CHAPTER III

Fragmentation of Homoallylic Alcohols : Geometric Requirements

FRAGMENTATION OF HOMOALLYLIC ALCOHOLS: GEOMETRIC REQUIREMENTS

Abstract——Synthesis of a number of γ-hydroxyepoxides of the bicyclo[2,2,1] heptane system and their fragmentation reactions in acidic and basic conditions are described in this Chapter. In basic medium fragmentation occurs only by synchronous concerted mechanism, while in acid medium it takes place by a free carbocation mechanism as well. For the former mechanism the anti-periplanarity of C-O and cleaving C-C bond is an essential geometrical requirement.

FRAGMENTATION OF HOMOALLYLIC ALCOHOLS: GEOMETRIC REQUIREMENTS

1. INTRODUCTION

In the last Chapter, fragmentation of 6-hydroxy-camphene(1) with different electrophiles was described. Conceivably, this fragmentation can proceed in a synchronous, concerted fashion(2) or through an acyclic species (3) (FIG.1). It is also evident that the synchronous, concerted fashion as depicted in 2 would require antiperiplanar geometry[1], whereas no such geometrical constraint would exist for the species 3. In order to gain some information regarding geometrical requirements for this fragmentation, work was undertaken which forms the subject matter of the present Chapter.

It was thought that 6-hydroxy-(both epimers) and 7-hydroxycamphene(both epimers) would provide appropriate substrates for such a study; it may be noted that the bicyclo[2,2,1]heptane system, for which such fragmentations have been demonstrated(Chapter II), has been retained in these substrates. In order to simulate the three-membered cyclic transition state[1], it was considered worth while to investigate the base-catalysed fragmentation of oxiranes derived from both the systems (1 and 5). It is generally

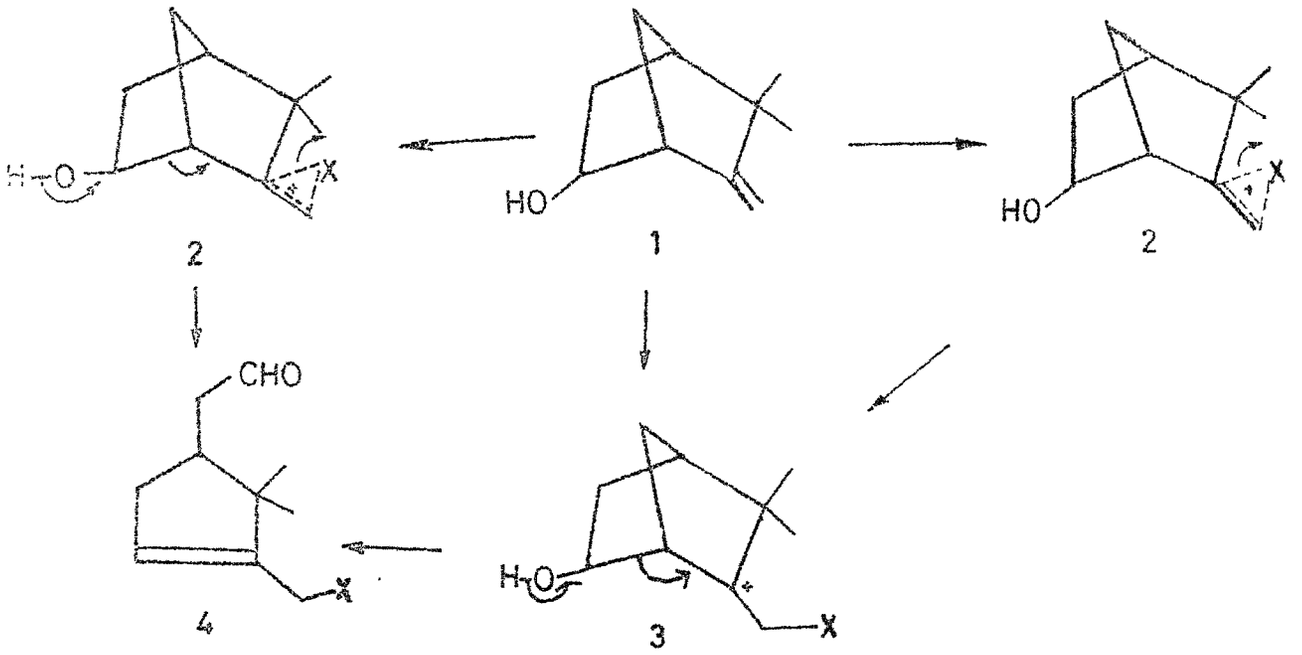
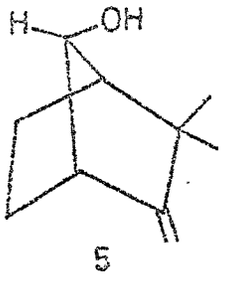


FIG:1



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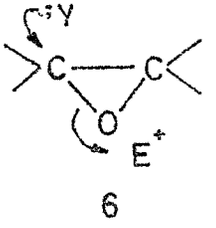

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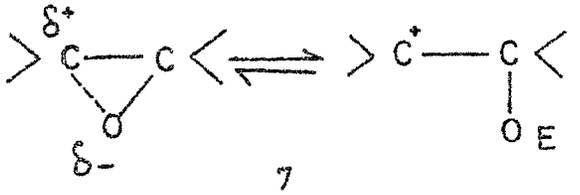

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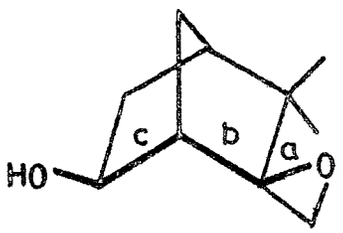
observed that the ring opening of oxirane under neutral and basic conditions proceeds *via* a back-side att ack[1] which is concerted in nature; the transition state for such a mechanism is shown in 6. On the other hand, cleavage in acidic condition is believed to proceed *via* a transition state having a good deal of carbonium ion character(7). Keeping these aspects in view, it was planned to investigate the fragmentation of following epoxides derivable from ~~the~~ 1 and 5. If the above considerations are valid, then fragmentation of epoxides 8, 10, 13 and 15 may be expected to occur under neutral/basic conditions; while epoxides 9,11,12 and 14 should resist such a fragmentation. On the other hand, all these epoxides may be expected to fragment under acidic condition.

We were able to successfully synthesise the five epoxides 8,9,11,12 and 13 and full details of these syntheses are given below. Fragmentation reactions of these five epoxides under both acidic and basic conditions have been studied and discussed later in the Chapter. Attempts to synthesise the rest of the epoxides 10,14 and 15 were not successful. In the case of 10, due to the complete control exerted by *endo*-hydroxyl group



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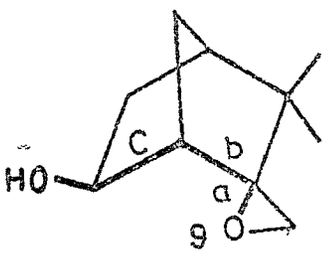

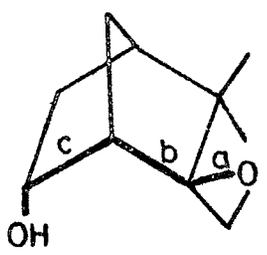

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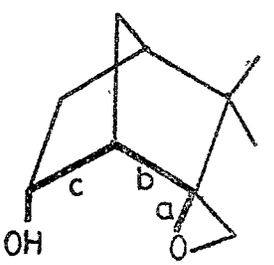

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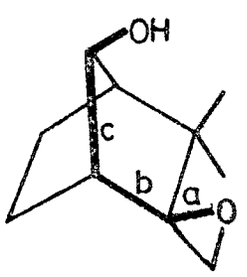

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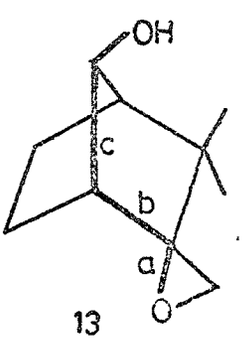

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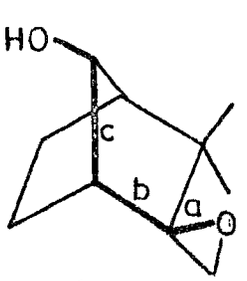

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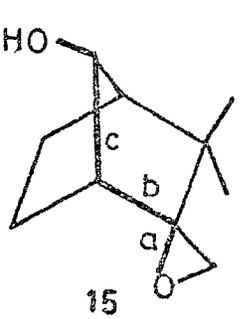

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on the direction[3] of attack by peracid on the corresponding olefin, we got epoxide 11 exclusively. In the case of 14 and 15 , we failed to make the starting olefin, namely, 7-anti-hydroxycamphene(17) by reduction of 7-ketocamphene (16). It is known[4] that reduction of 2-exo-methyl-7-ketonorborane with aluminium isopropoxide gives 7-anti-hydroxy derivative, whereas reduction with $NaBH_4$ gives 7-syn-hydroxy derivative. In the present case, however, reduction of 7-ketocamphene with either $NaBH_4$ or aluminium isopropoxide gave only 7-syn-hydroxycamphene exclusively. This may be due to the thermodynamic stability of 7-syn-hydroxycamphene by virtue of hydrogen bonding between hydroxyl group and olefinic bond[5].

2. SYNTHESIS OF EPOXIDES

2.1 6-exo-Hydroxy-2,10-epoxycamphanes(8 and 9):

6-exo-Hydroxycamphene(1) on treatment with peracetic acid, gave a mixture of two epoxides 8 and 9 (60:40; PMR) in quantitative yield. Their separation by conventional column chromatography on SiO_2-gel or Al_2O_3 was not possible because of their known rearrangement on these adsorbents[6]. So, 6-exo-hydroxycamphene(1) was converted to its formate 18 and then epoxidised as above to give the epoxy formates 19 and 20 in the ratio 60:40 (PMR) in quantitative yield. Preparative Gas Liquid Chromato-

graphy(GLC)(20% SE 30, 20 M, chromosorb W (40-60 mesh), 12' x 3/8", Al, 160°, 100 ml/min) led to the isolation of the major one (RRT=2.3) in the pure form. However, the minor component (RRT=2.5) could not be isolated in pure state. Nevertheless, since the major component could be isolated in pure state and its structure assigned unequivocally, the signals due to the minor component in the PMR spectrum of the mixture could be distinguished accurately. These signals were utilized to deduce the fate of this component during fragmentation of the mixture.

That the major component has the structure 18 was concluded from the following data.

(i) The propensity of exo-attack in bornane systems[7] is well established. It was therefore expected that the one formed in excess over the other should have exo-epoxide structure 19.

(ii) Anisotropic distribution of an epoxide ring is paramagnetic around the oxygen ring and diamagnetic at the neighbouring carbon atom[8](FIG.2). In the present case,

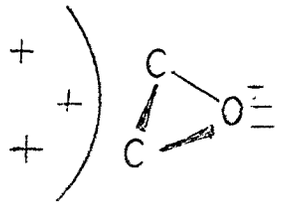


FIG.2: Anisotropic effect of the epoxide ring

in the PMR of the major component, proton α- to the formyloxy group appears at 4.87 ppm, whereas in the PMR of the mixture the corresponding signals appear at 4.87 and 5.05 ppm. The C_6-endo proton in endo epoxide 20 is on the same side of the epoxy oxygen and expected to experience a paramagnetic shift. In the exo-epoxide 19 , the epoxy-oxygen and C_6-endo proton are far apart. Hence the minor component was assigned endo-epoxide structure 20 and major component was assigned exo-epoxide structure 19.

iii) The configuration of the isolated pure epoxide is further confirmed by PMR lanthanide shift reagent study. We have used $Eu(FOD)_3$ complex with the epoxide for the assignment of its structure. In the pseudo contact interaction of lanthanide complex, the magnitude of Lanthanide Induced Shift(LIS) of a proton is dependent upon its average distance from the lanthanide metal ion[9]. However, the precise location of the lanthanide nucleus (metal ion) in such a system cannot be established with certainity. Hence, we adopted the method of Cockrill and co-workers[10]. These authors have suggested an alternative approach which obviates the need to know the precise location of the lanthanide nucleus.

Measurements or calculation of r from a specific proton to the periphery of the co-ordinating pair of electrons gives the observed relationship of $S^* \propto r^{-2.22}$.

The effect of incremental addition of $Eu(FOD)_3$ upon the chemical shift of C_6-endo proton and C_3-methyl groups is shown graphically in FIG-3. Whereas there is no ambiguity about the assignment of C_6-endo-protons, assignment of chemical shift of C_3-exo and endo-methyl group was based on the general observation that in bicyclo [2,2,1] heptane systems, the exo-methyl group appears downfield compared to endo-methyl group[11]. We have measured the distance between the centre of the hydrogen nucleus and the perimeter of the ion pair of oxygen of the oxirane, using Prentice Hall Framework Molecular Models. A plot between the shift parameter(s) and the $r^{-2.22}$ gives a straight line passing through zero as shown in FIG 4.

*The chemical shift of a particular hydrogen atom varies linearly with molar ratio of $Eu(FOD)_3$ to the substrate. The europium shift parameter 'S' can be determined from the slope of the graph of induced chemical shift vs molar ratio of shift reagent to the substrate and is equivalent in magnitude to the induced chemical shift produced by equimolar quantities of the shift reagent to the substrate.

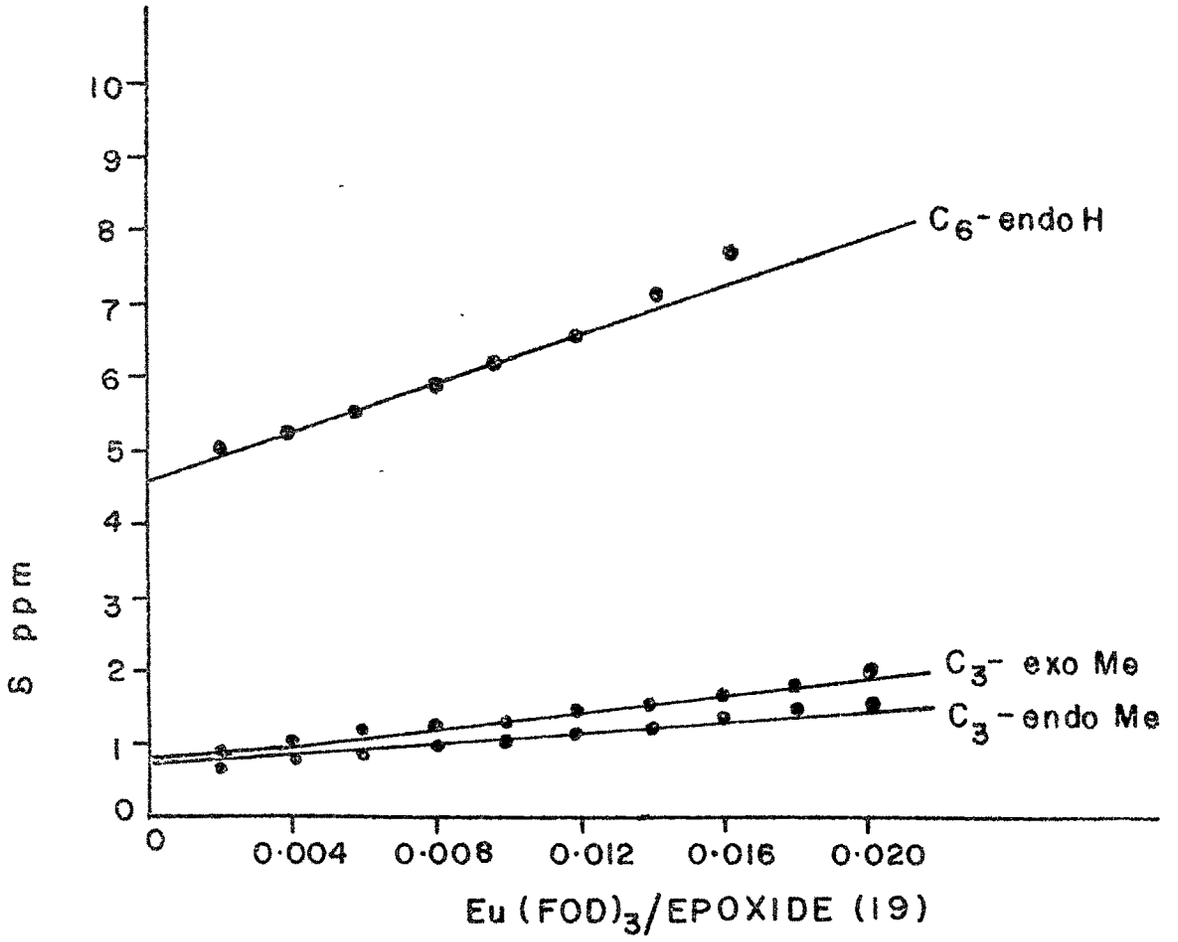


FIG. 3: THE RELATION BETWEEN CHEMICAL SHIFT AND THE MOLAR RATIO OF Eu (FOD)$_3$ / EPOXIDE (19).

