40 ml) was heated under reflux in a stream of nitrogen for 15 min. The solution was allowed to cool somewhat, and lead tetraacetate (5.8 g, 0.013 mole) was added. The mixture was stirred at 90-5° (bath) in a nitrogen atmosphere for 4 hr, and was then kept at room temperature overnight. The addition of water caused the precipitation of brown lead dioxide, indicating that all of the lead tetraacetate had not been consumed in the reaction. Work-up in the usual way yielded unchanged acid (0.60 g), and a neutral fraction which was distilled into a receiver cooled in a dry ice-ethanol bath to give a colourless liquid (0.71 g), $\nu_{max.}$ (film) 1750 (m), 1740(s), 1650(w), 1235(s) and 880(m) cm^{-1}. The product was analysed on the 300' Ukon capillary column at 140°. The retention times of the components were: tricyclene8 min 10 sec; camphene 8 min 50 sec; trans-8-methylcamphene 10 min 55 sec; bornyl acetate 27 min 50 sec; isobornyl acetate 28 min 35 sec; acetate of camphene hydrate 31 min 40 sec; acetate A 37 min 30 sec; acetate B 39 min 40 sec; and acetate C 40 min 30 sec. Bornane (retention time 8 min 30 sec) was not present under conditions where 0.5% in the camphene could have been detected. Methylcamphenilyl acetate (retention time 30 min 5 sec) was not observed under conditions where 1% of it in the acetate of camphene hydrate would have been detected. The quantitative composition of the product is shown in Table 18. The detector response factors for the hydrocarbons were assumed to be identical, as were the detector response factors for all the acetates. Response factors were determined from synthetic mixtures of camphene and isobornyl acetate, and the observed peak areas of the hydrocarbons

were multiplied by the factor for camphene (0.89), and the acetate peak areas were multiplied by the factor for isobornyl acetate (1.30).

Quantitative analysis was also carried out on a 3' Apiezon column (sample injected at 140° and column programmed to 180° at 20°/min when the camphene had been eluted). Under these conditions some baseline drift due to decomposition of the acetate of camphene hydrate was observed. This baseline drift contributed to the peak areas of hydrocarbons. The composition was found to be tricyclene (4%), camphene (59%), 8-methylcamphene (9%), bornyl and isobornyl acetate (15%), and acetates A + B + C (13%). These values are in reasonable agreement with those listed in Table 18.

(b) (+)-2-*endo* and (-)-2-*exo*-Carboxybornane.

The acid used was that recovered from its bornylamine salt from the preparation of the pure *exo* acid. The acid had m.p. 75-77°, $[\alpha]_D^{22}$ - 47 (c. 2.54, benzene) and was therefore a 57:43 *exo*:*endo* mixture.

A solution of the acid (0.95 g, 0.0052 mole) and pyridine (0.60 g, 0.0076 mole) in benzene (20 ml) was heated under reflux in a stream of nitrogen for 15 min. The solution was allowed to cool somewhat, and lead tetraacetate (2.9 g, 0.0065 mole) was added. The solution was stirred at 90-95° (bath) for 4½ hr. Water was added (lead dioxide was not precipitated) and the mixture was worked up in the usual way to give unchanged acid (0.060 g) and a neutral fraction. The latter was distilled into a receiver immersed in a dry ice-ethanol bath to give a colourless liquid (0.62 g), the infrared spectrum of which was identical

with that of the product obtained from the endo acid in (a). The composition found by analysis on the 300' Ukon capillary column is given in Table 18. Bornane and methylcamphenilyl acetate were not detected. Quantitative analysis on the 3' Apiezon column as described for the product from the endo acid in (a) showed the composition to be tricyclene (5%), camphene (62%), 8-methylcamphene (9%), bornyl + isobornyl acetate (13%) and acetate A + B + C (10%).

Oxidative decarboxylation of β-(2,2,3-trimethylcyclopent-3-enyl)propionic acid (101).

A solution of the acid (3.0 g, 0.0164 mole) and pyridine (20 g, 0.025 mole) in benzene (40 ml) was heated under reflux with lead tetraacetate (9.3 g, 0.021 mole) in a nitrogen atmosphere for 4 hr. Work-up as described for the previous decarboxylation products gave an acid fraction (1.30 g) as a viscous oil, which partly crystallised on standing. The infrared spectrum of this material was identical with that of the starting acid, except for a band at 1740 cm^{-1} (m, sh), and general broadening of the other bands. The neutral fraction was distilled into a receiver immersed in a dry ice-ethanol bath. The first fraction (0.24 g), b.p. to 130° (bath)/1 mm, showed infrared absorption at 1750 (m, sh), 1735 (s), 1650(w), 1245(s) and 880(s) cm^{-1}. This spectrum was virtually identical with the spectra of the distilled oxidative decarboxylation products of 2-exo and 2-endo-carboxybornane. V.p.c. analysis (6' Silicone column, sample injected at 140° and temperature

programmed to 200° at 4°/min) showed the following approximate composition (normalised peak areas only): tricyclene 7%, camphene 63%, 8-methylcamphene 9%, and acetates 21%. Capillary v.p.c. analysis (150' Apiezon column, 130°) confirmed the presence of camphene, 8-methylcamphene and isobornyl acetate, but 3 minor hydrocarbon and 2 major acetate peaks not observed in the other oxidative decarboxylation products were also recorded. α-Campholenyl acetate was shown to be absent by co-chromatography.

A second fraction (0.22 g), b.p. to 140° (bath)/1 mm was collected. Its infrared spectrum (film) showed acetate absorption at 1740(s) and 1245(s) cm^{-1}, and another carbonyl band at 1770 (m, sh) cm^{-1}. V.p.c. analysis (6' Silicone column, 170°) showed the presence of 4 main components: retention times 3 min (12%), 3 min 40 sec (21%), 6 min (11%) and 7 min 40 sec (56%). The viscous residue in the distillation flask (0.50 g) showed infrared bands at 1800(m), 1770(s), 1740(s), 1245(s) and 1030(s) cm^{-1}.

Because of the complex nature of these mixtures, they were not further investigated.

Reaction of camphenilone with ethylmagnesium bromide.

To an ethereal solution of ethylmagnesium bromide prepared from magnesium (1.44 g, 0.060 g - atom) and ethyl bromide (6.6 g, 0.060 mole) was added a solution of (±)camphenilone (5.0 g, 0.036 mole) in ether over a period of 15 min. The stirred solution was heated under reflux in a nitrogen atmosphere for 2 hr, and during this period a

white complex separated out from the solution. After the mixture had been kept at room temperature overnight, saturated ammonium chloride solution was added, the ether layer removed by decantation and the inorganic residue washed with ether. The combined ether layer was washed with water, dried, and the ether was removed by distillation through a short fractionating column to give a colourless liquid residue (60 g) which showed strong hydroxyl but no carbonyl absorption in the infrared region. Distillation gave a colourless oil (4.9 g), b.p. 100-103°/20 mm, which partly solidified on cooling. The distillate was diluted with a small volume of light petroleum, and the colourless crystals which separated were collected (2.3 g). Recrystallisation from a small volume of light petroleum gave camphenilol as colourless needles, m.p. 73-74° (lit.[108] m.p. 76°).

(Found: C, 76.8; H, 11.5. Calc. for $C_9H_{16}O$: C, 77.1; H, 11.5%).

V.p.c. examination (3' Apiezon column, 150°) showed that the material recovered from the mother liquor of the first recrystallisation consisted of camphenilol (44%, retention time 1 min 40 sec) and two other components (13% and 43%, retention times 2 min and 2 min 20 sec, respectively). This material (2.5 g) was chromatographed on neutral alumina (70 g) in hexane. The column was eluted with 1% ether-hexane and fractions (25 ml) were collected, concentrated through a short fractionating column, and analysed by v.p.c. Fractions 1-8 consisted of the component having retention time 2 min 20 sec, and were combined to yield 0.35 g of the tertiary alcohol (120). The n.m.r. spectrum was complex, and the only absorption readily discernible was at τ 9.13

and 9.06 (CH_3), and at 7.87 (bridgehead-CH-C(OH)-). The complete absence of absorption below τ 7.87 confirmed that the alcohol was tertiary.