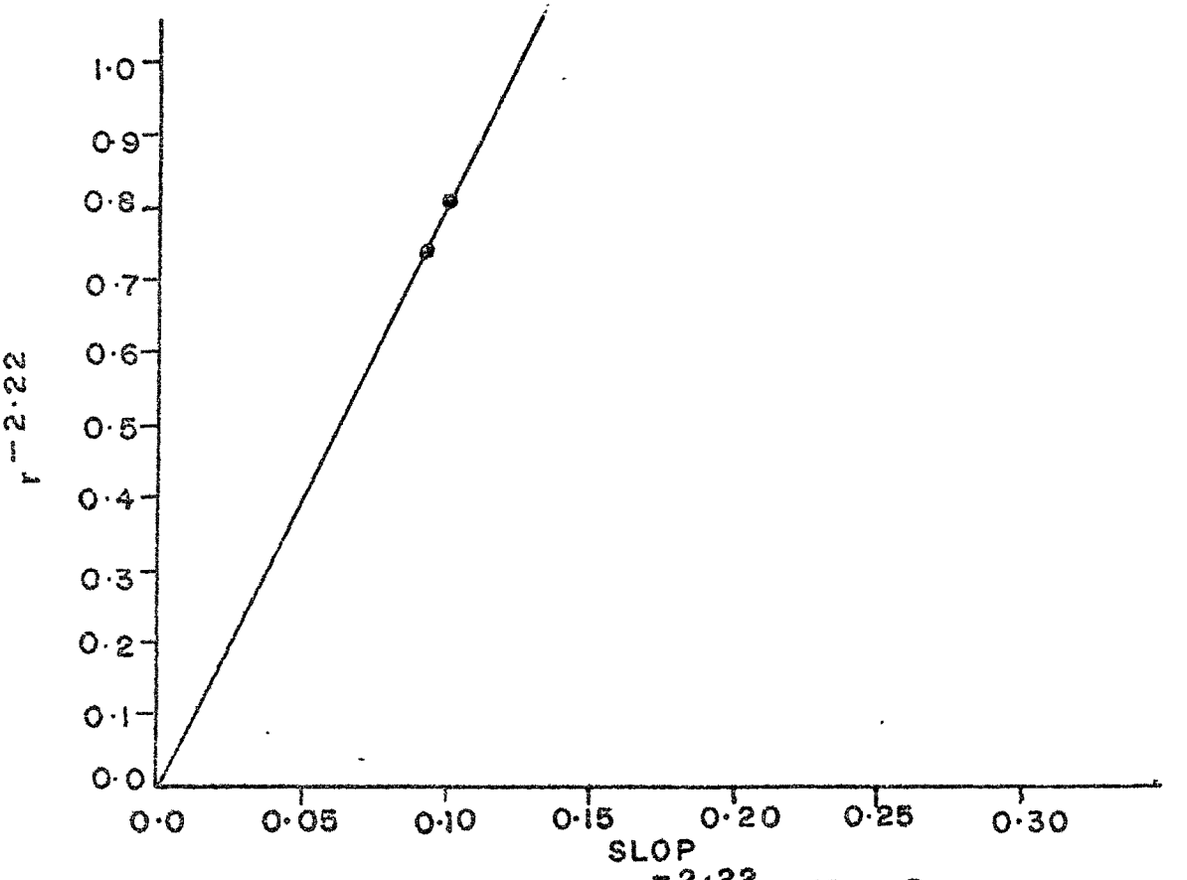


FIG. 4: GRAPH $r^{-2.22}$ VS S

The above epoxy formate 19 was converted to the desired hydroxy epoxide 8 by hydrolysis with aqueous $NaHCO_3$.

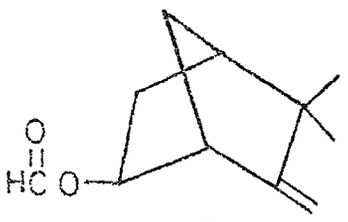
2.2 6-endo-Hydroxy-2,10-endo-epoxycamphane (11)

Epoxidation of 6-endo-Hydroxycamphene 1 (Chapter II) with peracetic acid gave a single epoxide in quantitative yield. Out of the two possible structures 10 and 11 for this epoxide, the former is ruled out based on mechanistic considerations as follows:

In the epoxidation of olefinic alcohols in non-polar solvent, it is known that the polar hydroxyl group influences the direction of attack by the peracid[3]. This directive effect of hydroxyl group has been suggested to arise because of hydrogen bonding between the hydroxyl group and the attacking peracid. For instance, the homoallylic alcohol 21[12] on epoxidation with perbenzoic acid in dichloromethane gives epoxide 22. In the present instance, the transition state can be depicted as shown in 23.

2.3 7-syn-Hydroxy-2,10-epoxycamphanes (12 and 13)

The starting material for the synthesis of these two epoxides 12 and 13 is obviously 7-syn-hydroxycamphene 5. This alcohol can be conveniently obtained by the selective reduction of 7-ketocamphene 16. We developed an efficient method for synthesising this ketone as described below.



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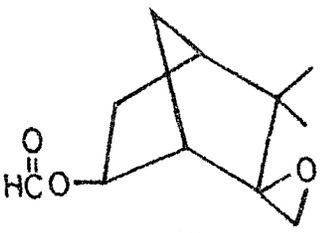

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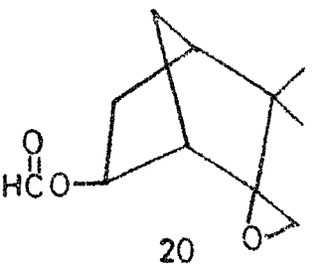

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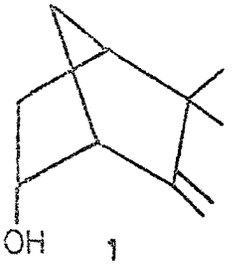

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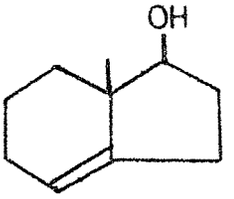

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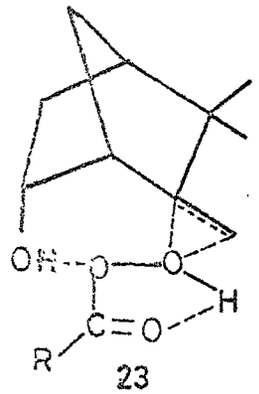

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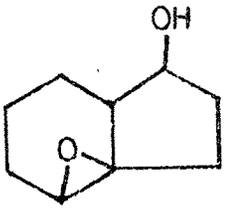

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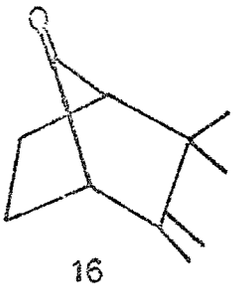

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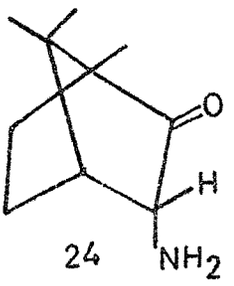

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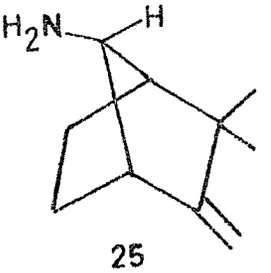

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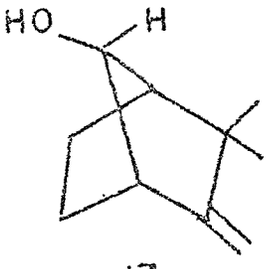

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The known[13] procedure calls for reduction of α-amino camphor 24 to 3-endo-aminoborneol /3-endo-aminoisoborneol, followed by rearrangement to 7-anti-aminocamphene 25, diozotisation and oxidation of the resulting 7-anti-hydroxycamphene. This sequence of reactions affords 7-ketocamphene 16 in an overall yield of < 15% from camphor. We now report a new[+] simpler route (FIG 5) leading to 16 in over 60% yield from camphor.

The key step in the new sequence (FIG 5) is the rearrangement of 3,3-ethylenedioxyisoborneol 27, readily available[15] in high yield from camphorquinone 26[16], to the required 7,7-ethylenedioxycamphene 29. Treatment of 27 with p-toluene sulphonyl chloride in pyridine at 88-90°(40 hr) gave a high yield of the corresponding tosylate 28, but no rearrangement took place[17]. However, in refluxing pyridine (56 hr), the desired 7,7-ethylenedioxycamphene (29; 55%), as was clear from the spectral characteristics of the product, together with the tosylate 28(~20%) and unreacted isoborneol 27(~10%) was formed. The same reaction,

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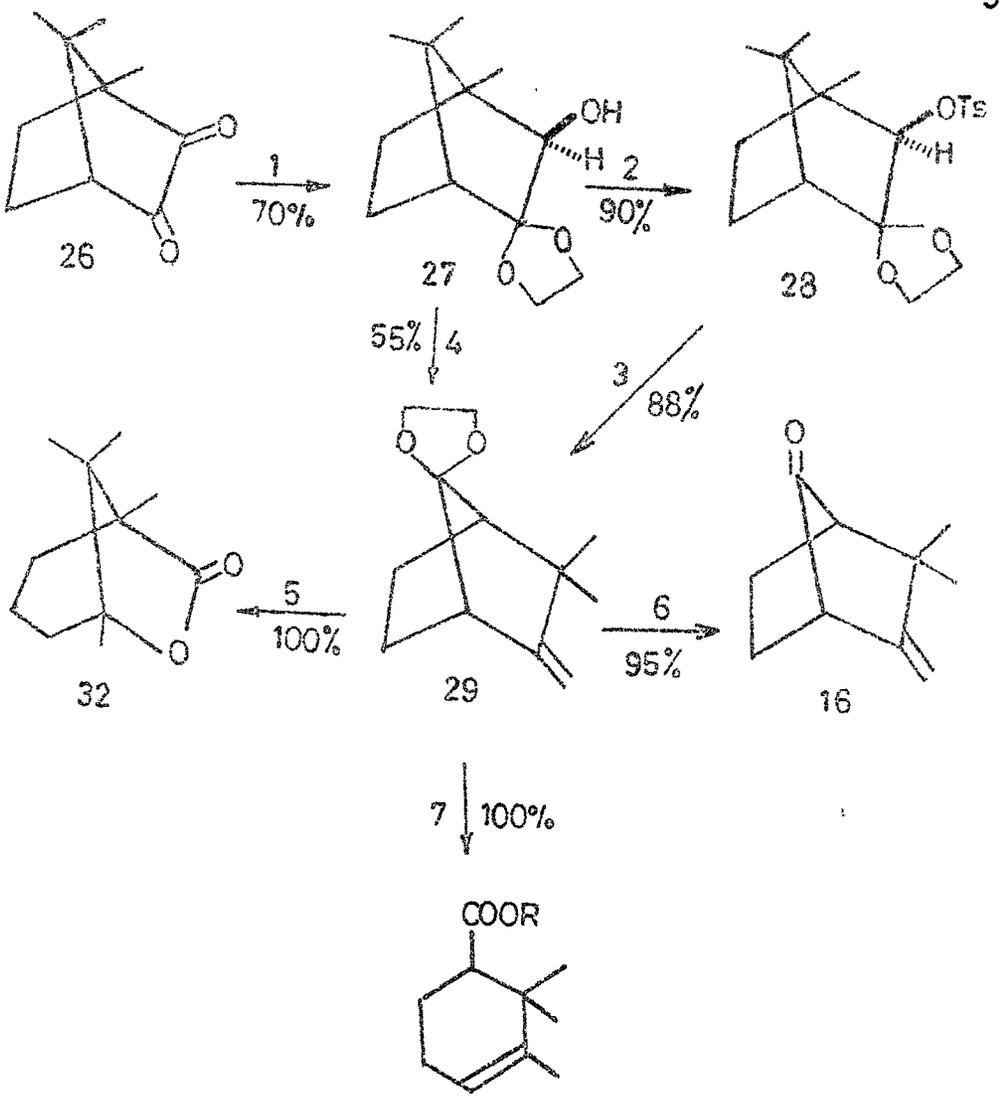
[+]A probable formation of 7-ketocamphene by acid catalysed rearrangement of chrysanthenone has also been reported[14].



30R = CH_2CH_2OH

31R = H

REAGENTS:-

(1) HO-$(CH_2)_2$-OH / P-TSA, LAH; (2) P-Me $C_6H_4SO_2Cl$ / 80-90°;

( ) Al_2O_3- Benzene / 80°; (4) P Me $C_6H_4SO_2Cl$ / 110°;

(5) 2N H_2SO_4 ; (6) 0·70% $HClO_4$ aq. dioxane (60 : 40 v/v);

(7) BF_3-Et_2O.