Subsequent fractions eluted from the column were mixtures.

8-Methylcamphene.

(a) A solution of the alcohol (120) (0.34 g) in dry pyridine (5 ml) was cooled and phosphorus oxychloride (1 ml) was added. After being kept at room temperature for 40 hr, the mixture was poured into cold dil. hydrochloric acid. Work-up by ether extraction gave a liquid (0.25 g), which still showed weak hydroxyl absorption in its infrared spectrum. The product was chromatographed on neutral alumina (20 g) and elution with hexane gave 8-methylcamphene (0.090 g), the infrared spectrum of which was identical with that of the material obtained from the lead tetraacetate reactions. The v.p.c. retention times of the samples were also identical (3' Apiezon column, 140°).

(b) Ethyltriphenylphosphonium bromide[109] (11.0 g, 0.033 mole) was added to a cold solution of n-butyllithium (0.030 mole) in ether (50 ml) maintained in a nitrogen atmosphere. The resulting deep red solution was stirred at 0° for 15 min and then at room temperature for 15 min. A solution of camphenilone (1.40 g, 0.010 mole) in ether (40 ml) was added, and the mixture was heated under reflux for 1 hr. The ether was then slowly distilled from the flask and was replaced by anhydrous tetrahydrofuran, and the mixture was then heated under reflux for 17 hr.

The reaction mixture was cooled, diluted with water, and extracted with hexane. The hexane extract was washed with water, dried, and concentrated in volume to ca. 20 ml. (Some triphenylphosphine oxide crystallised out at this stage.) The hexane extract was chromatographed on alumina (40 g) and fractions (50 ml) were collected. Fractions 1-2 yielded a colourless liquid, which lacked carbonyl absorption in the infrared region. Fractions 3-6 gave unchanged camphenilone (0.58 g). Distillation of the hydrocarbon fraction gave a liquid (0.54 g), b.p. 170-180° (bath), which was shown by v.p.c. (150' Apiezon capillary column, 140°) to consist of trans-8-methylcamphene (23%, retention time 5 min 45 sec, identical with that of the sample obtained from the phosphorus oxychloride reaction) and cis-8-methylcamphene (77%, retention time 6 min 15 sec). The n.m.r. spectrum of the mixture showed complex absorption at τ 9.07-8.11, a broad singlet at 7.53 (bridgehead $-\underset{|}{C}H-C=CH-$ of cis isomer), and overlapping quartets centred at 5.14 and 4.92 ($=C\underline{H}-CH_3$ of trans and cis isomers respectively). From the integration of the bridgehead proton areas, the product was an ca. 80:20 cis:trans mixture. The infrared spectrum (CCl_4) showed bands at 1485(m), 1463(s), 1450(s), 1385(m), 1363(s), 1343(w), 1305(w), 1300(w), 1288(w), 1270(w), 1250(w), 1165(w), 1155(w), 1108(m), 1028(w), 978(m), 946(w), 916(w), and 876(w) cm^{-1}. For analysis a sample was redistilled.

(Found: C, 86.6; H, 12.3. $C_{11}H_{18}$ requires C, 87.9; H, 12.1%).

The low carbon value for the analysis indicated the presence of some

impurity. A sample redistilled from sodium gave similar analytical figures.

(Found: C, 86.9; H, 12.1%).

Reaction of camphene with lead tetraacetate in benzene.

A solution of camphene (15.0 g, 0.11 mole) and lead tetraacetate (53 g, 0.12 mole) in dry benzene (120 ml) was heated under reflux in a nitrogen atmosphere for 4 hr. The solution was cooled and diluted with water (brown lead dioxide was precipitated at this stage due to the presence of unchanged lead tetraacetate). After the lead salts had been precipitated as lead chloride by the addition of dilute hydrochloric acid, the benzene and aqueous layers were removed by decantation. The benzene layer was separated and the aqueous layer was extracted with ether. The combined organic layers were washed with water, dried and the solvent slowly removed through a short fractionating column. The residue was distilled under reduced pressure, and fractions were analysed by v.p.c. (3' Apiezon column, 120°).

Fraction 1 (2.5 g), b.p. 55-60°/20 mm, consisted mainly of camphene.

Fraction 2 (0.60 g), b.p. 60-66°/20 mm consisted of approximately equal quantities of camphene and 8-methylcamphene.

Fraction 3 (0.20 g) b.p. 66-85°/20 mm consisted mainly of 8-methylcamphene.

Fractions 2 and 3 were combined and chromatographed on silver nitrate impregnated silica gel (30 g) in hexane. Fractions (25 ml)

were collected, concentrated, and analysed by v.p.c. Fractions 4-8 were homogeneous and were combined and concentrated to yield 8-methylcamphene (0.080 g), the infrared spectrum of which was identical with that of the sample isolated from the oxidative decarboxylation of (±)-2-endo-carboxybornane.

The remaining product was distilled to give a main fraction (5.5 g), b.p. 122-126°/20 mm, and a viscous residue (5.9 g). The distillate was analysed by v.p.c. (150' Apiezon capillary column, 130°) and its composition (normalised peak areas only) is given in Table 20(b).

Reaction of camphene with lead tetraacetate in acetic acid.

A solution of camphene (7.0 g, 0.051 mole) and lead tetraacetate (25 g, 0.056 mole) in glacial acetic acid (50 ml) was heated at 95-100° (bath) for 20 min. A small sample withdrawn at the end of this time did not liberate lead dioxide on being treated with water. The reaction mixture was cooled, diluted with water, and extracted with ether. After the ether extract had been washed with sodium carbonate solution, water, and dried, the residue obtained on evaporating the ether was distilled at 18 mm.

Fraction 1 (0.60 g), b.p. to 110° was shown by v.p.c. to consist mainly of camphene. 8-Methylcamphene could not be detected.

Fraction 1 (5.65 g), b.p. 110-126°, $\nu_{max.}$ (film) 1740(s), 1700(s), 1670(m) and 1220(s) cm^{-1}, was analysed by capillary v.p.c. and its composition (normalised peak areas only) is given in Table 20(b). Because of its complex nature, this mixture was not further examined.

A viscous oil (1.6 g) remained in the distillation flask.

Work described in part III.

Camphenilone (119).

This material, obtained by the ozonolysis of camphene according to Bailey,[122] was generously provided by Dr. G.E. Gream. (+)-Camphenilone, $[\alpha]_D^{18}$ + 61 (c. 2.46, benzene) was obtained from camphene $[\alpha]_D$ + 107. The calculated optical purity of the camphenilone was 80%, using the value $[\alpha]_D$ + 76.1 (benzene) for optically pure camphenilone reported by Vaughan and Perry.[123]

V.p.c. analysis of the lactone mixtures.

The lactone mixtures were analysed using a 3' Apiezon column. The samples (dissolved in benzene) were injected with the injector temperature at 260°, and the column temperature at 170°. The column temperature was programmed to 210° at 10°/min 1 min after the injection. Under these conditions, the following retention times were observed: endo lactone (125), 6 min; exo lactone (124), 6 min 15 sec; δ-lactone (129), 7 min. Because of overlap of the peaks due to the exo and endo lactones, the reported compositions (normalised peak areas) are regarded as accurate to ca. ± 4%. Several exo-endo mixtures were analysed on a 150' Apiezon capillary column at 190°, with the injector temperature at 260°. Under these conditions, the retention times of the endo and exo lactones were 13 min 0 ± 5 sec, and 14 min 0 ± 5 sec, respectively; slight "tailing" of the peaks was observed. The compositions of several mixtures were in good agreement (± 2%) with those determined on the 3' Apiezon column.

Attempted oxidative decarboxylation of 2-endo-carboxybornane.

The method was based on that of LeBel and Huber.[91] A solution of (±)-2-endo-carboxybornane (1.80 g, 0.01 mole) and fused sodium acetate (1.00 g, 0.012 mole) in glacial acetic acid (40 ml) was warmed to 60°. Lead tetraacetate (5.1 g, 0.0115 mole) was added and the temperature of the stirred solution was slowly raised to 116-118° over a period of 1 hr. During this time, no evolution of carbon dioxide was observed. After being kept at this temperature for 1½ hr and then at room temperature overnight, the solution was poured into water and the bulk of the acetic acid was neutralised by the addition of potassium carbonate. The solution was extracted with ether and the ether extract was washed with dilute potassium hydroxide solution (acidification of this extract followed by ether extraction gave unchanged acid (1.0 g), m.p. 73-75°), water and was dried. Removal of the ether left a semisolid residue (0.40 g) which from light petroleum yielded colourless plates (0.11 g), m.p. 97-100°. A second recrystallisation raised the m.p. to 101-103°.

(Found: C, 74.35; H, 9.2. $C_{12}H_{18}O_2$ requires C, 74.2; H, 9.3%). It showed infrared absorption (CCl_4) at 1777(s), 1465(m), 1421(m), 1386(m), 1366(m), 1297(m), 1282(m), 1261(s), 1250(s), 1201(w), 1185(m), 1171(s), 1147(m), 1131(m), 1121(m), 1072(w), 1065(w), 1026(m), 1013(m), 975(w), 970(m), 951(w), 917(m), 910(msh) cm^{-1}. Its n.m.r. spectrum showed signals at τ 9.02 (6H, $2CH_3$), and 8.88-7.57 (complex, 12H). V.p.c. analysis showed that this product was a 79:21 mixture of the exo lactone (124) and the endo lactone (125).

Action of lead tetraacetate on camphene in acetic acid. cf.[105a]

A solution of (±)-camphene (5.0 g, 0.038 mole), fused sodium acetate (3.3 g, 0.040 mole) and lead tetraacetate (18.0 g, 0.040 mole) in glacial acetic acid (50 ml) was stirred at 100-110° for 75 min and then kept at room temperature overnight. The mixture was poured into excess of water and work-up by ether extraction in the usual fashion gave an oil (6.2 g) which was distilled to give a small hydrocarbon forerun and a main acetate fraction (3.1 g), b.p. 112-122°/15 mm. The distillation residue (1.4 g), after being freed from further volatile material by distillation at 100° (bath)/2 mm, was diluted with light petroleum. The solid material (0.16 g) was collected and recrystallised twice from light petroleum to give colourless plates (0.040 g), m.p. 101-103° (lit.[105a] m.p. 101°), undepressed in admixture with the product from the attempted oxidative decarboxylation of 2-endo-carboxybornane. The infrared spectra of the two samples were also identical. Capillary v.p.c. analysis showed the product to be a mixture containing 83% exo lactone and 17% endo lactone. A sample in admixture with the pure synthetic (±)-endo lactone melted at 101-102°.

Tertiary alcohol (127).

To an ethereal slurry of allylmagnesium chloride[124] (0.10 mole) maintained in an atmosphere of nitrogen was added an ethereal solution of (±)-camphenilone (6.0 g, 0.043 mole) over a period of 10 min. The mixture was stirred at room temperature for 1 hr, and was then heated under reflux for 4 hr. After the mixture had been kept at room temp-

erature overnight, saturated ammonium chloride solution was added. The ether layer was separated by decantation and the inorganic residue was washed thoroughly with ether. The combined ether extract was washed with water and dried. Removal of the ether and distillation of the residue yielded a colourless oil (6.8 g, 87%), b.p. 68-71°/1mm. V.p.c. analysis (150' Apiezon and 300' Ukon capillary columns) indicated > 99% purity. For analysis a sample was redistilled.

(Found: C, 80.2; H, 11.2. $C_{12}H_{20}O$ requires C, 79.9; H, 11.2%).

The optically active alcohol (127), $[\alpha]_D^{18}$ + 44.4 (c. 1.90, benzene) was obtained in similar yield from (+)-camphenilone.

Hydroboration - oxidation of the tertiary alcohol (127).

(a) A cooled solution of the (±)-alcohol (2.3 g, 0.014 mole) and sodium borohydride (1.5 g, 0.040 mole) in dry diglyme (50 ml) maintained in an atmosphere of nitrogen was treated dropwise with boron trifluoride etherate (5.0 g, 0.035 mole). When the addition was completed, the mixture was stirred at room temperature overnight and then oxidised by the addition of sodium hydroxide (3N, 10 ml) and hydrogen peroxide (30%, 10 ml). The mixture was stirred at 50-60° for 2 hr, cooled, diluted with water, and extracted with ether. The ether extract was washed thoroughly with water and dried. Removal of the ether gave a colourless viscous oil (2.5 g) which on trituration with light petroleum yielded colourless plates (1.1 g, 42%), m.p. 66-67°. Two recrystallisations from light petroleum gave pure diol

(128, R=R'=H), m.p. 68-69°.

(Found: C, 72.9; H, 11.15. $C_{12}H_{22}O_2$ requires C, 72.7; H, 11.2%).

(b) A similar reaction was carried out using optically active tertiary alcohol (127) (7.0 g), sodium borohydride (4.6 g) and boron trifluoride etherate (7.1 g) in diglyme (100 ml). The product obtained by work-up following the alkaline peroxide oxidation was distilled to yield a viscous oil (6.1 g), b.p. 125-130°/0.5 mm, which could not be induced to crystallise. Thin layer chromatography (silica gel in 1:1 ether-hexane) revealed the presence of two components (Rf 0.15 and 0.13) other than the desired diol (Rf 0.09). Part of the product (3.30 g) was chromatographed on a column of silica gel (50 g) in 50% ether-hexane. Elution with 70% ether-hexane gave a fraction (0.42 g) m.p. 79-81° which consisted mainly of the component Rf 0.15. Two recrystallisations from hexane gave the diol (140) as colourless needles, m.p. 83-84°.

(Found: C, 73.0; H, 11.2. $C_{12}H_{22}O_2$ requires C, 72.7; H, 11.2%). The n.m.r. spectrum showed signals at τ 9.07 (singlet, 6H, 2 tertiary CH_3); 8.93 - 8.15 (complex, 12H, $-CH_2-$ and $-\overset{|}{C}H-$, $-CH(OH)CH_3$); 7.67 (broad singlet, 1H, bridgehead $-\overset{|}{C}H-C(OH)-$); 7.0-6.20 (broad, 2H, OH); 5.87 (complex, 1H, $-\overset{|}{C}H(OH)CH_3$). Further elution with 70% ether-hexane yielded fractions (total 0.58 g) shown to be mixtures of the components Rf 0.15 and 0.13. This material was rechromatographed on silica gel (15 g) and elution with 50% ether-hexane yielded a further quantity of the diol (140), followed by essentially pure material, Rf 0.13 (0.060 g). Recrystallisation of the latter material from

hexane gave the diol (141) as colourless needles, m.p. 94-95°.

(Found: C, 72.6; H, 11.2 $C_{12}H_{22}O_2$ requires C, 72.7; H, 11.2%). The n.m.r. spectrum showed absorption at τ 9.02 and 8.98 (singlets, 6H, 2 tertiary CH_3); 8.93-8.0 (complex, 12H, $-CH_2-$ and $-CH-$, $-CH(OH)CH_3$); 7.92 (broad singlet, 1H, bridgehead $-CH-C(OH)-$); 6.36 (singlet, 2H, OH); 5.89 (complex, 1H, $-CH(OH)CH_3$).

Elution of the first column with ether gave the required diol (128, R=R'=H) as an oil (2.20 g) which slowly crystallised. Recrystallisation from light petroleum gave colourless plates (1.10 g), m.p. 54-56°, $[\alpha]_D^{18}$ + 23.1 (c. 1.58, ethanol).

β-(2-endo-Hydroxy-3,3-dimethyl-2-norbornyl)propionic acid lactone (125).

(a) A stirred solution of the (±)-diol (128, R=R'=H) (0.40 g) in acetone (100 ml) was treated dropwise with Jones' reagent until the colour of the reagent persisted. The mixture was stirred at room temperature for 1 hr, after which the excess of oxidising agent was destroyed by the addition of ethanol. After the addition of water to the solution, the mixture was concentrated under reduced pressure. The aqueous residue was extracted with ether and the ether extract washed with water and dried. Removal of the ether gave the endo lactone (125) as colourless plates, m.p. 98-102° (0.38 g, 95%). One recrystallisation from light petroleum raised the m.p. to 102-103°.

(Found: C, 74.2; H, 9.4. Calc. for $C_{12}H_{18}O_2$: C, 74.2; H, 9.3%).