FIG-5 : 7,7-ETHYLENEDIOXY CAMPHENE AND ITS DEKETALISATION

when carried out with methane sulphonyl chloride proved more sluggish, only ~ 10% of 29 having been formed after 24 hr at reflux. In an effort to improve the yield of 29, solvolytic type rearrangement of the readily accessible tosylate 28 in alumina matrix[18] was investigated. When 28 was adsorbed on Al_2O_3 and allowed to stand at room temperature (~30°) for 48 hr 29 was formed to the extent of only 10-15%, balance being the unrearranged starting material. In a modification aimed at hastening the reaction, 28 was stirred with Al_2O_3 in refluxing benzene; this resulted in a much improved yield of 29 (~70%) together with a new product (~30%). This by-product is assigned structure 30 on the basis of spectral characteristics. IR:(CCl_4) (FIG 21): COOR 1735, 1155 cm^{-1}; OH 3450, 1080 cm^{-1}; C=C 1060 cm^{-1}. PMR(CCl_4) (FIG 22): two tert-Me's (3H, singlets at 1.01, 1.12 ppm); Me-C=C(3H, s, 1.67 ppm); $-COOCH_2-CH_2-OH$ (2H, m, 4.11-4.23 ppm), $COOCH_2-CH_2-OH$(2H,m,3.66-3.80 ppm); $C=CH-CH_2$(1H,bs, 5.3 ppm).Structure 30 was readily confirmed by its saponification to the known 31[13]. Conceivably, 30 arises from acid-catalyzed (at the Bronsted/Lewis acid sites of alumina[19]) fragmentation of 7,7-ethylenedioxy-camphene 29, on the lines depicted in FIG-6. If this

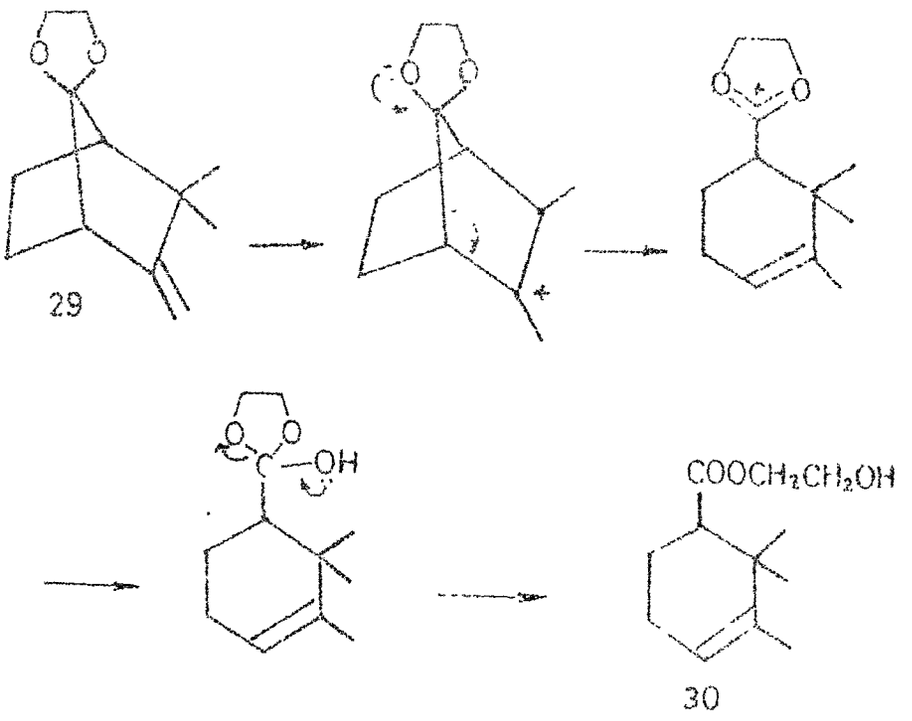
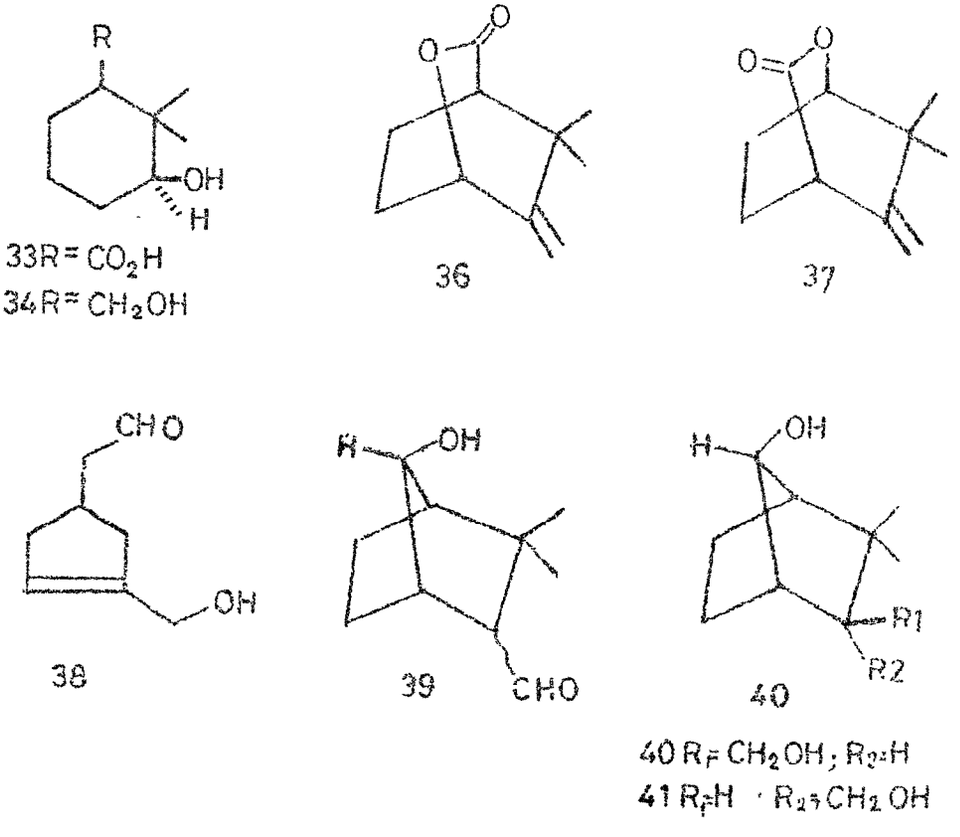


FIG. 5 ; POSSIBLE MECHANISM OF ACID-CATALYZED FRAGMENTATION OF 7,7-ETHYLENEDIOXYCAMPHENE (29)

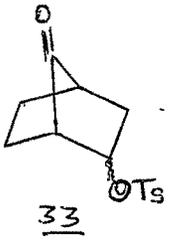


indeed is the path way to 30, then it may be possible to suppress this reaction by suitably blocking the acid sites on alumina. In practice, addition of pyridine(20%, on alumina w/w) to the reaction mixture resulted in an excellent yield (88%) of the required 29.

The susceptibility of 29 to acid-induced fragmentation, as experienced above, was expected to vitiate the next step, viz deketalisation of 29 to the required 7-keto-camphene (16). 7,7-Ethylenedioxycamphene 29 offers two sites for protonation. Preferential protonation at the ethylenedioxy moiety may be expected to give rise to the desired 7-ketocamphene 16, while protonation at the exocyclic olefinic bond may be expected to trigger the fragmentation reaction. In view of these considerations, exposure of 29 to a variety of acidic environments was investigated. Treatment of 29 with 1 to 4% HCl aq. gave varying proportions of 16 and 30. Interaction of 29 with BF_3-Et_2O led to the exclusive formation of 30. Treatment with 2N and 6N H_2SO_4 in aq. dioxane led solely to the formation of yet another product, which has been formulated as 32; the basis for this structural assignment will be discussed later. Lactone 32 can arise from both 16 and 30, the products of acid hydrolysis of ketal 29. Whereas unsaturated ester can lactonise with or without the prior formation of acid 31, 7-ketocamphene

must, however, first fragment to the acid 31. It may be noted that 7-ketocamphene 16 may be specially prone to this type of fragmentation , as the presence of SP^2 carbon at C_7 of bicyclo [2,2,1] heptane system would mean widening of the $C_{(1)}$-$C_{(7)}$-$C_{(4)}$ angle resulting in greater strain in the molecule[23]. After a series of protracted experiments to evaluate the effect of acid concentration on the above reactions, it was found that lower acid concentrations favour formation of 7-ketocamphene, while higher acid concentrations favour fragmentation and lactonisation. It was finally found that the action of 0.7% perchloric acid in aq. dioxane (42-46°; 56 hr) on 29 resulted in an excellent (95%) yield of the desired 7-ketocamphene 16.

No. fragmentation during solvolysis of 33 has been observed[20], though the corresponding 7-ketal does fragment[21].



33

A similar fragmentation followed by lactonisation has recently[22] been observed in the SbF_5-catalysed rearrangement of 3-exo-bromocamphor.

That the new product obtained from the interaction of 29 and 2-6N H_2SO_4 in aq. dioxane (vide supra) has the structure 32, was essentially clear from its spectral characteristics, especially the presence of an absorption at 1767 cm^{-1} due to the lactone and the presence of a 3H singlet at 1.21 ppm(CH_3-C-O) and 1H singlet at 2.10 ppm (CH-CO) in PMR spectrum. The structure was further secured by its saponification to the hydroxy acid 34. IR:OH 3584, 1106 cm^{-1}; COOH 1690, 920 cm^{-1}. 34 could be reconverted to the lactone 32 by treatment with methane sulphonyl chloride and pyridine or 6N H_2SO_4 aq. On LAH reduction 32 was converted to the diol 35. PMR: CH_2OH(2H, m, 3.39-3.85 ppm).

While repeating the deketalisation of 29 it was observed that whenever dioxane was contaminated with its hydroperoxides, the resulting 7-ketocamphene underwent some Baeyer-Villiger type oxidation, leading to a mixture of lactones 36 and 37. Indeed, 16 on treatment with 2N-sulphuric acid in dioxane containing peroxides gave a mixture of 36,37 and 32 (4:1:2 by PMR), which could be separated by chromatography into pure 36 and a mixture of 32 and 37. The structure of 36 and 37 are based on their spectral characteristics(Experimental). It is noteworthy that under the reaction condition, no epoxidation of exo-

cyclic olefinic bond of 16 took place. This is in contrast to the reaction of 7-ketocamphene 16 with peracetic acid in which the epoxidation and Baeyer-Villiger type oxidation products were formed in ratio (PMR) of 4:1. The synthetic potential of dioxane hydroperoxide for selective Baeyer-Villiger type oxidation is being explored.

Finally, the epoxidation of 7-syn-hydroxycamphene 5, obtained by the reduction of 7-ketocamphene with $NaBH_4$, with peracetic acid in dichloromethane gives a single epoxide in quantitative yield. On the other hand, the epoxidation of the corresponding formate gives a mixture of two epoxides in the ratio 8:2(PMR), which on hydrolysis gives a mixture of 7-syn-hydroxycamphane epoxides (12 and 13), in which major one is identical to the single epoxide obtained by direct epoxidation of 7-syn-hydroxycamphene. This clearly shows that 7-hydroxy group is directing the attack of peracid leading to a single epoxide with the exo-configuration. When hydroxyl group is protected the directing influence of C_7 hydroxyl group is lost but in view of the ease of exo- attack, the exo-epoxide still predominates in the product. Thus the major epoxide was assigned the exo- configuration and formulated as 12 . The minor epoxide 13 could not be isolated in pure state but its fragmentational behaviour was studied in the mixture of two epoxides.

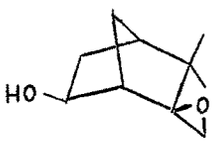
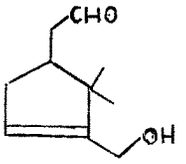
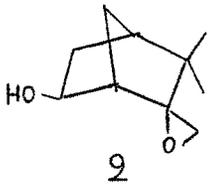
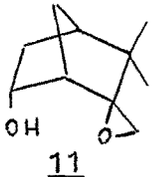
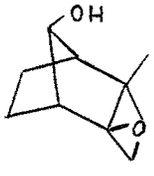
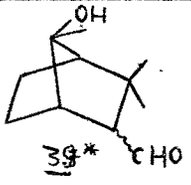
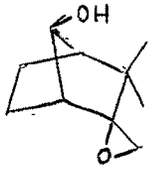
3. FRAGMENTATION OF EPOXIDES

The hydroxy-epoxides 8, 9, 11, 12 and 13 were subjected to fragmentation under various conditions and results are summarised in Table I.

3.1. Fragmentation of 6-exo-hydroxy-2,10-exo-epoxy camphane(8)

When epoxide 8 was treated with 0.25% $HClO_4$ in 90% aq.dioxane, it smoothly fragmented to give the expected aldehyde 38 in almost quantitative yield, which was homogeneous on TLC and PMR (FIG 35). The PMR spectrum of this product shows two quaternary Me's each as singlet at 0.86 and 1.06 ppm and a broad signal at 4.15 ppm and a triplet at 9.78 ppm(J = 1.5 Hz). It's IR spectrum(FIG 34) shows a carbonyl frequency at 1730 cm^{-1} and absorption at 2720 cm^{-1} assignable to the aldehyde function. This product gives strong yellow colour with TNM indicating the presence of double bond. Based on the mechanistic consideration and spectral data, the product was assigned structure 38. Also, this epoxide 8 fragments under basic conditions (NaH/THF, 60°) to give the same aldehyde 38, as shown by the PMR of the aliquots withdrawn at various stages of the reaction.

Table-I : Fragmentation of epoxides

Substrate	Reagent	Product	Yield
 8	i) H^+ ii) NaH/THF	 38	~100%
 9	i) H^+ ii) NaH/THF	36 No reaction	~100% -
 11	i) H^+ ii) NaH/THF	36 No reaction	~100% -
 12	i) H^+ ii) NaH-THF	 39*	~100% -
 13	i) H^+ ii) NaH-THF	39* No fragmentation	~90%

* Hyaroxy aldehyde 38 was identified by reduction with LAH to the corresponding diols (40 & 41).

3.2 Fragmentation of 6-exo-hydroxy-2,10-endo-epoxycamphane(9)

The behaviour of this system was studied using the mixture of the two epoxides 8 and 9. When this mixture was treated with 0.35% $HClO_4$ in 90% aq. dioxane, both the epoxides fragmented smoothly to give the hydroxy aldehyde 38. But, when the same mixture of epoxides was treated with base (NaH-THF, 60°) only one of them, namely, 8, fragmented, while the other epoxide 9 remained intact, as revealed by PMR of aliquots withdrawn at various stages of the reaction.

3.3 Fragmentation of 6-endo-hydroxy-2,10-endo-epoxycamphane, (11)

Exposure of epoxide 11 to 0.35% $HClO_4$ in 90% aq. dioxane (10°, 15 min) furnished, in almost quantitative yield a monocyclic aldehyde 38, but the same epoxide failed to fragment under basic conditions (NaH-THF, 60°).

3.4 Fragmentation of 7-syn-hydroxy-2,10-exo-epoxycamphane(12)

Treatment of 12 with 0.35% $HClO_4$ in 90% aq.dioxane (10°, 15 min) furnished in almost quantitative yield, a mixture of epimeric aldehydes 39, (IR:CHO 2720, 1725 cm^{-1}), which was further characterised by reduction (LAH) to diols 40 (PMR-$\dot{C}$-Me's 1.24, 0.88 ppm; C<u>H</u>OH, 1H,s,4.1 ppm; $C\underline{H}_2OH$, 2H, m, 3.6 to 3.9 ppm) and 41 (PMR-$\dot{C}$-Me's 1.24, 0.98 ppm; C<u>H</u>OH ,1H,s,4.1 ppm; $C\underline{H}_2OH$, 2H, m, 3.6 to 3.9 ppm);

in which 40 predominated. The formation of both epimers rather than only 40, is ascribed to acid catalysed epimerisation (to some extent) at C_2 under the reaction condition. But the epoxide 12 remains intact under basic condition (NaH-THF, 60°, 24 hr) and the starting epoxide was isolated.

3.5 Fragmentation of 7-syn hydroxy-2,10-endo-epoxy camphane (13)

The behaviour of this system was studied using the mixture of two epoxides 12 and 13. This mixture, when treated with $HClO_4$ in aq.dioxane (10°, 15 min) furnished in almost quantitative yield a mixture of epimeric aldehydes 39, which was further characterised by reduction (LAH) to diols 40 and 41 as above.

4. REACTION OF 7-SYN-HYDROXYCAMPHENE (5)

4.1 With Bromine

Treatment of 5 in CCl_4 with one molar equivalent of bromine (5% solution in CCl_4 added dropwise at 0° over a period of 5 min.) in presence of excess sodium carbonate, furnished in almost quantitative yield, a mixture of vinyl bromides 42 and 43 in the ratio 8:2 (PMR) respectively, which was separated by SiO_2-gel column chromatography into pure 42 and 43. The structure

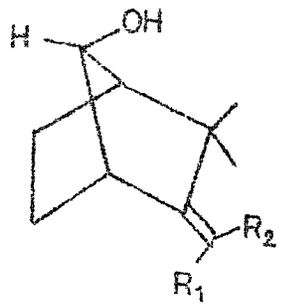
assignment of the two bromides 42 and 43 was easily made on the basis of difference in chemical shift of bridge head allylic proton in the PMR spectrum. This proton appears down field (3.10 ppm) in 42 compared to 43(2.6 ppm). The strong deshielding[24] of the allylic bridge head proton leads to the assignment of the bromine as anti with respect to gem-dimethyl group at C_3 in 42.

4.2 With Mercury (II) Acetate

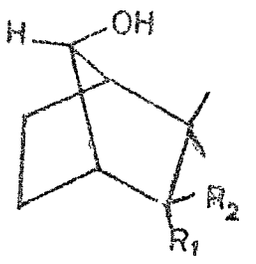
Treatment of 5 with mercuric acetate/$NaBH_4$ gave the normal oxymercuration-demercuration[25] products 44 and 45 in the ratio 7:3 (PMR) in almost quantitative yield. The formation of both epimers (44 and 45), rather than only 44, is ascribed to the formation of free carbonium ion followed by attack of the external nucleophile to give the major exo epimer 44. The pure 44 was obtained by chromatography, which on dehydration with alumina gave the starting 7-syn-hydroxycamphene 5.

5. DISCUSSION

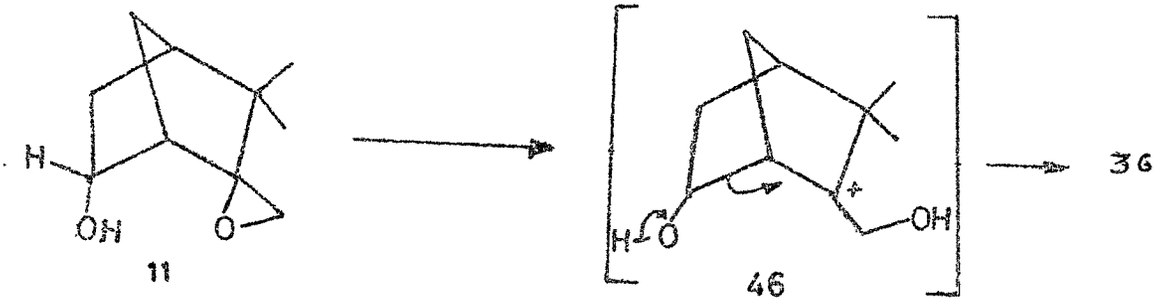
As expected, only the epoxide 8 which possesses a favourable geometry fragments under basic conditions. The epoxides 9, 11 and 13 where the cleaving bond C-C and C-O bond are synclinal, remain unreacted under these conditions.



42 R_1 = Br ; R_2 = H
43 R_1 = H ; R_2 = Br



44 R_1 = CH_3 ; R_2 = OH
45 R_1 = OH ; R_2 = CH_3



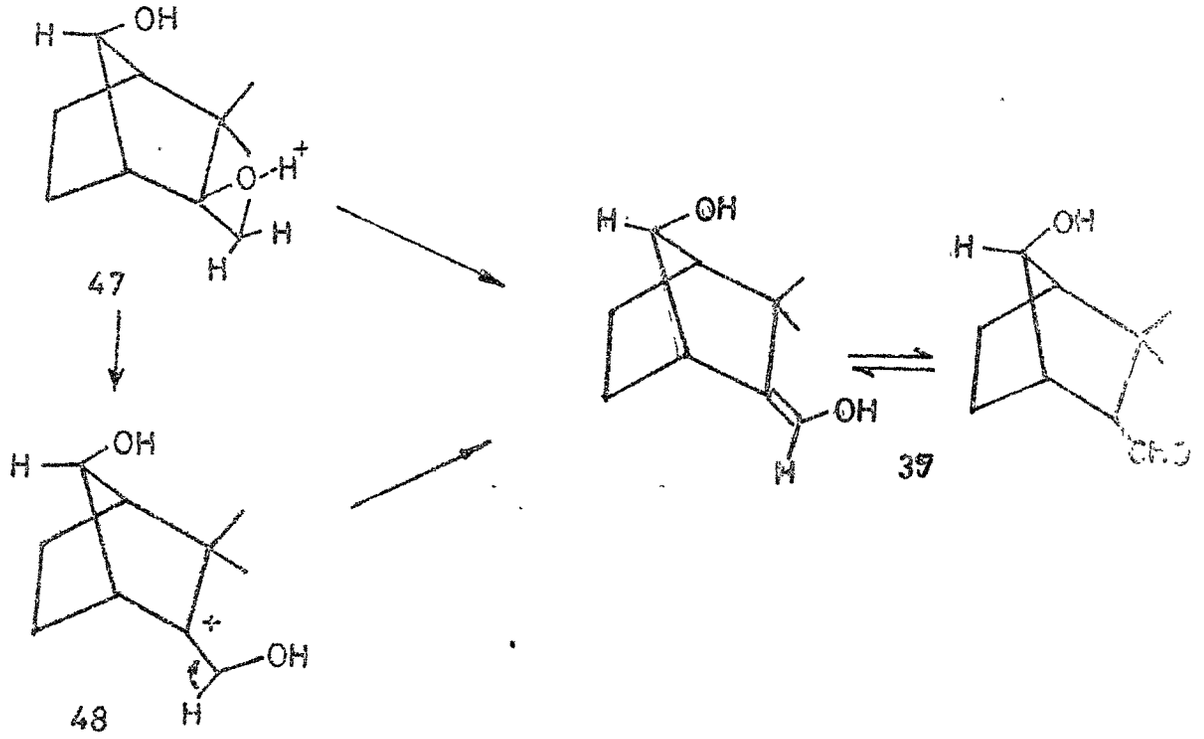


FIG. 7

Under acidic condition, all three 6-hydroxy-2,10-epoxycamphanes (8,9 and 11) fragment to give the corresponding monocyclic aldehyde 38. However, 7-syn-hydroxycamphene with electrophilic reagents such as bromine, mercury(II)acetate or even 7-syn-hydroxy-2,10-epoxycamphane 12 on treatment with acids failed to fragment. The epoxide 12 under acidic condition undergoes normal rearrangement to the aldehyde 39 which is in contrast to the fragmentation of the epoxide 9/11 under the same conditions. The difference in the behaviour of 12 versus 9/11 could originate from the following reasons:

In 9/11 the oxirane ring which is on the endo- side of the bicyclo[2,2,1] heptane skeleton experiences interaction from the endo substituents at C_5 and C_6, which forces it to open up to a free carbonium ion 46, which then cleaves. The oxirane ring in 12, on the other hand, is exo, which, under acidic condition either does not open up to a free carbonium ion(but forms a protonated bridged species 47, which can rearrange[26]) or if it does form 48, the overlap of the vacant p-orbital in the free carbonium ion with C_1-C_7 bonding orbital is not sufficient[27] to cause fragmentation.

In the oxymercuration of norbornane 49, exo-methoxy-norborane derivative 50 or acetoxy derivative 51 are formed[27].

The reaction is believed to proceed either *via* a mercurium ion A followed by *cis*-opening of three membered cyclic transition state with a nucleophile or a free carbonium ion B as an intermediate in this reaction (FIG.7 B).

7-*syn*-Hydroxycamphene (5) when treated with mercuric acetate gave mostly a mixture of two epimeric diols 43 and 44 and no fragmentation took place. Whether the intermediate is a free carbonium ion or three membered transition state, the capture of an external nucleophile (*viz* OH/OAc-ions) appears to be favoured over the collapse of C_1-C_7 bond.

Similarly, the bromonium ion 52 derived by treatment of 5 with bromine quenches itself by eliminating a proton to a mixture of vinyl bromides 41 and 42.

Thus, it is unequivocally established that in basic medium fragmentation occurs only by synchronous concerted mechanism and also that the antiperiplanarity of C-O and cleaving C-C bond is an essential geometrical requirement for such a mechanism. In acidic condition only 6-hydroxycamphene or its epoxides fragment smoothly but it seems that 7-*syn*-hydroxycamphene or its corresponding epoxide possess geometric features unfavourable for such fragmentation.

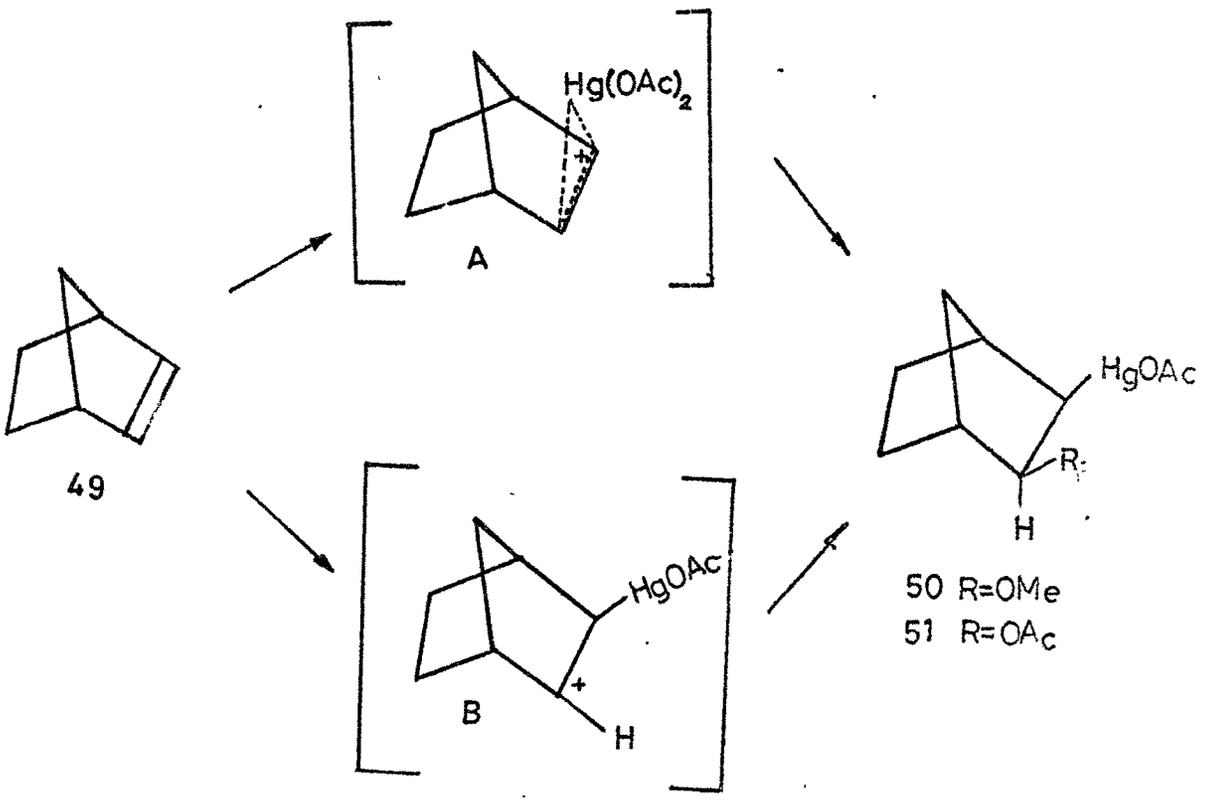
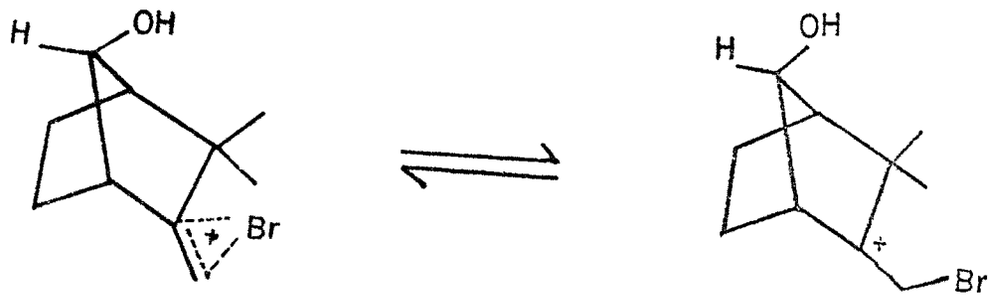


FIG.7B



52

EXPERIMENTAL

For general remarks see Chapter-II of this thesis.

6-exo-Hydroxy-2,10-epoxycamphanes (8 and 9)

Peracetic acid (82 mg, 1.1 m mol) was added dropwise to a precooled (25^{o}) solution of 6-exo-hydroxycamphene 1 (152 mg, 1 m. mol) in dichloromethane and anhydrous sodium carbonate (100 mg) and kept at -5 ± 1^{o} for 36 hours. Then the reaction mixture was diluted with dichloromethane(15 ml). Excess of peracetic acid was removed by washing with water till neutral and dried. Removal of solvent gave a yellow coloured liquid (158 mg, 95%), the mixture of epoxides 8 and 9 in ratio of 3:2 (PMR) respectively. IR(CCl_4)(FIG 8): OH 3610, 3495 and 1040 cm^{-1}; epoxide 3045,1220 and 880 cm^{-1}. PMR(CCl_4) (FIG 9): tert Me's singlets at 0.81, 0.85 ppm for 8, 0.69, 0.95 ppm for 9 ; CHOH (1H, dd, 3.87 ppm for 8 , 4.09 ppm for 9). (Found: H, C, 71.32; H, 9.52.$C_{10}H_{16}O_2$ requires C, 71.42; H, 9.52%).

6-exo-Formyl-2,10-epoxycamphanes(19 and 20)

6-exo-Hydroxycamphene 1 (456 mg, 3 m mol) was dissolved in a mixture of acetic anhydride (306 mg,3 m mole) and formic acid (138 mg, 3 m mole) and stirred for 15 minutes. Acetic acid formed was removed under high vacuum (2 mm) to furnish a colourless liquid, 6-exo-formyl camphene 18 (0.540 mg,~100%).

To a cooled solution of the above formate (540 mg, 3 m mole) in dichloromethane was added an aq. solution of peracetic acid (228 mg, 3 m mole). The reaction mixture was kept at $-5\pm1^{\circ}$ for 24 hours and worked up as above to give epoxides 19 and 20 in the ratio of 3:2 respectively. PMR(CCl_4) (FIG 10): tert Me's singlets at 0.87, 0.89 ppm for 19, 0.75, 0.99 ppm for 20 ; CHOH(1H, dd, 4.87 ppm for 19, 5.05 ppm for 20). Preparative GLC (20%, SE 30, 20M chromosorb W (45-60 mesh), 12' x 3/8", Al, 160°, 100 ml/min) provided a mixture of 20 and 19 and pure 19 .

Compound 19, B.P. 120°C/8 mm. IR (CCl_4) (FIG 11): COOR 1725,1155 cm^{-1}; epoxide 3045, 1220 cm^{-1}. PMR(CCl_4)(FIG 12): two tert Me's (3H, s, 0.87, 0.89 ppm); CHOH (1H, dd, 4.87 ppm, J_1= 10 Hz, J_2=3.5 Hz) ; $C\overset{O}{\diagdown\!\diagup}CH_2$ (2H, q, 2.63 ppm, J_1 = 6 Hz, J_2= 11Hz).

6-exo-Hydroxy-2,10-exo-epoxycamphane (8)

6-exo-Formyl-2,10-exo-epoxycamphane 19 (90 mg, 0.5 m mole) was dissolved in 10% $NaHCO_3$ in methanol aq. (50:50, 20 ml) and stirred at room temperature (~30°) for 12 hr. The mixture was diluted with water (10 ml) and extracted with ether (10 ml x3). The ether extracts were washed with brine (10 ml) and dried.