Capillary v.p.c. analysis showed that the lactone was homogeneous. It showed infrared absorption (in CCl_4) at 1780(s), 1465(s), 1447(m), 1420(m), 1387(m), 1365(m), 1325(w), 1295(m), 1280(s), 1258(m, sh), 1253(s), 1203(s), 1185(s), 1170(s), 1155(s), 1135(w), 1095(w), 1065(s), 1045(m), 1025(s), 1006(m), 997(s), 975(s), 920(s), 913(s) and 880(m)cm^{-1}.

(b) The (+)-diol (128, R=R'=H) (0.40 g) was oxidised as described in (a) to give 0.39 g of crude lactone, m.p. 110-114°. Recrystallisation from hexane yielded colourless plates (0.22 g), m.p. 114-115°, $[\alpha]_D^{18}$ + 32.0 (c. 2.04, chloroform). This lactone was vapour chromatographically homogeneous, and its infrared spectrum was identical with that of the (±)-lactone described in (a).

Unsaturated acid (134).

This synthesis was modelled on recent work of Büchi and co-workers.[125]

Acetic anhydride (5 ml) was added to a cooled solution of the (±)-diol (128, R=R'=H) (0.45 g) in pyridine (ca. 40 ml). After being kept at room temperature overnight, the mixture was poured into water and worked up by ether extraction in the usual fashion to give the hydroxyacetate (128, R=H, R'=$COCH_3$) (0.47 g), $\nu_{max.}$ (film) 3550, 1740 and 1240 cm^{-1}. This crude product was dissolved in pyridine (ca. 50 ml), cooled to 0°, and then treated dropwise with phosphorus oxychloride (10 ml). After being kept at room temperature for 1 hr, the mixture was warmed on a steam bath for 1 hr, cooled, poured into iced water, and acidified with dilute hydrochloric acid. Work-up by ether extrac-

tion yielded the unsaturated acetate (139, R=$COCH_3$) (0.40 g); $\nu_{max.}$ (film) 1730 and 1220 cm^{-1}. This acetate was heated under reflux with excess of lithium aluminium in ether for 1 hr, and work-up gave the unsaturated alcohol (139, R=H) (0.34 g) as an oil; $\nu_{max.}$ (film) 3350 cm^{-1}. The crude alcohol was dissolved in acetone (50 ml) and treated dropwise with an excess of Jones' reagent and stirred at room temperature for 1 hr. Work-up gave a crystalline acid fraction (0.19 g), m.p. 80-90°. Successive recrystallisations from aqueous methanol and light petroleum gave the acid (134) as colourless plates, m.p. 104-105° (lit.[112] m.p. 105-106°).

(Found: C, 74.25; H, 9.3. Calc. for $C_{12}H_{18}O_2$: C, 74.2; H, 9.3%). Its n.m.r. spectrum showed signals at τ 8.97 and 8.93 (singlets, 6H, 2 tertiary CH_3); 8.86 - 7.90 (complex, 7H, saturated $-CH_2-$ and $-CH-$); 7.09 (broad, 1H, $-CH-C=C$); 6.98 (doublet J=7, 2H, $=CH-CH_2-CO_2H$); 4.95 (triplet J=7, 1H, $-C=CH-CH_2-$); -1.90 (singlet, 1H, $-CO_2H$).

Preparation and solvolysis of the ditrifluoroacetate (128, R=R'=$COCF_3$).

A solution of the (+)-diol (128, R=R'=H) (0.80 g) in anhydrous ether (25 ml) was treated with trifluoroacetic anhydride (6 ml) and kept at room temperature for 30 hr. The solution was poured into dilute sodium bicarbonate solution and the ether layer was separated, washed with water, and dried. Evaporation of the ether gave a colourless oil, the infrared spectrum of which lacked OH absorption and showed strong trifluoroacetate absorption at 1780 and 1240-1130 cm^{-1}. This product was stirred with calcium carbonate (2 g) in aqueous acetone

(50% V/V, 100 ml) at room temperature for 40 hr, and the mixture was then refluxed for 4 hr. Work-up by ether extraction yielded an oil (0.70 g), the infrared spectrum of which was identical with that of the unsaturated alcohol (139, R=H). This crude product was treated with Jones' reagent to give a crystalline acid fraction (0.35 g, 43% overall), which after successive recrystallisations from aqueous methanol and light petroleum had m.p. 100-102°, $[\alpha]_D^{16}$ + 95 (c. 1.16, chloroform). The infrared spectrum of this acid was identical with that of the (±)-acid (134) synthesised from (±)-camphenilone.

Tricycloekasantalic acid (126).

A commercial mixture of α- and β-santalol (Fluka) was oxidised with aqueous potassium permangante.[126] The acid crystallised from aqueous acetic acid as colourless plates, m.p. 76-77° (lit.[127] m.p. 76-77°), $[\alpha]_D^{18}$ + 21.2 (c. 5.88, chloroform) (lit.[115] $[\alpha]_D$ + 19.4). The methyl ester, prepared by treating the acid with ethereal diazomethane was vapour chromatographically homogeneous (150' Apiezon capillary column, 150°).

Lactone mixture from tricycloekasantalic acid.

(a) Tricycloekasantalic acid (1.10 g) was heated under reflux with aqueous sulphuric acid (25%, 100 ml) for 15 min. The cooled solution was poured into water, and work-up by ether extraction yielded an acid fraction consisting of starting material (0.5 g), and a neutral fraction (0.52 g), m.p. 85-95°, the infrared spectrum of which was identical with that of the lactone mixture from camphene.

V.p.c. analysis showed that the product consisted of exo lactone (54%), endo lactone (33%) and δ-lactone (13%). After three recrystallisations from light petroleum the product melted at 101-103°, and was shown to be a 69:31 mixture of exo : endo lactone.

(b) The acid (0.21 g) was heated under reflux with formic acid (98%, 20 ml) for 30 min. The cooled solution was diluted with water, and ether extraction gave the lactone as plates (0.19 g), m.p. 94-97°. V.p.c. analysis showed that the product was a 62 : 38 mixture of exo : endo lactone. After four recrystallisations from light petroleum the product was a 73 : 27 mixture, m.p. 101-103°.

(c) The acid (0.20 g) was added to sulphuric acid (98%, 10 ml) which had been cooled to -10°. The mixture became homogeneous after being shaken for 2-3 min. The solution was kept at -10° for 25 min, and was then poured onto crushed ice. Ether extraction yielded 0.18 g of crystalline neutral product, which after recrystallisation from hexane gave colourless plates (0.10 g), m.p. 65-75°, $[\alpha]_D^{20}$ 0 (c. 2.80, chloroform). The infrared spectrum showed carbonyl bands of equal intensity at 1780 (γ-lactone) and 1745 cm^{-1} (δ-lactone). The n.m.r. spectrum showed peaks at τ 9.02 (singlet, tertiary CH_3), 8.76 (singlet, CH_3-C(-)-OCO- of δ-lactone), and 8.70-7.64 (complex, $-CH_2-$ and $-CH-$). From the methyl signal areas, the product was ca. a 1:1 γ- : δ-lactone mixture. V.p.c. analysis gave the following composition : exo lactone (32%), endo lactone (12%), and δ-lactone (56%).

In a separate experiment, tricyclocekasantalic acid was shaken with 98% sulphuric acid at -10° for 5 min. The product was again ca. a 1:1 γ- : δ-mixture as judged by the infrared spectrum. In an attempt

to separate the lactones, the mixture (0.10 g) was refluxed with sodium hydroxide (ca. 0.1 g) in water (4 ml) for 3-4 min. The clear solution was cooled, acidified with dilute sulphuric acid and was then extracted with ether. The ether was washed with dilute sodium hydroxide, but acidification and ether extraction of the sodium hydroxide layer did not yield any material. Evaporation of the ether layer gave back the original mixture (0.90 g).

(d) Tricycloekasantalic acid (2.35 g) was refluxed with sulphuric acid (15%, 350 ml) for 45 min. Ether extraction gave 2.1 g of neutral product, m.p. 75-100°. The infrared spectrum indicated the presence of some δ-lactone (carbonyl shoulder at 1750 cm^{-1}), and v.p.c. showed the product to consist of exo lactone (47%), endo lactone (39%), and δ-lactone (14%). Two recrystallisations from hexane yielded colourless plates (1.4 g), m.p. 100-104°, $[\alpha]_D$ + 15 (c. 4.32, chloroform), shown by v.p.c. to be a 73 : 27 exo : endo mixture.