Removal of solvent furnished a colourless liquid, 6-exo-hydroxy-2,10-exo-epoxycamphane 8 (70 mg , 100%). IR(CCl_4) (FIG 13): OH 3610, 3495 and 1040 cm^{-1}; epoxide 3045,1220 cm^{-1}. PMR(CCl_4)(FIG 14): tert-Me's singlets at 0.79, 0.85 ppm; $C\overset{O}{\diagdown\diagup}CH_2$ (2H, q, 2.55 ppm, J_1 = 55 Hz, J_2= 11 Hz); C<u>H</u>OH (1H, dd, 3.87 ppm, J_1=10 Hz, J_2=3.5 Hz). (Found : C, 71.21; H, 9.48. $C_{10}H_{16}O_2$ requires C, 71.42; H, 9.52%).

6-<u>endo</u>-Hydroxy-2,10-<u>endo</u>-epoxycamphane (<u>11</u>)

Peracetic acid (82 mg, 1.1 m.mole) was added dropwise to a precooled (5°) solution of 6-<u>endo</u>-hydroxycamphene <u>1</u> (152 mg, 1 m. mole) in dichlromethane (5 ml) and sodium carbonate (50 mg) and kept at $-5\pm1^{\circ}$ for 36 hr. Then the reaction mixture was diluted with dichloromethane (15 ml). Excess of peracetic acid was removed by washing with 10% Na_2SO_3 aq. (10 ml x 2). It was washed till neutral and dried. Removal of solvent gave a colourless liquid 6-<u>endo</u>-hydroxy-2,10-<u>endo</u>-epoxycamphane <u>11</u> (158 mg, 100%). IR(CCl_4): OH 3610, 3495 and 1040 cm^{-1}; epoxide 3040, 1220 cm^{-1}. PMR(CCl_4)(FIG.15): tert-Me's singlets at 0.91, 1.05 ppm; $C\overset{O}{\diagdown\diagup}CH_2$ (2H, s, 2.6 ppm); C<u>H</u>OH(1H, bs, 4.2 ppm).(Found C, 71.31; H, 9.49. $C_{10}H_{16}O_2$, requires C, 71.42; H, 9.52%).

Reaction of 3,3-ethylenedioxyisoborneol 27 with p-toluene sulphonyl chloride

(i) Formation of 2-exo-tosyloxy-3,3-ethylenedioxy bornane(28):

A solution of 27[15] (0.638 g; 3 m mol) containing p-toluene sulphonyl chloride (0.665 g, 3.5 m mole) was heated at 88-90° for 40 hr. The mixture was cooled to room temperature (~30°) and poured onto crushed ice (30 g) when a crystalline precipitate was formed which was filtered off, washed with water (10 ml), dried (5 torr/30°) and crystallised from light petroleum to give 28 (0.91 g, 88%); m.p. 92-93°. IR(Nujol) (FIG 16): OTs 1352, 1178 cm^{-1}. PMR(CCl_4)(FIG 17): tert-Me's singlets at 0.64, 0.79, 1.06 ppm; ArMe(3H,s,2.45 ppm); O-CH_2-CH_2-O (2H, m, 3.70-3.91 ppm); CH-OTs (1H, s, 4.29 ppm); aromatic H's (4H, m, 7.25-7.85 ppm).(Found C, 62.26; H,6.97. $C_{19}H_{26}O_5S$ requires : C, 62.28; H, 7.15%).

(ii) Dehydrative rearrangement of 27 : A mixture of 27 (1.50 g, 0.5 m mol) and p-toluene sulphonyl chloride(3.0 g, 20mmol) in pyridine (25 ml) was refluxed for 56 hr . The mixture was cooled to room temperature and poured with stirring into ice cold water (200 ml) and extracted with ether (50 ml x 3). The ether combined extracts were washed and dried. Removal of solvent gave a residue (1.1 g) which was chromatographed over neutral alumina (IIB, 36 x 1.5 cm column).

Fr. 1	Light petroleum	50ml x 3	0.730 g	essentially 29
Fr. 2	Benzene	50ml x 3	0.220 g	essentially 28
Fr. 3	5% EtOAc in C_6H_6	50ml x 3	0.150 g	unreacted 27

Fraction 1 was distilled to yield 29; b.p. 82-83°/8 mm (93% pure by glc, 10% carbowax, 20 M, 12', 160°). IR (CCl_4)(FIG 18): $C=CH_2$ 3040, 1650 and 875 cm^{-1}; ketal 1189, 1120 and 1079 cm^{-1}. PMR(CCl_4)(FIG 19): tert-Me's singlets at 1.08, 1.26 ppm; $C\underline{H}-C=CH_2$ (1H, d, 2.22 ppm, J = 3.5 Hz); $O-C\underline{H}_2-C\underline{H}_2-O$ (4H,m,3.65-3.96 ppm); $C=C\underline{H}_2$(two 1H singlets, 4.58, 4.70 ppm). Mass: m/e 194(M^+,63%), 179(41%), 152(90%), 151(20%), 113(19%), 107(67%), 99(100%), 94(52%), 93(38%), 91(48%).(Found C, 73.95;H,9.18 $C_{12}H_{18}O_2$ requires C, 74.19; H, 9.54%).

Rearrangement of the tosylate 28

(i) At room temperature: The tosylate 28(0.122 g, 0.3 m mol) was adsorbed on a dry column of alumina (I, 12 g, 20 x 1.5 cm) and allowed to stand at room temperature (~ 30°) for 48 hr. Elution with benzene (50 ml) gave a mixture of 28 and 29 (85:15, 106 mg).

(ii) In refluxing C_6H_6 : A mixture of 28 (2.15 g, 6 m mol) and alumina (I, 10 g) in benzene (15 ml) was refluxed for 24 hr. It was cooled to room temperature and filtered. Alumina was washed with excess benzene (20 ml x3). The solvent was

removed from the combined organic extracts to get 29 (0.75, 70%). Alumina was further washed with 20% EtOAc in C_6H_6 (10 ml x3). Removal of solvent furnished a yellow liquid (300 mg, homogeneous on tlc, SiO_2-gel, EtOAc-C_6H_6, 5:95) which was found to be 30.

(iii) In refluxing benzene and in presence of pyridine:

A mixture of 28 (1.0 g, 2.7 m mol) and alumina (I, 10 g) in benzene (15 ml) and pyridine (2.0 g) was refluxed for 24 hr . It was worked up as usual to give 29 (0.470 g, 85%).

Saponification of 30

The hydroxy ethyl ester 30 (50 mg, 0.2 m mol) in methanol (10 ml) was mixed with 20% NaOH aq (15 ml) and the contents were refluxed for 12 hr. After dilution with water (50 ml), the mixture was acidified with 3 N.HCl and extracted with ether (30 ml x 3). The organic extracts were washed and dried. Removal of solvent and crystallisation of the residue from light petroleum furnished 31 (30 mg, 100%); m.p. 78-80°(Lit[1] m.p. 77.6-78.6°).

Hydrolysis of ketal 29

(i) Reaction of 29 with 2N H_2SO_4-formation of lactone 32: 7,7-Ethylendioxycamphene 29 (194 mg, 1 m mol) was dissolved in 2 N H_2SO_4 in aq dioxane (40:60, 20 ml) and stirred at room temperature ($\sim 30^{\circ}$) for 6 hr. The mixture was neutralised with 5% $NaHCO_3$ aq.(5 ml), diluted with water (50 ml) and extracted with ether (10 ml x 3). The ether layer was washed and dried. Removal of solvent furnished a white solid which on crystallisation from light petroleum ether gave 32. (168 mg, 100%); m.p.107.8°(sealed tube).(95% purity by glc, 5% carbowax, 20 M, 6', 170°). IR ($CHCl_3$)(FIG 20):C=O 1767, 1100 and 946 cm^{-1}. PMR($CDCl_3$) (FIG 21):tert-Me's (6H,s,1.05 ppm); CH_3-C-O (3H,s,1.23 ppm), CH-CO (1H, b s, 2.10 ppm). Mass m/e 168 (M^+,0.6%), 140(17%), 125(11%), 124(12%), 111(15%), 109(37%), 108(20%), 97(13%), 83(16%), 82(100%) (Found: C,71.15; H, 9.41. $C_{10}H_{16}O_2$ requires: C, 71.39; H, 9.59%).

(ii) Reaction of 29 with BF_3-Et_2O : $BF_3.Et_2O$ (0.1 ml) was added to a stirred solution of 29 (20 mg) in anhydrous ether (20 ml) at 0°. The mixture was stirred for additional 30 min, diluted with water (30 ml) and extracted with ether(20 mlx3). The ether layer was washed and dried. Removal of solvent furnished 30 (12 mg) which was homogeneous by tlc.

IR(CCl_4)(FIG 21):COOR: 1735, 1155 cm^{-1}; OH 3450,1080 cm^{-1} C=C 1666 cm^{-1}. PMR(CCl_4)(FIG 22): two tert-Me's(3H singlets at 1.01, 1.12 ppm); Me-C=C (3H,s,1.67 ppm),-$COOCH_2$-CH_2-OH (2H, m, 3.66-3.80), -$COOCH_2$-CH_2-OH (2H, m, 4.11-4.23 ppm), C=CH.CH_2 (1H, bs, 5.5 ppm). Mass: m/e 212(M^+, 17%), 151(20%), 150(44%), 123(44%), 122(62%),108(18%), 107(100%), 96(50%), 93(19%), 91(18%), (Found:C,67.97; H, 9.18. $C_{10}H_{20}O_3$ requires C, 67.89; H, 9.50%).

(iii) Reaction of 29 with $HClO_4$: A solution of 29 (195 mg, 1 m mol) and 70% $HClO_4$(0.3 ml) in aq.dioxane (40:60, 30 ml) was stirred at 42-46° for 56 hr. The mixture was cooled to room temperature, neutralised with 5% $NaHCO_3$ aq(20 ml) and extracted with ether (25 mlx3). The ether layer was washed with brine (10 ml x 3) and dried. Careful removal of solvent furnished the desired 16 in almost quantitative yield (150 mg); m.p. 70-71°(Lit[13] 55- 6°). IR($CHCl_3$)(FIG 23):C=O 1772, 1750 cm^{-1}, PMR(CCl_4) (FIG 24):two tert-Me's (3H,s,1-09, 1.24 ppm); C=C-CH-(1H, d, 2.45 ppm, J=4.0 Hz); $C=CH_2$ (1H singlets at 4.80, 4.88 ppm).

Saponification of lactone 32

The lactone (168 mg, 1 m mole) in methanol (10 ml) was mixed with 20% KOH aq(15 ml). The mixture was refluxed for 12 hr cooled to room temperature and diluted with water (25 ml). After acidification with 10 N.HCl, it was extracted with ether (20 ml x 3) and the combined

ether extract was adried. Removal of solvent gave 33 (160 mg, 100%); m.p.105°. IR($CHCl_3$)(FIG 25); OH 3584, 1108 cm^{-1};COOH 1690, 920 cm^{-1}. PMR($CDCl_3$)(FIG 26): two tert-Me's singlets at 1.06, 1.12 ppm; CH_3-C-OH (3H, s, 1.19 ppm); $CHCO_2H$ (1H, bs, 2.55 ppm).(Found: C, 64.39; H, 9.53.$C_{10}H_{18}O_3$.requires:C, 64.49,H,9.74%).

Lactonisation of hydroxy acid 33

A solution of 33 (10 mg) in pyridine (3 ml) containing $MeSO_2Cl$ (20 mg) was refluxed for 2 hr. It was worked up in the usual manner to get a product (8 mg) which was identical with 32 (m.p.,tlc, IR,PMR).

LAH reduction of lactone 32

Lactone 32 (84 mg,0.5 m mol) was reduced with LAH (40 mg, 1 m mole) in dry ether (20 ml). After usual work up, gave diol 34 in quantitative yield. IR(CCl_4) (FIG 27): OH 3600, 3380, 1255 and 1010 cm^{-1}. PMR(CCl_4) (FIG 28): tert-Me's singlet at 0.92,1.01 ppm; CH_3-C-OH (3H, s, 1.20 ppm); CH_2OH(2H, m, 3.39-3.85 ppm).(Found: C, 69.52; H, 11.55. $C_{10}H_{20}O_2$ requires: C, 69.72; H,11.70%).

Baeyer-Viliger oxidation of 7-ketocamphene(16)

7-Ketocamphene (25 mg) was stirred in 5% H_2SO_4 in aqueous dioxane (60:40, 30 ml) containing some dioxane hydroperoxide, for 56 hr at 42-46° and worked up in the usual manner. The PMR of the residue indicated it to be mixture of 36, 37 and 32. Column Chromatography of the product on silica gel (II, 5 g, 25 x 0.7 cm) using benzene and 2% EtOAc in benzene as eluent, provided a mixture of 32 and 37 and pure 36.

Compound 36, m.p. 76°(light petroleum/benzene). IR ($CHCl_3$) (FIG 29): C=O 1750 cm^{-1}; C=C 3062, 1650 and 910 cm^{-1}. PMR ($CDCl_3$)(FIG 30): tert-Me's singlets at 1.15, 1.22 ppm; -CH-OCO (1H, d, 4.76 ppm, J= 3.5 Hz); $C=CH_2$(1H singlets at 4.95 and 5.09 ppm). Mass: m/e 166(M^+, 16%), 138(21%),122(52%), 109(23%), 107(100%), 96(39%), 94(21%), 93(48%), 91(37%),79(59%). (Found: C, 72.04; H, 8.36. $C_{10}H_{14}O_2$ requires: C,72.26;H,8.49%). Compound 37, PMR (deduced from that of mixture of 32 and 37): OCOCH-C=CH_2(1H, bs, 3.07 ppm);-CH-O-CO(1H, bs, 4.12 ppm); $C=CH_2$(1H singlets at 4.88, 5.02 ppm).

Reduction of 7-ketocamphene 16

(i) With $NaBH_4$: A mixture of 7-ketocamphene 16 (150 mg, 1 m mol) and $NaBH_4$ (150 mg,5 m mol) in methanol (15 ml) was stirred for 3 hrs at room temperature (30°) under nitrogen. Excess of $NaBH_4$ was destroyed by adding 15% aq AcOH (1 ml); then it was

diluted with water (10 ml) and extracted with ether (15 ml x 3). The organic extracts were washed till neutral with water (10 ml x2) and dried. Removal of solvent offered 5 (148 mg,100%) which was crystallised from pet ether, m.p. 88-90° (Lit[13] 80-85°). IR(CCl_4) (FIG 31): OH 3500, 1650 cm^{-1}, C=C, 1650,920 cm^{-1}. PMR(CCl_4) (FIG 32): two tert-Me's singlets at 1.10, 1.19 ppm; $H_2C{=}C\text{-}C\underline{H}$- (1H, bs, 2.45 ppm); $C\underline{H}OH$(1H, bs, 3.99 ppm); $C{=}C\underline{H}$ (1H singlets at 4.72,4.85 ppm).

(ii) With aluminium isopropoxide: Into a 50 ml flask fitted with a partial reflux head a magnetic stirrer were placed 2 ml of a 0.032 M solution of 5 in diethyl ether along with aluminium isopropoxide (100 g) and isopropyl alcohol(5 ml). This mixture was heated to 50°C and stirred for 2 days. After cooling to room temperature the mixture was poured into saturated aq.NH_4Cl(200 ml) and solution extracted with ether (20 ml x 3). Usual work up gave 7-syn-hydroxycamphene 5 in quantitative yield:

7-syn-Hydroxy-2,10-exo-epoxycamphane(12)

Peracetic acid (82 mg, 1.1 m mole) was added dropwise to a precooled (5°) solution of 7-syn-hydroxycamphene 5

(152 mg , 1 m mole) in dichloromethane (5 ml) and sodium carbonate (50 mg) and kept at $-5\pm1^{\circ}$ for 36 hr. Then the reaction mixture was diluted with dichloromethane(15 ml). Excess of peracetic acid was removed by washing with 10% Na_2SO_3 aq.(10 ml x2). It was washed till neutral and dried. Removal of solvent gave a colourless liquid, 7-syn-hydroxy-2,10-exo-epoxycamphane 12 (160 mg, 100%). IR (CCl_4) (FIG 32): 3610, 3495 and 1040 cm^{-1}; epoxide 3040, 1220 cm^{-1}. PMR(CCl_4)(FIG 33): tert-Me's singlets at 0.95, 1.09 ppm; $C\overset{O}{\diagup\diagdown}CH_2$ (2H, s, 2.55 ppm); CHOH(1H, bs, 4.05 ppm). (Found C, 71.31; H, 9.51. $C_{10}H_{16}O_2$ requires C, 71.42; H, 9.52%).

7-syn-Hydroxy-2,10-epoxycamphanes(12 and 13)

7-syn-Hydroxycamphene 5 (456 mg, 3 m mol) was dissolved in a mixture of acetic anhydride (306 mg, 3 m mol) and formic acid (138 mg, 3 m mol) and stirred for 15 minutes. Acetic acid formed was removed under high vacuum (2mm) to furnish a colourless liquid 7-syn-formyloxycamphene(0.540 mg,~100%).

To a cooled solution of the above formate (540 mg, 3 m mol) in dichloromethane was added an aq. solution of peracetic acid (228 mg, 3 m mol). The reaction mixture was kept at $-5\pm1^{\circ}$ for 24 hrs. and worked up as above to give mixture of two epoxides in the ratio 8:2(PMR), which on hydrolysis with 5% $NaHCO_3$(10 ml) at room temperature

gives a mixture of 7-syn-hydroxy-2,10-epoxides 12 and 13 (550 mg,100%). PMR(CCl_4): tert-Me's singlet at 0.92, 1.06 ppm for 12, 0.81, 1.13 ppm for 13, CHOH(1H, bs, 4.05 ppm for 12, 4.05 ppm for 13); O—CH_2(2H, s, 2.55 ppm of 12, 2H, q, 2.72 ppm for 13).

Fragmentation of epoxide 8

(i) With acid: To a solution of 0.35% $HClO_4$ in 90% dioxane (10 ml) at 10°C was introduced the epoxide 8 (168 mg, 1 m mole) in one lot. The reaction mixture was stirred at the same temperature for 15 minutes, then quenched with 5% $NaHCO_3$ aq. (15 ml) and extracted with ether (15 ml x 3). The ether extracts were washed till neutral with water (10 ml x 3) and dried. Removal of solvent furnished 38 in almost quantitative yield. I.R (CCl_4)(FIG.34): OH 3500, 1050 cm^{-1}; C=O 2720, 1725 cm^{-1}. PMR(CCl_4)(FIG.35): tert-Me's singlets at 0.86, 1.06 ppm, CH_2OH(2H, bs, 4.15 ppm), C=CH (1H, bs, 5.58 ppm), CHO(1H, t, 9.75 ppm, J= 1.5 Hz).(Found C, 71.31; H, 9.52. $C_{10}H_{16}O_2$ requires C, 71.52, H, 9.52%).

(ii) With base: To a stirred suspension of NaH(cleaned from the mineral oil by washing with dry ether) (60 mg, 3 m mol) in dry THF(5 ml) under an atmosphere of nitrogen was added dropwise a solution of epoxide 8 (152 mg,1 m mol) in dry THF (1 ml) and stirred under reflux for 16 hr. Aliquots were withdrawn at the intervals of 4 h, 8 h and 12 h and worked up as usual and their PMR's were recorded. The PMR

indicated the presence of hydroxyaldehyde 38(CHO, 9.73 ppm, CH_2OH, 2H, s, 4.15 ppm, C=CH 1H, bs, 5.37 ppm).

Fragmentation of epoxides 8 and 9

(i) With acids: To a solution of 0.35% $HClO_4$ in 90% dioxane (10 ml) at 10° was introduced the mixture of epoxides 8 and 9 (152 mg, 1 m mol) in one lot. The reaction mixture was stirred at the same temperature for 15 minute. Usual work up (describe above) gave hydroxy aldehyde 38(150 mg, 90%).

(ii) With base: To a stirred suspension of NaH (60 mg, 3 m mol) in dry THF (5 ml) under an atmosphere of nitrogen was added dropwise a solution of epoxides 8 and 9 (152 mg, 1 m mol) in dry THF (1 ml) and stirred under reflux for 16 hr. Aliquots were withdrawn at the intervals 4 h, 8 h and 12 h ,and worked up as usual and their PMR's were recorded. The PMR's indicated the presence of hydroxyaldehyde 38 (CHO ,1H, t., 9.73 ppm; CH_2OH, 4.15 ppm; C=CH, 1H; bs, 5.37 ppm) and also that of the unreacted epoxide 9 (tert-Me's 0.69, 0.95 ppm; CHOH, 1H, m, 4.09, 4.12 ppm).

Fragmentation of the epoxide 11

i) With acid: To a solution of 0.35% $HClO_4$ in 90% dioxane (10 ml) at 10° was introduced the epoxide 11 (168 mg, 1 m mol) in one lot. The reaction mixture was stirred at the same temperature for 15 minutes. Usual work-up gave the hydroxy aldehyde 38 (150 mg, ~ 90%)

(ii) With base: To a stirred suspension of NaH (60 mg, 3 m mol) in dry THF (5 ml) under an atmosphere of N_2 was added dropwise a solution of epoxide 11 (168 mg, 1 m mol) in dry THF (1 ml) and stirred under reflux for 16 hr. After 16 hrs the starting epoxide 11 was isolated back.

Reaction of 7-syn-hydroxy-2,10-exo-epoxycamphane 12

(i) With acid: To a solution of 0.35% $HClO_4$ in 90% dioxane (10 ml) at 10° was introduced the epoxide 12 (168 mg, 1 m mol) in one lot. The reaction mixture was stirred at the same temperature for 15 minutes. Usual work up gave the mixture of epimeric hydroxy aldehydes 39 (IR; CHO, 2720, 1725 cm^{-1}, OH, 3600, 3380 cm^{-1}) in quantitative yield.

The above aldehydes 39 (168 mg, 1 m mol) in dry ether(10 ml) was added dropwise to a stirred slurry of LAH (50 mg) in dry ether (10 ml) and stirred at room temperature (~30°) for 6 hr under N_2. Usual work up gave the mixture of diols 40 and 41 in the ratio of 7:3 (PMR). IR($CHCl_3$) (FIG 36):3400,3440,1050, 920 cm^{-1}. PMR($CDCl_3$)(FIG 37):-C-Me singlets at 0.86 and 1.25 ppm for 40;0.98and 1.25 ppm 41; CH_2OH (2H, bs, 3.71ppm); CHOH(1H, bs, 4.05 ppm). (Found C,74.92; H, 11.12. required: C,75.00; H, 11.22%).

(ii) With base: To a stirred suspension of NaH (60 mg, 1m mol) in dry THF (5 ml) under an atmosphere of nitrogen, was added dropwise a solution of epoxide 12 (168 mg, 1 m mol) in dry THF (1 ml) and stirred under reflux for 16 hr. Usual work up gave back the starting epoxide 12.

Fragmentation of epoxide 12 and 13

(i) With acid: To a solution of 0.35% $HClO_4$ in 90% dioxane (10 ml) at 10° was introduced the mixture of epoxides 12 and 13 (168 mg, 1 m mol) in one lot. The reaction mixture was stirred at the same temperature for 15 minute. Usual work up gave the epimeric mixture of hydroxy aldehyde 39 which on reduction with LAH gave the epimeric diols 40 and 41 (150 mg, 100%).

(ii) With base: Reaction of epoxide mixture (12 and 13) with NaH in refluxing THF for 16 h followed by usual work up gave a complex mixture, which did not possess the fragmentation product (no CHO peak in PMR spectrum).

Reaction of 7-syn-hydroxycamphene(5)

With bromine: To a cooled solution of homoallylic alcohol 5 (152 mg, 1 m mol) in carbontetrachloride (10 ml) containing sodium carbonate (100 mg) was introduced a cold solution of bromine in CCl_4 (5 ml, 160 mg of bromine 1 m mol) during a period of 5 minutes. The solid was filtered off and the

solvent is removed to give a solid, a mixture of vinyl bromides 42 and 43 in the ratio 8:2 (from PMR and GLC). They were separated by chromatography on SiO_2(II, 10g, 15 x 0.7 cm) using benzene as eluent.

Compound 42, mp. 115.0-116.0° . IR:(CCl_4) (FIG 38): C=C 1645, 850 cm^{-1}. PMR (CCl_4)(FIG 39): two tert-Me's singlets at 1.12, 1.38 ppm; C=C-CH (1H, bs, 3.05 ppm); CHOH(1H, bs, 4.15 ppm); CHBr (1H, s, 5.19 ppm). Compound 43, m.p. 116°C. PMR(CCl_4)(FIG 40): two tert-Me's singlets at 1.32, 1.56 ppm ; C=C-CH (1H, bs, 2.41 ppm); CHOH (1H, bs, 4.15 ppm); -C=CHBr (1H, s, 5.98 ppm).

With mercuric acetate: To a stirred solution of mercuric acetate (316 mg, 1 m mol) in water (5 ml) and THF (2.5 ml) was added a solution of 5 (152 mg, 1 m mol) in THF(2.5 ml) at 26° for 30 min. In situ reduction of organomercurial with 0.5 M $NaBH_4$ in 3M NaOH (5 ml) followed by usual work up gave a mixture of epimeric diols 44 and 45 in the ratio 7:3 (from PMR). 44 was isolated pure by chromatography on SiO_2 using benzene as eluent. Compound 44 m.p. 110°C, IR($CHCl_3$) 3600, 3580, and 1255 cm^{-1}. PMR($CDCl_3$): tert-Me's singlets at 0.88, 0.90 ppm; CH_3-C-OH(3H, s, 1.21 ppm), CHOH(1H, bs 4.10 ppm).

Dehydration of 44 with alumina gave 7-syn-hydroxy-camphene 5.

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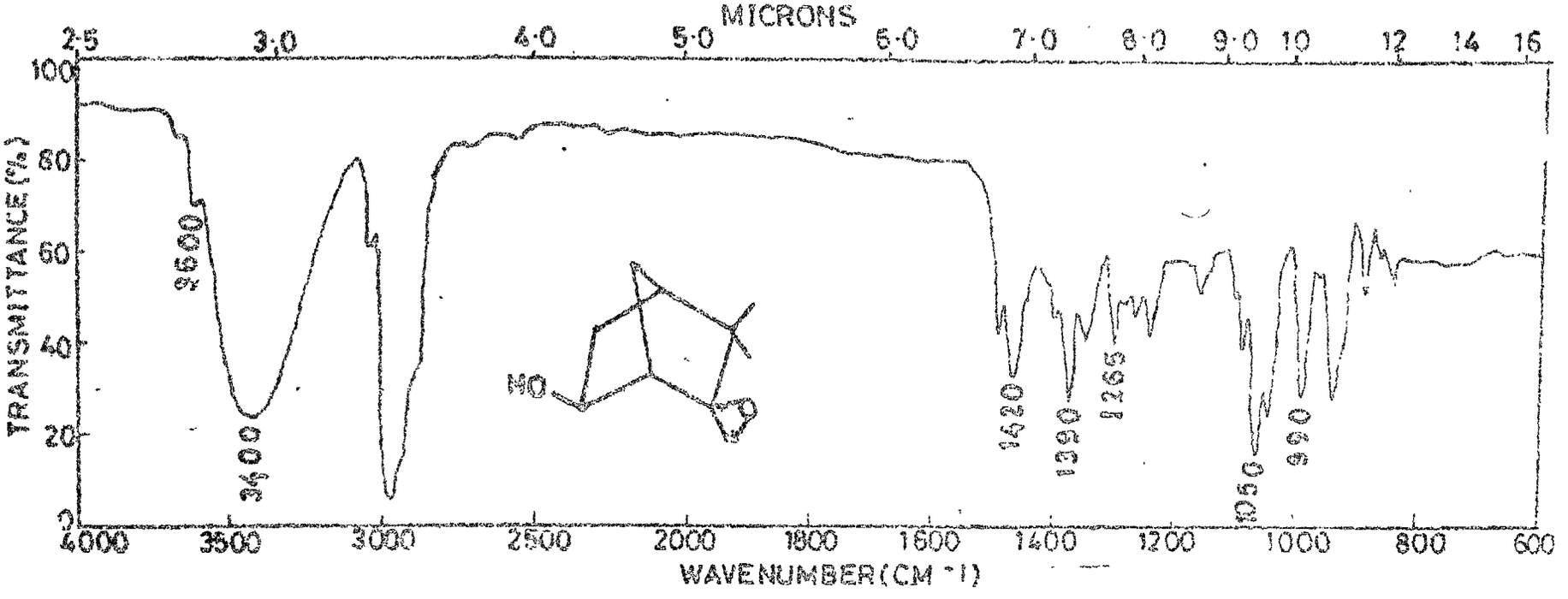


FIG. 8 : IR SPECTRUM OF 7-EXO-HYDROXY-2,10-EPOXYCAMPHANE (8,9)

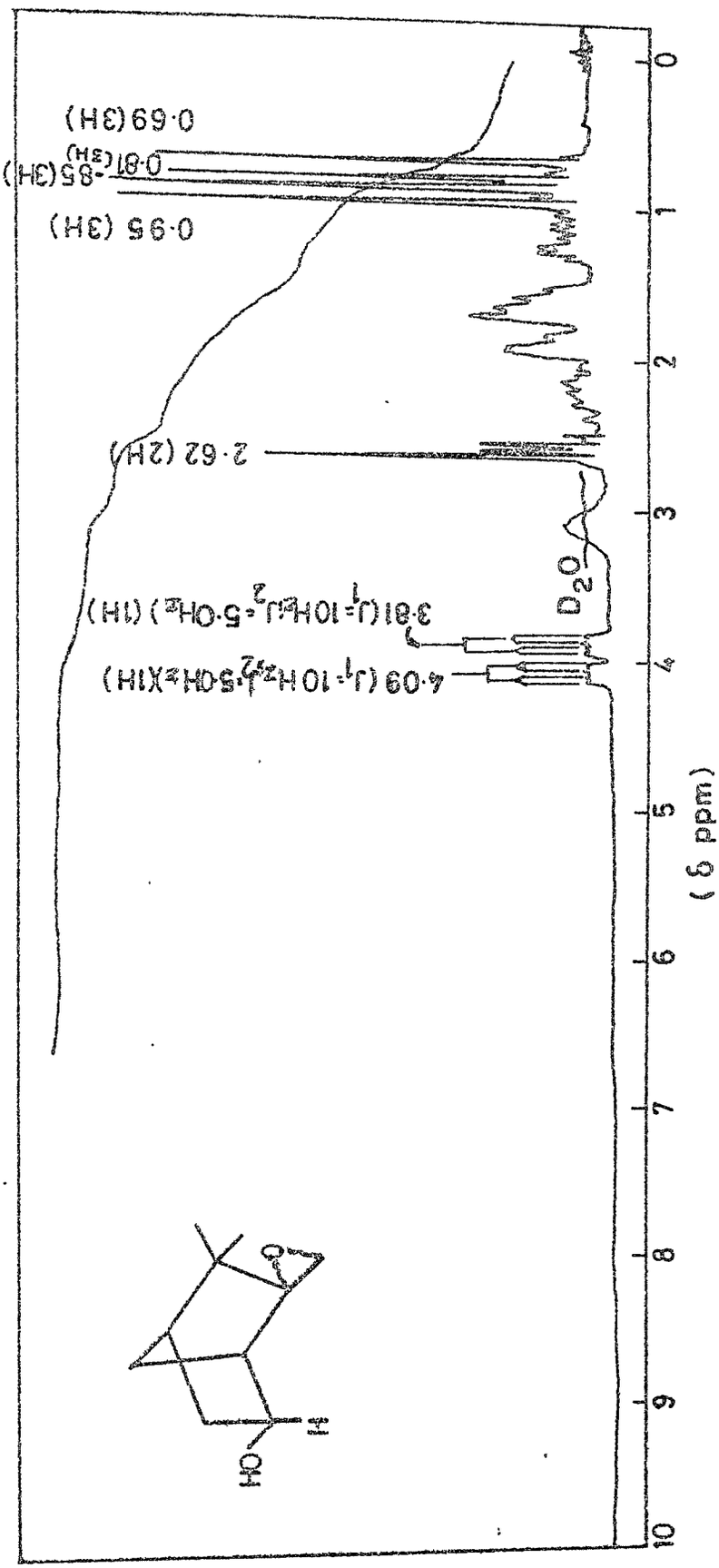


FIG. 9: PMR SPECTRUM OF 6-EXO-HYDROXY-2,10-EPOXYCAMPHANE (8 AND 9)