Lithium aluminium hydride reduction of the lactone from tricycloekasantalic acid.

The lactone, $[\alpha]_D$ + 15, used was that prepared as described in (d) above. A solution of the lactone (1.60 g) in ether (50 ml) was added to a suspension of $LiAlH_4$ (1.0 g) in ether (50 ml), and the mixture was stirred at room temperature for 2 hr, and was then refluxed for 1 hr. The cooled mixture was treated with water, and work-up in the usual manner yielded a colourless waxy product (1.5 g) which showed strong hydroxyl but lacked carbonyl absorption in the infrared

spectrum. The product was redissolved in warm ether (50 ml), and on cooling the diol (131, R=R'=H) separated out as long colourless needles (0.60 g, 38%), m.p. 132-133°, $[\alpha]_D^{19}$ + 22.7 (c. 1.50, ethanol) (lit.[113] m.p. 112°, $[\alpha]_D^{28}$ + 1.94). Recrystallisation from benzene raised the melting point to 133-134°; $[\alpha]_D^{20}$ + 25.0 (c. 2.00, ethanol).

(Found: C, 73.0; H, 11.1. Calc. for $C_{12}H_{22}O_2$: C, 72.7; H, 11.2%). A sample mixed with the (±)-endo diol melted at 65-115°. The ether mother liquor from above was concentrated and cooled to yield a second crop of needles (0.13 g), m.p. 105-115°, which after recrystallisation from benzene showed m.p. 108-110°, $[\alpha]_D^{19}$ + 8.0 (c. 1.70, ethanol). This was apparently a mixture of exo and endo diols.

Oxidation of the exo diol (131, R=R'=H). Preparation of pure exo lactone.

The diol having m.p. 113-134°, $[\alpha]_D$ + 25 (0.12 g) was oxidised with Jones' reagent in the usual way to yield colourless plates (0.10 g), m.p. 117-119°. Recrystallisation from hexane gave 0.058 g, m.p. 120-121°, $[\alpha]_D^{20}$ + 40 (c. 0.80, chloroform). The lactone was vapour chromatographically homogeneous and its retention time (peak enhancement) was identical with that of the major component of the lactone mixtures from tricycloekasantalic acid and the lead tetraacetate reactions.

Lactone from the unsaturated acid (134).

The (±)-acid (134) (0.040 g) was heated under reflux with sulphuric acid (25%, 10 ml) for 10 min. Work-up gave a neutral fraction

(0.032 g), m.p. 82-93°, which after recrystallisation from light petroleum was a 68 : 32 exo : endo lactone mixture, m.p. 97-99°.

Acid catalysed equilibrations of the lactones.

(a) The lactone (0.030 - 0.050 g) was refluxed with the appropriate acid (3-5 ml) for the time indicated in Table 22. The product was isolated by ether extraction, and the composition was determined by v.p.c. analysis (Table 22).

(b) The (+)-endo lactone, m.p. 114-115° (0.20 g) was refluxed with formic acid (98%, 20 ml) for 90 min. Work-up by ether extraction gave 0.20 g of slightly discoloured product, which was a 60 : 40 exo : endo mixture. After 2 recrystallisations from hexane the product had m.p. 98-101°, $[\alpha]_D^{20}$ 0 (c. 1.84, chloroform), and was a 65 : 35 exo : endo mixture.

Degradation of the (+)-exo-diol (131, R=R'=H) to the acid (134).

The pure exo-diol, m.p. 133-134°, $[\alpha]_D$ + 25 (0.44 g) was converted into the hydroxy-acetate (131, R=H, R'= $COCH_3$) by treatment with acetic anhydride-pyridine at room temperature overnight. The crude hydroxy-acetate was dissolved in pyridine (50 ml) and phosphorus oxychloride (5 ml) was added. After being kept at room temperature for 1 hr, the mixture was heated at ca. 80° for 1 hr. The cooled mixture was poured into cold water, and work-up by ether extraction gave 0.45 g of unsaturated acetate (139, R= $COCH_3$), contaminated by a small amount of unchanged hydroxy-acetate as indicated by weak hydroxyl

absorption in the infrared spectrum. This product was reduced with lithium aluminium hydride in ether to the unsaturated alcohol (139, R=H). Oxidation with Jones' reagent gave an acid fraction (0.15 g, 34% overall), m.p. 75-85°. Successive recrystallisations from aqueous methanol and hexane gave the acid (134) as colourless plates, m.p. 95-96°, $[\alpha]_D^{20}$ - 118 (c. 0.574, chloroform). A mixture of this product and the acid m.p. 100-102°, $[\alpha]_D$ + 95, melted at 104-105°. The infrared spectra (CCl_4) of the two samples were identical with that of (±)-(134).

REFERENCES.

1. A. Streitwieser, Jr., "Solvolytic Displacement Reactions," McGraw-Hill, New York, 1962.
2. C.A. Bunton, "Nucleophilic Substitution at a Saturated Carbon Atom," Elsevier, New York, 1963.
3. F.R. Thornton, "Solvolysis Mechanisms," Ronald Press, New York, 1964.
4. C.K. Ingold, "Structure and Mechanism in Organic Chemistry," G. Bell and Sons Ltd., London, 1953, p.312.
5. B. Capon, Quart.Rev., 18, 45 (1964).
6. S. Winstein, C.R. Lindegren, H. Marshall and L.L. Ingraham, J.Amer.Chem. Soc., 75, 147 (1953).
7. J.A. Berson, in "Molecular Rearrangements," Volume 1, P. de Mayo (Ed.), Interscience, New York, 1963.
8. a.S. Winstein and D. Trifan, J.Amer.Chem. Soc., 71, 2953 (1949).
   b.S. Winstein and D.Trifan, J.Amer.Chem. Soc., 74, 1147 (1952).
   c.S. Winstein and D. Trifan, J.Amer.Chem.Soc., 74, 1154 (1952).
9. S. Winstein and K.C. Schreiber, J. Amer.Chem.Soc., 74, 2165 (1952).
10. J.D. Roberts, C.C. Lee and W.H. Saunders Jr., J.Amer.Chem.Soc., 76, 4501 (1954).
11. S. Winstein, B.K. Morse, E. Grunwald, H.W. Jones, J. Corse, D. Trifan and H. Marshall, J.Amer.Chem.Soc., 74, 1127 (1952).
12. T.P. Nevall, E. deSalas and C.L. Wilson, J.Chem.Soc., 1188 (1939).

13. a. H. Meerwein and K. van Emster, Ber., 53, 1815 (1920).

b. H. Meerwein and K. van Emster, Ber., 55, 2500 (1922).

14. F. Brown, E.D. Hughes, C.K. Ingold and J.F. Smith, Nature, 168, 65 (1951).

15. P. Beltrame, C.A. Bunton, A. Dunlop and D. Whittaker, J.Chem.Soc., 658 (1964).

16. W. Hückel and M. Heinzel, Tet. Letters, 2141 (1964).

17. G. LeNy, Compt. rend., 251, 1526 (1960).

18. C.F. Wilcox Jr. and S.S. Chibber, J.Org.Chem., 27, 2332 (1962).

19. R.G. Lawton, J.Amer.Chem. Soc., 83, 2399 (1961).

20. P.D. Bartlett and S. Bank, J.Amer.Chem.Soc., 83, 2591 (1961).

21. S. Winstein and P. Carter, J.Amer.Chem.Soc., 83, 4485 (1961).

22. a. P.D. Bartlett, S. Bank, R.J. Crawford and G.H. Schmid, J.Amer.Chem.Soc., 87, 1288 (1965).

b. P.D. Bartlett and G.D. Sargent, J.Amer.Chem.Soc., 87, 1297 (1965).

23. H.C. Brown in "The Transition State," Special Publication No. 16, Chemical Society, London, 1962.

24. a. H.C. Brown, F.J. Chloupek and M.-H. Rei, J. Amer.Chem.Soc., 86, 1246 (1964).

b. H.C. Brown, F.J. Chloupek and M.-H. Rei, J. Amer.Chem.Soc., 86, 1247 (1964).

c. H.C. Brown, F.J. Chloupek and M.-H. Rei, J. Amer.Chem. Soc., 86, 1248 (1964).

25. H.C. Brown and F.J. Chloupek, J.Amer.Chem.Soc., 85, 2322 (1963).

26. P. von R. Schleyer, D.C. Kleinfelter and H.C. Richey, J.Amer.Chem.Soc., 85, 479 (1963).

27. S. Winstein, Reaction Mechanism Conference at Brookhaven National Laboratory, Upton, N.Y. 1962; quoted by H.C. Brown in reference 23.

28. a. H.C. Brown and H.M. Bell, J. Amer.Chem.Soc., 86, 5003 (1964).
b. H.C. Brown and M.-H. Rei, J. Amer.Chem.Soc., 86, 5004 (1964).
c. H.C. Brown and H.M. Bell, J.Amer.Chem.Soc., 86, 5006 (1964).
d. H.C. Brown and H.M. Bell, J. Amer. Chem. Soc., 86, 5007 (1964).
e. H. C.Brown and M.-H. Rei, J. Amer.Chem.Soc., 86, 5009 (1964).

29. P. von R. Schleyer, M.M. Donaldson and W.E. Watts, J. Amer. Chem. Soc., 87, 375 (1965).

30. a. A. Colter, E.C. Friedrich, H.J. Holmes and S. Winstein, J.Amer.Chem.Soc., 87, 378 (1965).
b. R. Rowe, E.C. Friedrich and S. Winstein, J. Amer.Chem.Soc., 87, 379 (1965).

31. S. Winstein, J.Amer.Chem. Soc., 87, 381 (1965).

32. H. C. Brown, K.J. Morgan and F.J. Chloupek, J.Amer.Chem.Soc., 87, 2137 (1965).

33. E.J. Corey, J. Casanova Jr., P.A. Vatakencherry amd R. Winter, J. Amer.Chem.Soc., 85, 169 (1963).

34. G. Smith and J.P. Petrovich, Tet. Letters, 3363 (1964).

35. W.S. Trahanovsky, J.Org.Chem., 30, 1666 (1965).

36. J.A. Berson in "Molecular Rearrangements," Volume 1, P. deMayo (Ed.), Interscience, New York, 1963, p.205.

37. J.A. Berson and A. Remanick, J. Amer.Chem.Soc., 86, 1749 (1964).

38. W. Hückel and F. Nerdel, Ann., 528, 57 (1937).

39. W. Hückel and P. Rieckmann, Ann., 625, 1 (1959).

40. R.R. Sauers and J.M. Landesberg, J.Org.Chem., 26, 964 (1961).

41. E.J. Corey and J. Casanova Jr., J.Amer.Chem.Soc., 85, 165 (1963).

42. N.C. Deno in "Progress in Physical Organic Chemistry," Volume 2, Interscience, New York, 1964 p.129.

43. a. P. von R. Schleyer, W.E. Watts, R.C. Fort Jr., M.B. Comisarow and G.A. Olah, J.Amer.Chem.Soc., 86, 5679 (1964).

b. M. Saunders, P. von R. Schleyer and G.A. Olah, J.Amer.Chem.Soc., 86, 5680 (1964).

44. a. R.R. Sauers, J.Amer.Chem.Soc., 81, 925 (1959).

b. M. Harispe and D. Mea, Bull.Soc.chim.France, 1562 (1960).

45. F. Tiemann, Ber., 29, 3006 (1896).

46. a. F. Tiemann, Ber. 30, 242 (1897).

b. J.L. Simonsen, "The Terpenes", Volume 2, Cambridge University Press, 1949, p.437-439.

47. R. E. Partch, J.Org.Chem., 28, 276 (1963).

48. R.T. Blickenstaff and F.C. Chang, J. Amer.Chem. Soc., 80, 2726 (1958).

49. a. F. C. Chang and R.T. Blickenstaff, J. Amer.Chem. Soc., 80, 2906 (1958).

b. A.P. Johnson and A. Pelter, J.Chem. Soc., 520 (1964).

50. J.P. Bain, A.H. Best, B.L. Hampton, G.A. Hawkins and L.J. Kitchen, J. Amer.Chem. Soc., 72, 3124 (1950).

51. N.A. LeBel, G.M.J. Slusarczuk and L.A. Spurlock, J.Amer.Chem.Soc., 84, 4360 (1962).

52 a. J. Bertram and H. Walbaum, J.prakt.Chem., [ii], 49, 8 (1894).

b. J.L. Simonsen, "The Terpenes," Volume 2, Cambridge University Press, 1949, p.316.

53. W.F. Erman, J.Amer.Chem.Soc., 86, 2887 (1964).

54. W.R. Vaughan, G. T. Goetschel, M.H. Goodrow and C.L. Warren, J. Amer. Chem. Soc., 85, 2282 (1963).

55. W. Hückel, Ber., 77, 805 (1944).

56. A.C. Cope, S. Moon and C.H. Park, J.Amer. Chem.Soc., 84, 4850 (1962).

57. M.L. Bender, J.Amer.Chem.Soc., 75, 5986 (1953).

58. A. Moffat and H. Hunt, J.Amer.Chem.Soc., 79, 54 (1957).

59. A. Moffat and H. Hunt, J.Amer. Chem. Soc., 81, 2082 (1959).

60. N.B. Chapman, R.E. Parker and R.J.A. Smith, J. Chem.Soc. 3634 (1960).

61. C. A. Bunton, K. Khaleeludin and D. Whittaker, J.Chem.Soc., 3290 (1965).

62. T.D. Nevitt and G. S. Hammond, J. Amer.Chem.Soc., 76, 4124 (1954).

63. K. Hacker, G. Keicher and K.H. Hiltenberger, Tet. Letters, 2987 (1965).

64. L.F. Fieser, "Experiments in Organic Chemistry," D.C. Heath and Co., Boston, 1957, p.281.

65. a. L.W. Trevoy and W.G. Brown, J.Amer. Chem.Soc., 71, 1675 (1949).

b. D.S. Noyce and D.B. Denny, J. Amer.Chem.Soc., 72, 5743 (1950).

66. H.C. Brown and R.F. McFarlin, J. Amer. Chem. Soc., 80, 5372 (1958).

67. R.H. Pickard and W.O. Littlebury, J.Chem.Soc., 91, 1973 (1907).

68. O. Wallach, Ann., 230, 225 (1885).

69. O. Ashan, Ber., 41, 1092 (1908).

70. S. Moycho and F. Zienkowski, Ann., 340, 17 (1905).

71. W. Hückel, W. Doll, S. Eskola and H. Weidner, Ann., 549, 186 (1941).

72. J. Bertram and H. Walbaum, J. prakt.Chem., [ii], 49, 1 (1894).

73. W. Reusch, M.W. DiCarlo and L. Traynor, J.Org.Chem., 26, 1711 (1961).

74. J.K. Kochi and G. S. Hammond, J. Amer. Chem.Soc., 75, 3443 (1953).

75. R.S. Tipson, J.Org.Chem., 9, 235 (1944).

76. G.B. Frankforter and F.C. Frary, J. Amer.Chem. Soc., 28, 1461 (1906).

77. K. Auwers, Ber., 22, 604 (1889).

78. S. Winstein, E. Grunwald and L.L. Ingraham, J.Amer.Chem.Soc., 70, 821 (1948).

79. Y. Pocker, Proc.Chem.Soc., 216 (1960).

80. M. deBotton, Bull.Soc.chim.France, 372 (1958).

81. a. S.J. Cristol and G.D. Brindell, J.Amer.Chem.Soc., 76, 5699 (1954).

b. C.C. Lee and E. W.C. Wong, J.Amer.Chem.Soc., 86, 2752 (1964).