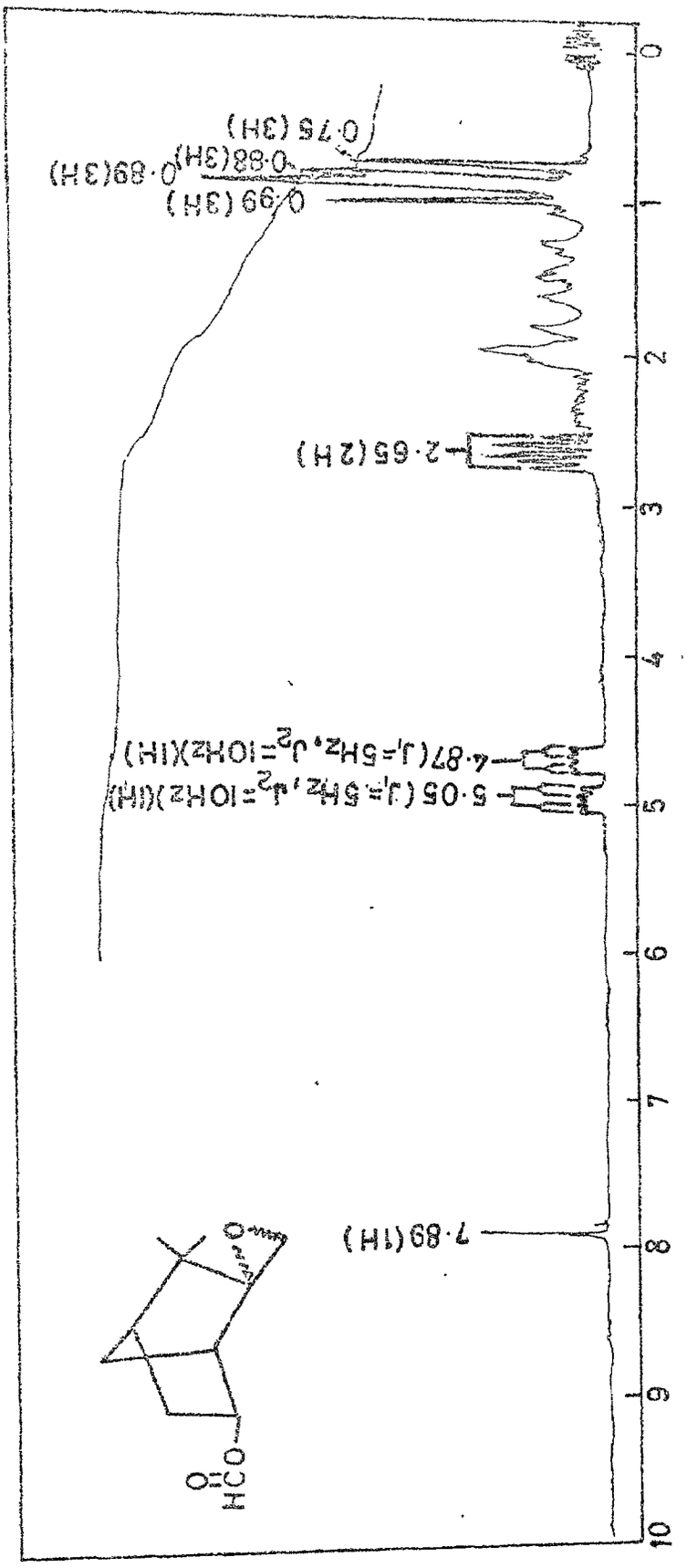


FIG.10: PMR SPECTRUM OF 6-EXO -FORMYL-2,10-EPOXYCAMPHANES (19 AND 20)

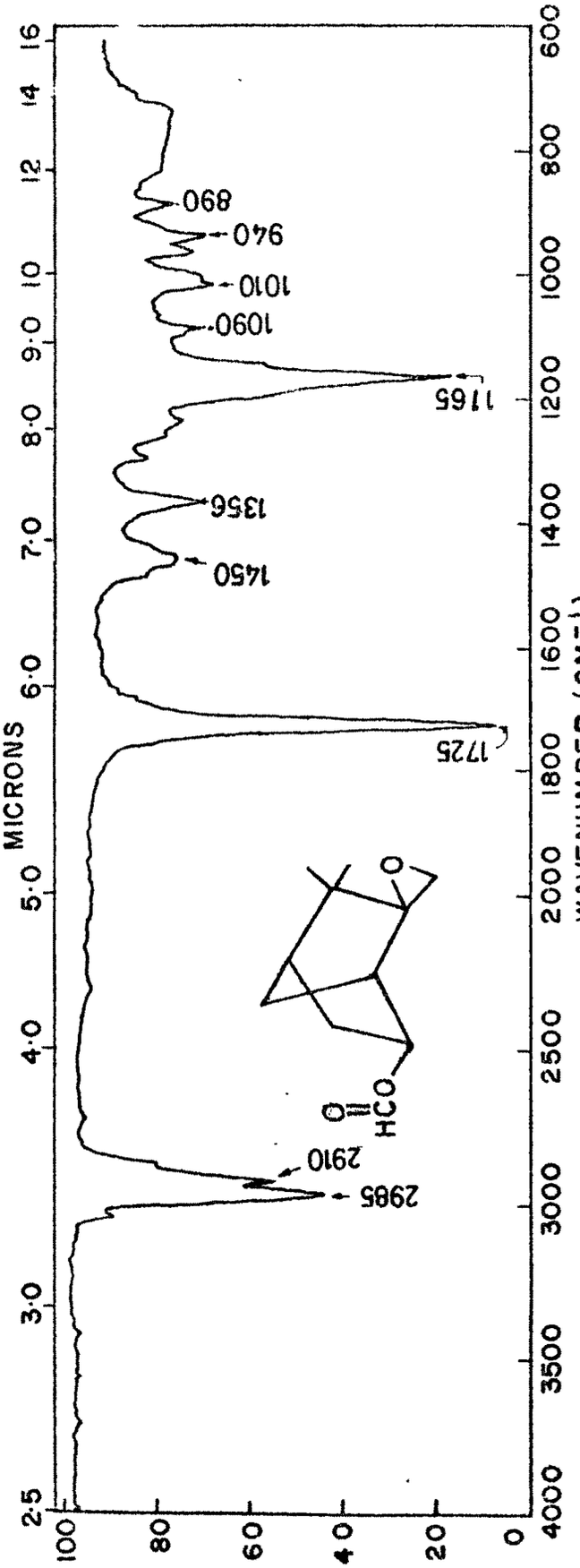


FIG.11: IR SPECTRUM OF 6-EXO-FORMYL-2,10-EXO-EPOXYCAMPHANE (19)

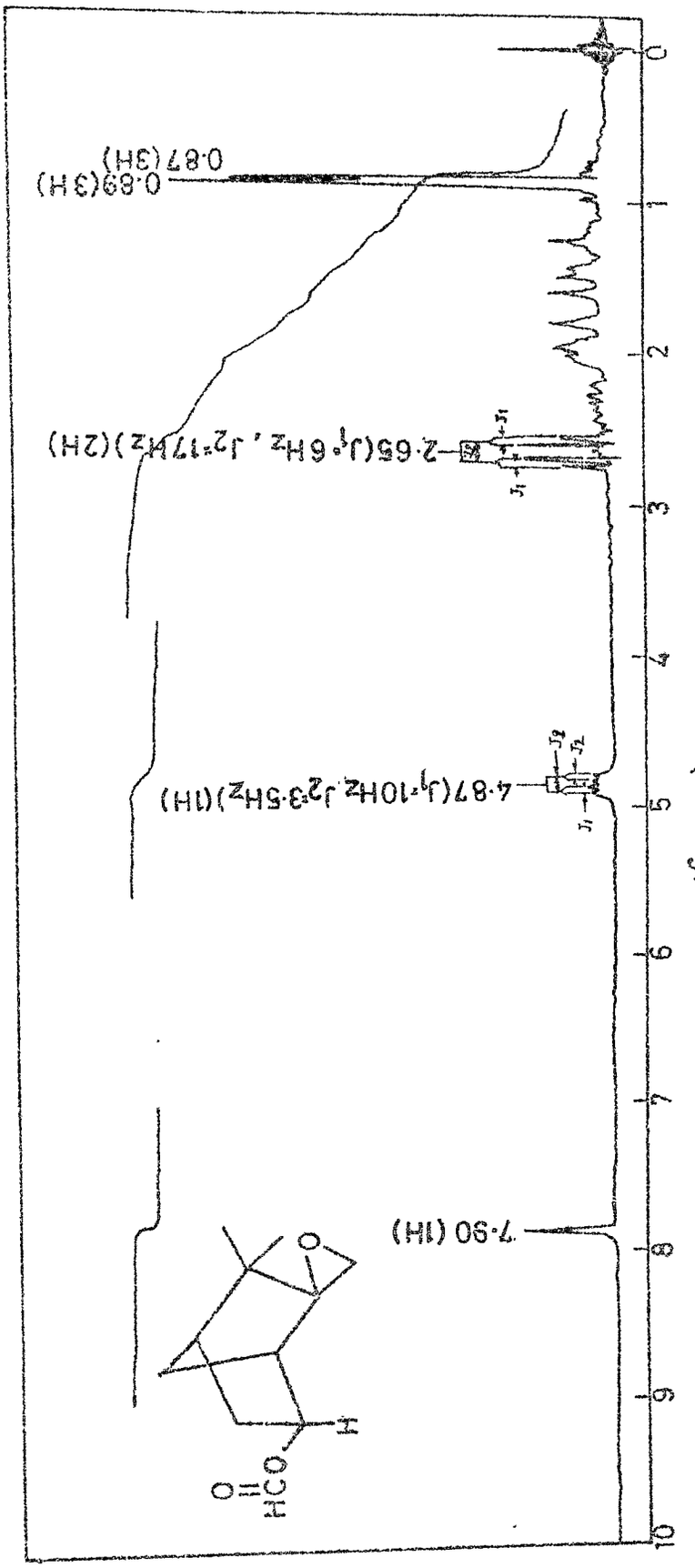


FIG. 12: PMR SPECTRUM OF 6-EXO-FORMYL-2,10-EXO-EPOXY CAMPHANE (19)

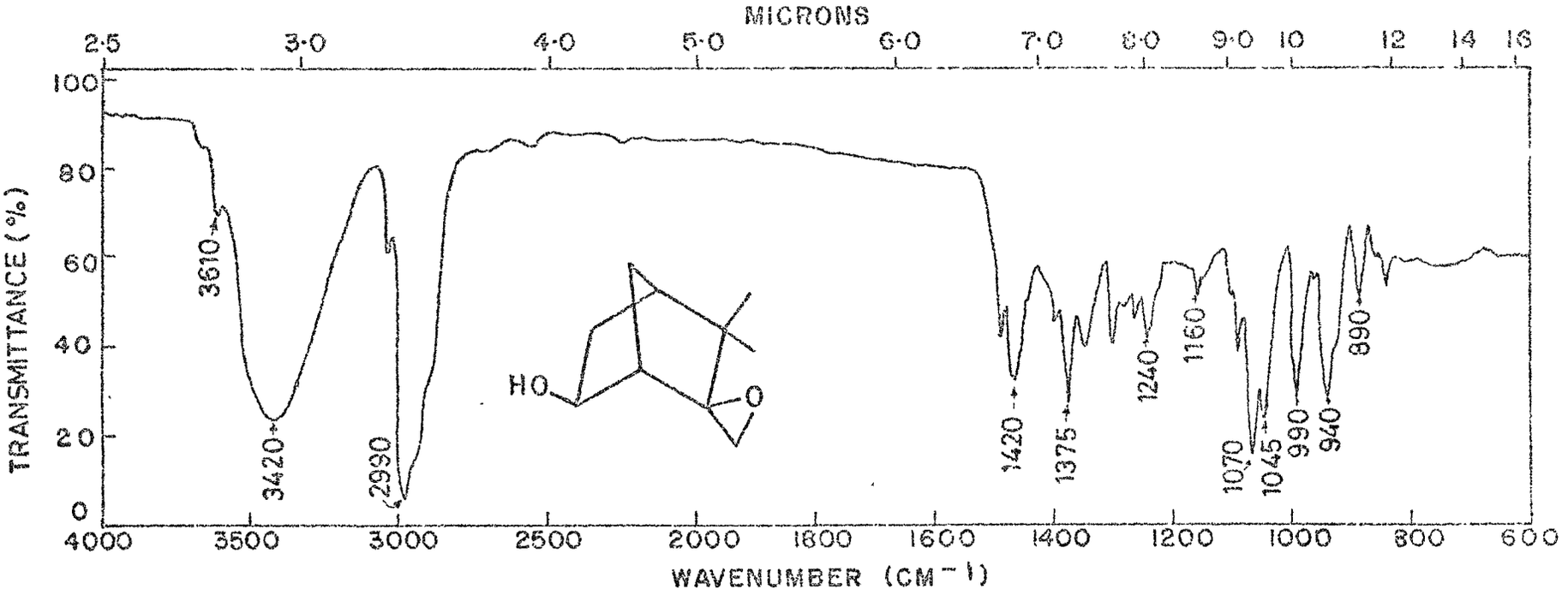


FIG.13 : IR SPECTRUM OF 6-EXO-HYDROXY - 2,10-EXO -EPOXYCAMPHANE (8)