82. W.F. Erman and T.J. Flautt, J.Org.Chem., 27, 1526 (1962).

83. T.J. Flautt and W.F. Erman, J. Amer. Chem.Soc., 85, 3212 (1963).

84. H. C. Brown and C. A. Brown, J. Amer. Chem. Soc., 85, 1003 (1963).

85. H.C. Brown and G. Zweifel, J. Amer. Chem. Soc., 83, 1241 (1961).

86. A. Bowers, T.G. Halsall, E.R.H. Jones and A.J. Lemin, J.Chem.Soc., 2548 (1953).

87. H. Rupe and H. Hirschmann, Helv.Chim.Acta, 11, 1180 (1928).

88. G. Wittig and U. Schoellkopf, Org.Synth., 40, 66 (1960).

89. R. Greenwald, M. Chaykovski and E.J. Corey, J.Org. Chem., 28, 1128 (1963).

90. M.O. Forster, J.Chem.Soc., 73, 386 (1898); see also reference 38.

91. N.A. LeBel and J.E. Huber, J.Amer. Chem.Soc., 85, 3193 (1963).

92. D. Benson, L.H. Sutcliffe and J. Walkey, J.Amer.Chem.Soc., 81, 4488 (1959).

93. W.H. Starnes Jr., J.Amer.Chem.Soc., 86, 5603 (1964).

94. J.K. Kochi, J.Amer.Chem.Soc., 87, 3609 (1965).

95. D.I. Davies and C. Waring, Chem.Comm., 263 (1965).

96. J.A. Berson and C.J. Olsen, J.Amer.Chem.Soc., 84, 3178 (1962).

97. J.A. Berson, C.J. Olsen and J.S. Walia, J.Amer.Chem.Soc., 84, 3337 (1962).

98. S. Trippett in "Advances in Organic Chemistry," Volume 1, Interscience, New York, 1960, p.91.

99. a. L.F. Fieser and F. C. Chang, J.Amer.Chem.Soc., 64, 2043 (1942).
b. L.F. Fieser, R.C. Clapp and W.H. Daudt, J. Amer. Chem.Soc., 64, 2052 (1942).

100. R. Criegee in "Newer Methods of Preparative Organic Chemistry," Volume 2, W. Foerst (Ed.), Academic Press, New York, 1963, p.373.

101. F.W. Semmler, Ber., 33, 3420 (1900).

102. P. Lipp, Ann., 399, 241 (1913).

103. a. P. Lipp, P. Küppers and M. Noll, Ber., 60, 1575 (1927).
b. P. Lipp and M. Quaedvlieg, Ber., 62, 2311 (1929).

104. a. G. Clement, Compt. rend., 232, 2016 (1951).

b. G. DuPont, R. Dulou and G. Clement, Bull.Soc.chim.France, 1002, (1951).

105. a. W. Hückel and K. Hartmann, Ber., 70, 959 (1937).

b. W. Hückel and H.G. Kirschner, Ber., 80, 41 (1947).

106. J. Wolinsky, J.Org.Chem., 26, 704 (1961) and references therein.

107. L. Wolff, Ann., 394, 86 (1912).

108. S. Beckmann and R. Mezger, Ber., 89, 2738 (1956).

109. G. Wittig and D. Wittenberg, Ann, 606, 1 (1957).

110. R. Criegee in "Newer Methods of Preparative Organic Chemistry," Volume 2, W. Foerst (Ed.), Academic Press, New York, 1963, p.378.

111. E.J. Corey, R. Hartmann and P.A. Vatakencherry, J.Amer.Chem.Soc., 84, 2611 (1962) and references therein.

112. A. Bhati, J.Org.Chem., 27, 2135 (1962).

113. a. F.W. Semmler, Ber., 40, 1120 (1907).

b. L. Ruzicka and G. Thomann, Helv.Chim.Acta, 18, 355 (1935).

c. S.C. Bhattacharyya, Science and Culture (Calcutta), 13, 158 (1947).

114. H.C. Brown and B.C. Subba Rao, J. Amer. Chem.Soc., 81, 6428(1959).

115. S. Ramaswami, S.K. Ramaswami and S.C. Bhattacharyya, J.Org. Chem., 27, 2791 (1962).

116. a. G. Ourisson, Chem. and Ind., 918 (1953).

b. G. Ourisson, Bull.Soc.chim.France, 895 (1955).

117. E.J.Corey, S.W. Chow and R.A. Scherrer, J.Amer.Chem.Soc., 79, 5773 (1957).

118. C.J. Collins, Z.K. Cheema, R.G. Werth and B.M. Benjamin, J. Amer.Chem.Soc., 86, 4913 (1964).

119. a. J.A. Berson, R.G. Bergman, J.H. Hammons and A.W. McRowe, J.Amer. Chem.Soc., 87, 3246 (1965).

b. J.A. Berson, J.H. Hammons, A.W. McRowe, R.G. Bergman, A. Remanick and D. Houston, J.Amer.Chem.Soc., 87, 3248 (1965).

120. A. Nickon and J.H. Hammons, J.Amer. Chem.Soc., 86, 3322 (1964).

121. H.L. Goering and C.B. Schewene, J.Amer.Chem. Soc., 87, 3516 (1965).

122. P.S. Bailey, Ber., 88, 795 (1955).

123. W.R. Vaughan and R. Perry Jr., J. Amer.Chem.Soc., 75, 3168 (1953).

124. M.S. Kharash and C.F. Fuchs, J. Org.Chem., 9, 359 (1944).

125. G. Büchi, W.D. MacLeod Jr., and J. Padilla O, J.Amer.Chem.Soc., 86, 4438 (1964).

126. A.C. Chapman, J.Chem.Soc., 79, 134 (1901).

127. A.E. Bradfield, A.R. Penfold and J.L. Simonsen, J.Chem.Soc., 309 (1935).

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Reprinted from

TETRAHEDRON LETTERS

The International Organ for the Rapid Publication of Preliminary Communications in Organic Chemistry

PERGAMON PRESS

OXFORD · LONDON · NEW YORK · PARIS

Tetrahedron Letters No.10, pp. 535-540, 1964. Pergamon Press Ltd.
Printed in Great Britain.

CONVERSION OF (+)-CAMPHOR TO THE ENANTIOMERIC HYDROCAMPHENYL-ISOBORNYL CATIONS BY THE σ- AND π-ROUTES OF SOLVOLYSIS

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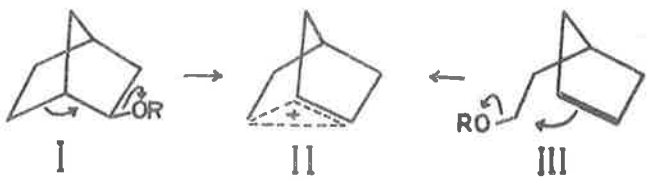
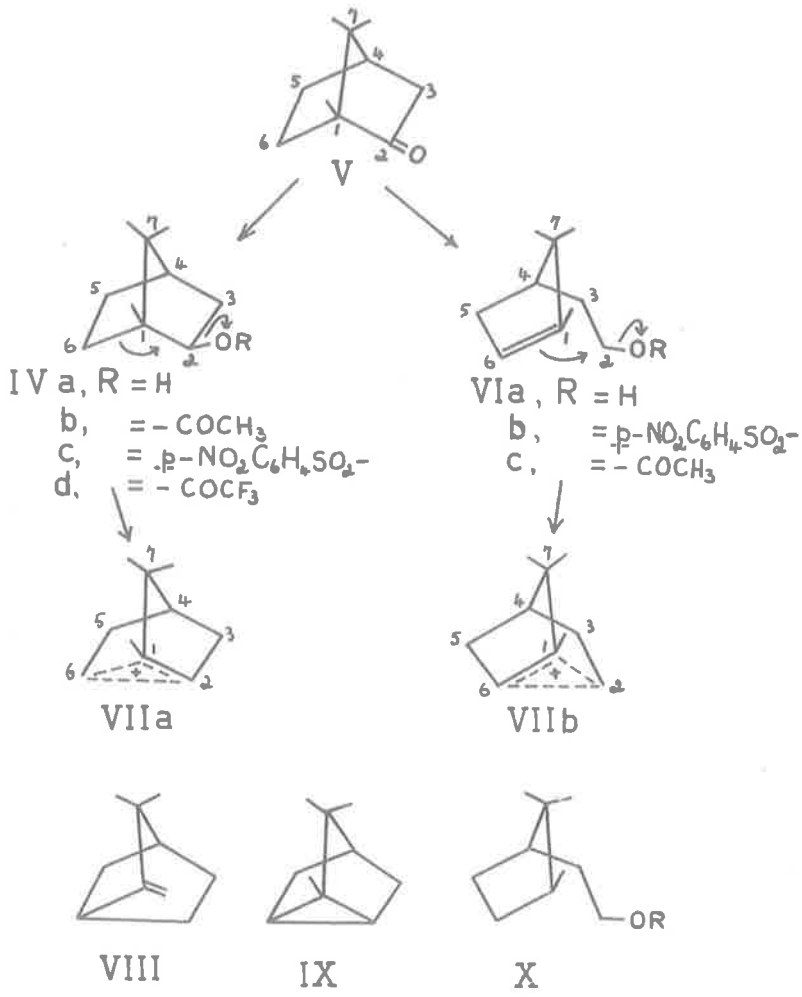
(Received 30 December 1963)

Winstein and Carter (1) have conveniently classified anchimerically assisted ionisations of substrates in which the neighbouring group contributes σ or π electrons as the σ- and π-routes to the corresponding cations. For the norbornyl cation (II), the σ-route may be illustrated by the solvolysis of exo-norbornyl p-bromobenzenesulphonate (I, R = p-bromobenzenesulphonyl) (2), while the π-route is shown by solvolysis of β-(cyclopent-3-enyl)ethyl arenesulphonates (III, R=arenesulphonyl) (3,4)



We now report the conversion of (+)-camphor (V) to the enantiomeric hydrocamphenyl-isobornyl cations (VIIa and VIIb) by the σ- and π-routes of solvolysis. (+)-α-Campholenyl p-nitrobenzenesulphonate (VIb), m.p. 87-8° (dec.), $[\alpha]_D^{20}$ + 3.4 ($CHCl_3$) was prepared from (+)-α-campholenol (VIa) which was obtained from (+)-camphor via (+)-camphor-10-sulphonic acid by


V
IV a, R = H
b, = - COCH3
c, = p-NO2C6H4SO2-
d, = - COCF3
VIa, R = H
b, = p-NO2C6H4SO2-
c, = - COCH3
VIIa
VIIb
VIII
IX
X
OR

known reactions (5). Acetolysis of the sulphonate VIb for 5 hours at 100° in the presence of excess of sodium acetate yielded a mixture consisting of camphene (VIII, 73%), tricyclene (IX, 2%), isobornyl acetate (IVb, 14%), α-campholenyl acetate (VIc, 8%) and an unidentified compound (3%).* The camphene isolated from this reaction had $[\alpha]_D^{21}$ - 98 (benzene), lit. (6) $[\alpha]_D^{25}$ + 107 (benzene).

Using standard techniques (7), good first order kinetics were observed when VIb (ca. 0.02M) was solvolysed in ca. 0.04M acetic acid solution of sodium acetate at various temperatures. The rate constant (4.08×10^{-4} sec^{-1}) at 60° is 3.7 times greater than that reported (3) for β-(cyclopent-3-enyl)ethyl p-nitrobenzenesulphonate (III, R=p-nitrobenzenesulphonyl): this increase undoubtedly is due to the electron-donating methyl group at C_1 in VIb. This rate constant was also 203 times greater than that observed at 60° for the saturated p-nitrobenzenesulphonate (X, R=p-nitrobenzenesulphonyl) m.p. 64-65°, thus indicating a considerable degree of anchimeric assistance by the double bond in the ionisation.

From an Arrhenius plot, k_{VIb} at 100° was found to be 1.26×10^{-2} sec^{-1}, this value being 153 times the one observed with X at 100°. Because of this large ratio, it may be thought that the monocyclic unsaturated acetate VIc is derived by acetate ion attack on C_2 of the bridged ion VIIb. There seems, however, to be no report in the literature of the unsaturated alcohol VIa, or any of its derivatives, having been identified in solvolyses involving the non-classical carbonium ion VIIa. This is consistent with our observation that the unsaturated acetate VIc could not be detected after acetolysis of (-)-isobornyl trifluoroacetate (see below).

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* The analyses were carried out by gas phase chromatography

It would thus seem that the non-classical carbonium ions VIIa and VIIb generated by the σ- and π-routes differ to a small extent, and that one, or maybe both, undergo reactions before the most stable carbonium ion configuration is reached.

We wished to compare the solvolysis products of isobornyl p-nitrobenzenesulphonate (IVc) with those of α-campholenyl p-nitrobenzenesulphonate. All attempts, however, to prepare sulphonic acid esters of isoborneol failed. Reduction of (+)-camphor with lithium tri-tert-butoxyaluminohydride yielded a mixture of (-)-isoborneol (96%) and (+)-borneol (4%) (8). Attempted esterification of this mixture with p-nitrobenzenesulphonyl chloride in pyridine at room temperature for 10 days yielded the expected quantity of bornyl p-nitrobenzenesulphonate m.p. 94-95° (dec.), together with camphene (60%) $[\alpha]_D^{27}$ + 110 (benzene) and unchanged isoborneol (40%). Similar results were obtained when the reaction temperature was 0°, or when p-toluenesulphonyl or methanesulphonyl chlorides were employed. Esterification is apparently very slow due to the hindered nature of the hydroxyl group in isoborneol, but once formed, the sulphonates rapidly solvolyse via the σ-route to yield camphene of high optical purity. The preparation of isobornyl p-toluenesulphonate has been reported by Hückel (9). The remarkable lack of solvolytic reactivity reported for this compound, together with the known great reactivity of isobornyl chloride, make it extremely doubtful that Hückel's compound was in fact a derivative of isoborneol.

A new σ-route to the hydrocamphenyl-isobornyl cation has been provided by acetolysis of (-)-isobornyl trifluoroacetate (IVd), b.p. 87-88°/15 mm, $[\alpha]_D^{19}$ = - 32.5 ($CHCl_3$). Solvolysis of IVd (containing 4%

(+)-bornyl trifluoroacetate) in buffered acetic acid at 100° for 5 hours gave a mixture consisting of camphene (76%), tricyclene (4%), isobornyl acetate (12%), an unidentified compound (3%) and unchanged bornyl trifluoroacetate (5%). The camphene from this reaction had $[\alpha]_D^{21}$ + 103 (benzene).

Of special interest is the fact that the non-classical carbonium ions produced by the σ- and π-routes of solvolysis, VIIa and VIIb respectively, are non-superimposable mirror images. In the formation of VIIa, the C_1-C_6 bond initially present in camphor migrates, resulting in C_6 being partially bonded to both C_1 and C_2. In the preparation of campholenol, however, the C_1-C_2 bond initially present in camphor is broken, resulting ultimately in C_2 being partially bonded to C_1 and C_6 in VIIb. Because of the unique properties of VIIa and VIIb, it has been possible to prepare both (+)- and (-)-camphene of high optical purity from (+)-camphor.

In view of the current interest in the exact nature of carbonium ions such as VIIa, a comparison of the solvolysis products of other isobornyl, bornyl and α-campholenyl derivatives is being made.

REFERENCES

1 S. Winstein and P. Carter, J.Am.Chem.Soc., 83, 4485 (1961).

2 S. Winstein and D. Trifan, J.Am.Chem.Soc., 71, 2953 (1949); 74, 1147, 1154, (1952); S. Winstein, B.K. Morse, E. Grunwald, H.W. Jones, J. Corse, D. Trifan and H.J. Marshall, ibid, 74, 1127 (1952).

3 R.G. Lawton, J.Am.Chem.Soc., 83, 2399 (1961).

4 P.D. Bartlett and S. Bank, J.Am.Chem.Soc., 83, 2591 (1961).

5 R.R. Sauers, J.Am.Chem.Soc., 81, 925 (1959).

6 W.R. Vaughan, C.T. Goetschel, M.H. Goodrow and C.L. Warren, J.Am.Chem.Soc., 85, 2282 (1963).

7 S. Winstein, E. Grunwald and L.L. Ingraham, J.Am.Chem.Soc., 70, 821 (1948).

8 Compare O.H. Wheeler and J.L. Mateos, Can.J.Chem., 36, 1431 (1958), who claimed that the product was a 75-25 borneol-isoborneol mixture.

9 W. Hückel, Ber., 77, 805 (1944).