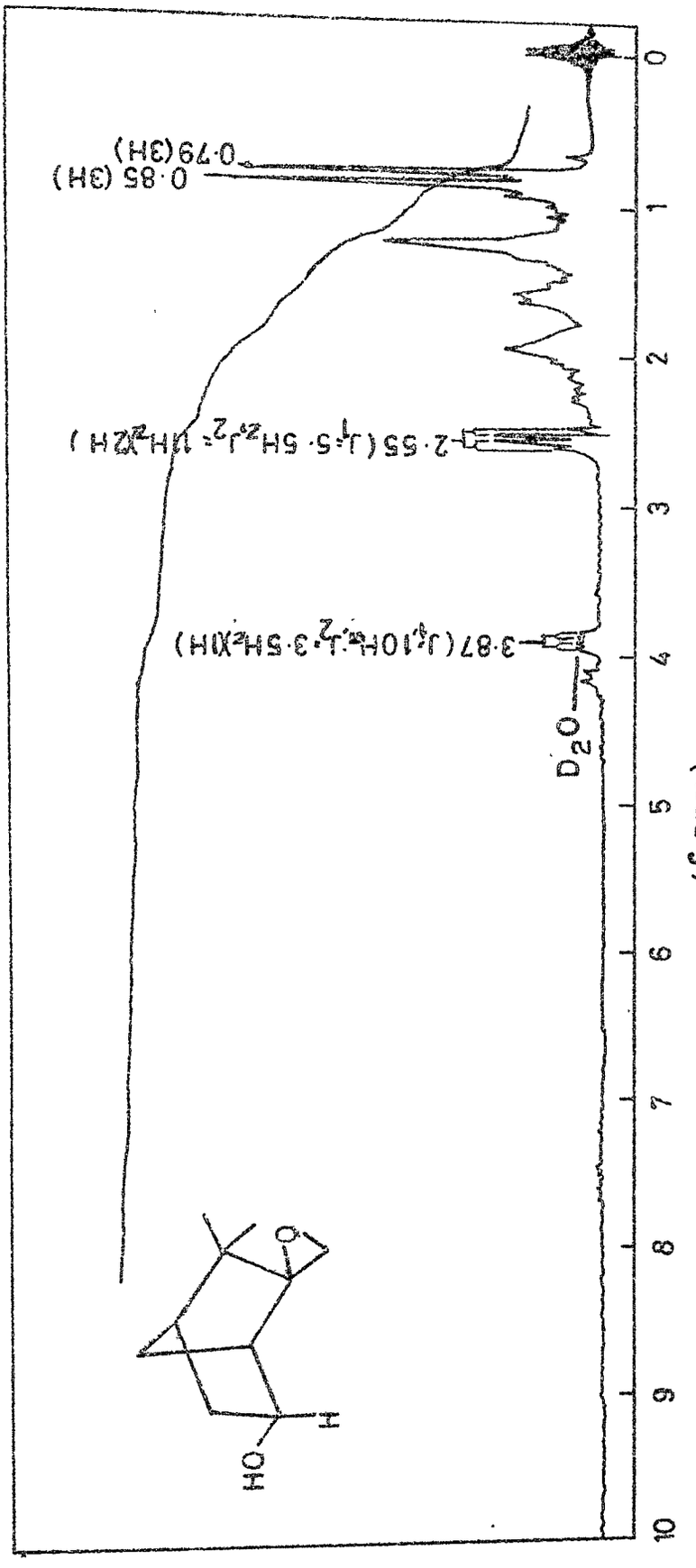


FIG.14 : PMR SPECTRUM OF 6-EXO - HYDROXY - 2,10 - EXO - EPOXYCAMPHANE (8)

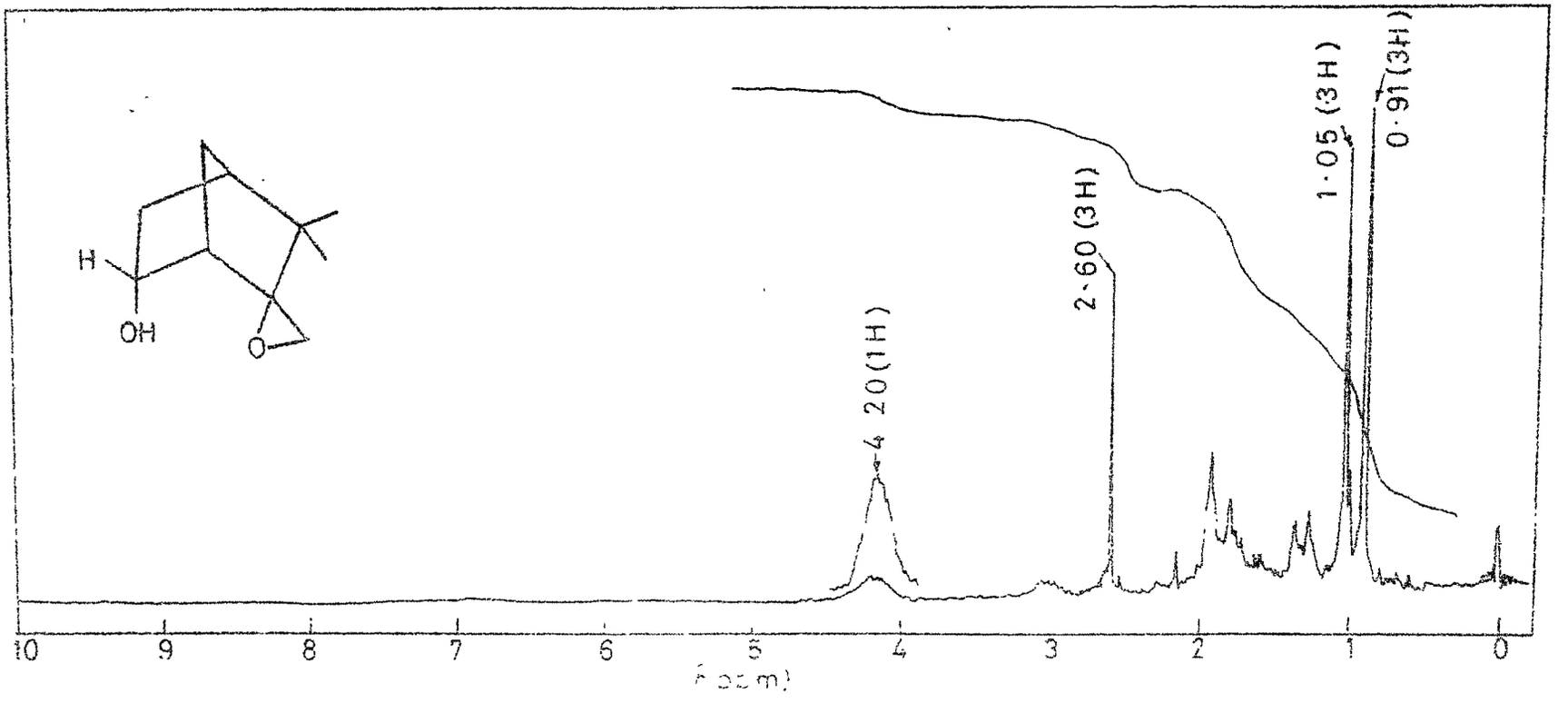
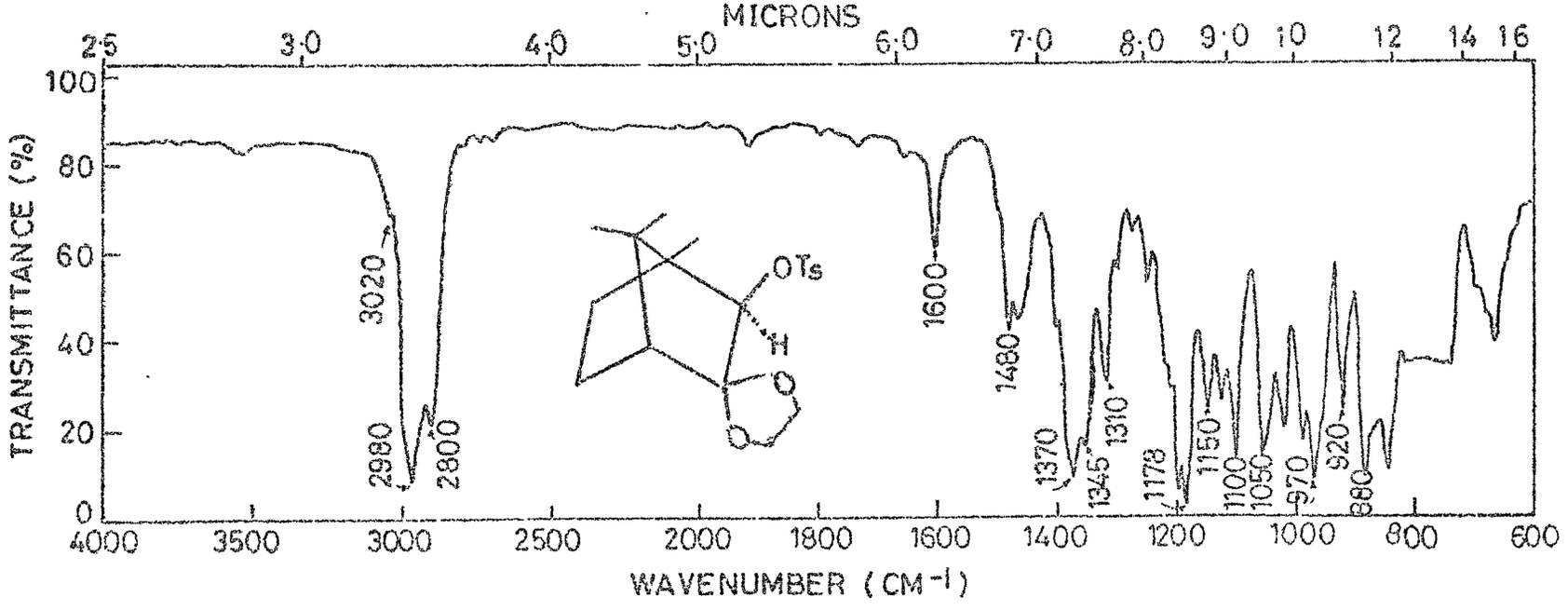


FIG 15: PMR SPECTRUM OF 8-ENDO-HYDROXY-2,10-ENDO-EPOXY-CAMPHANE (11)



FIG·16; IR SPECTRUM OF 2-EXO-TOSYLOXY-3,3-ETHYLENEDIOXY BORNANE (28)

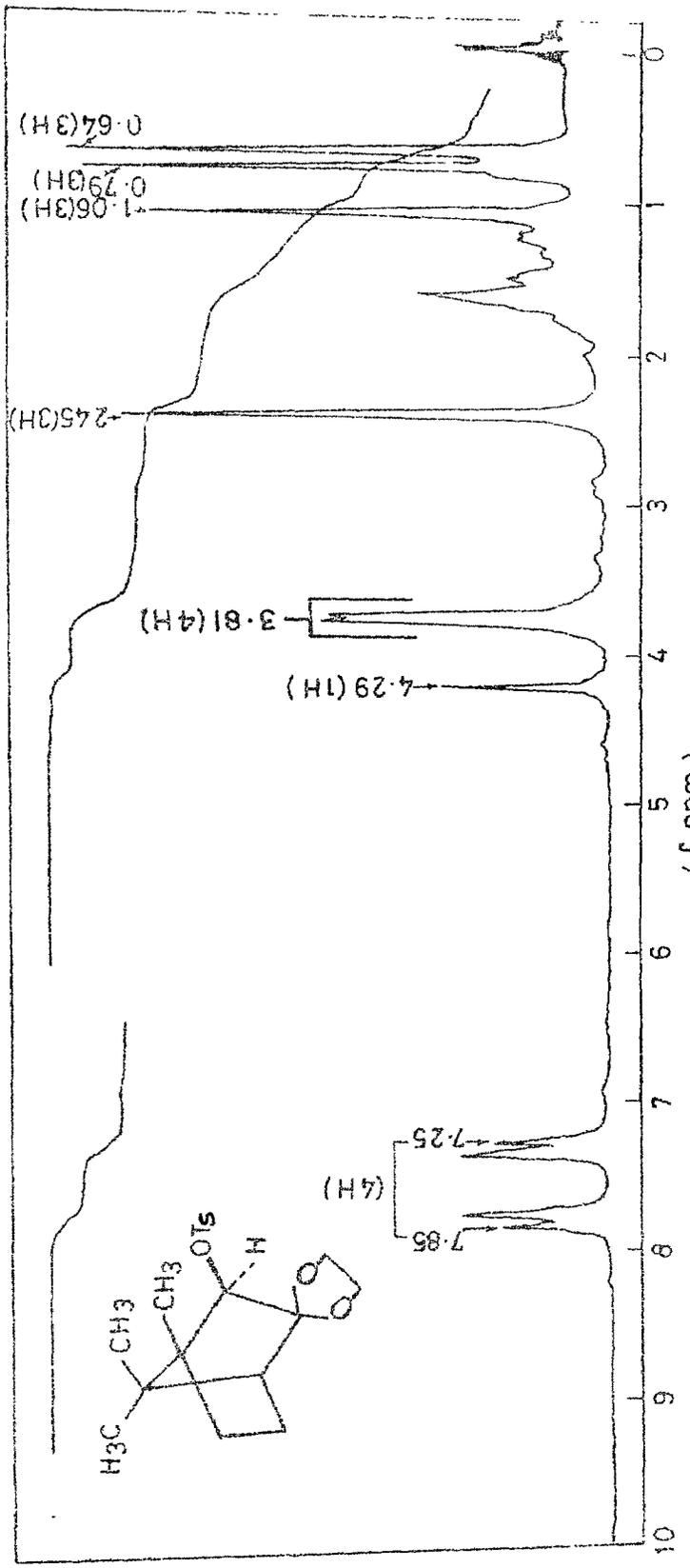


FIG.17 PMR SPECTRUM OF 2-EXO-TOSYLOXY-3,3-ETHYENEDIOXYBORNANE (28)

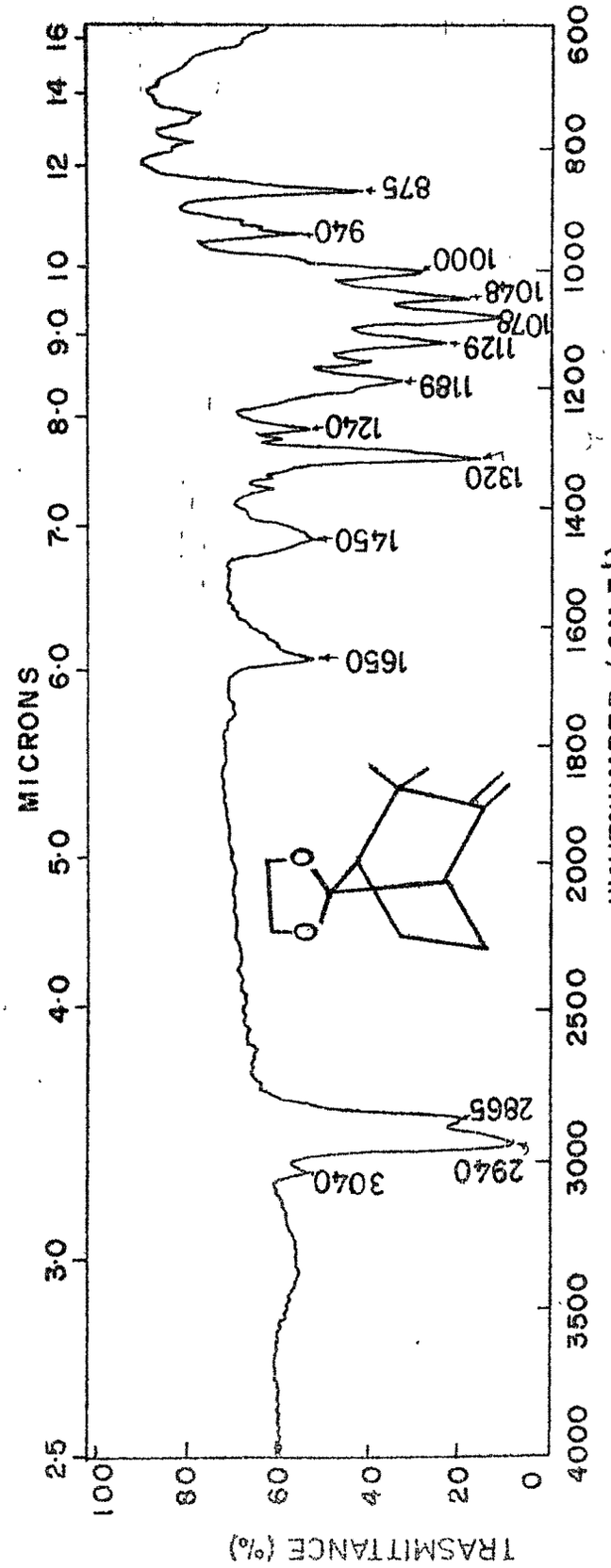


FIG. 18: IR SPECTRUM OF 7,7-ETHYLENEDIOXYCAMPHENE (29)

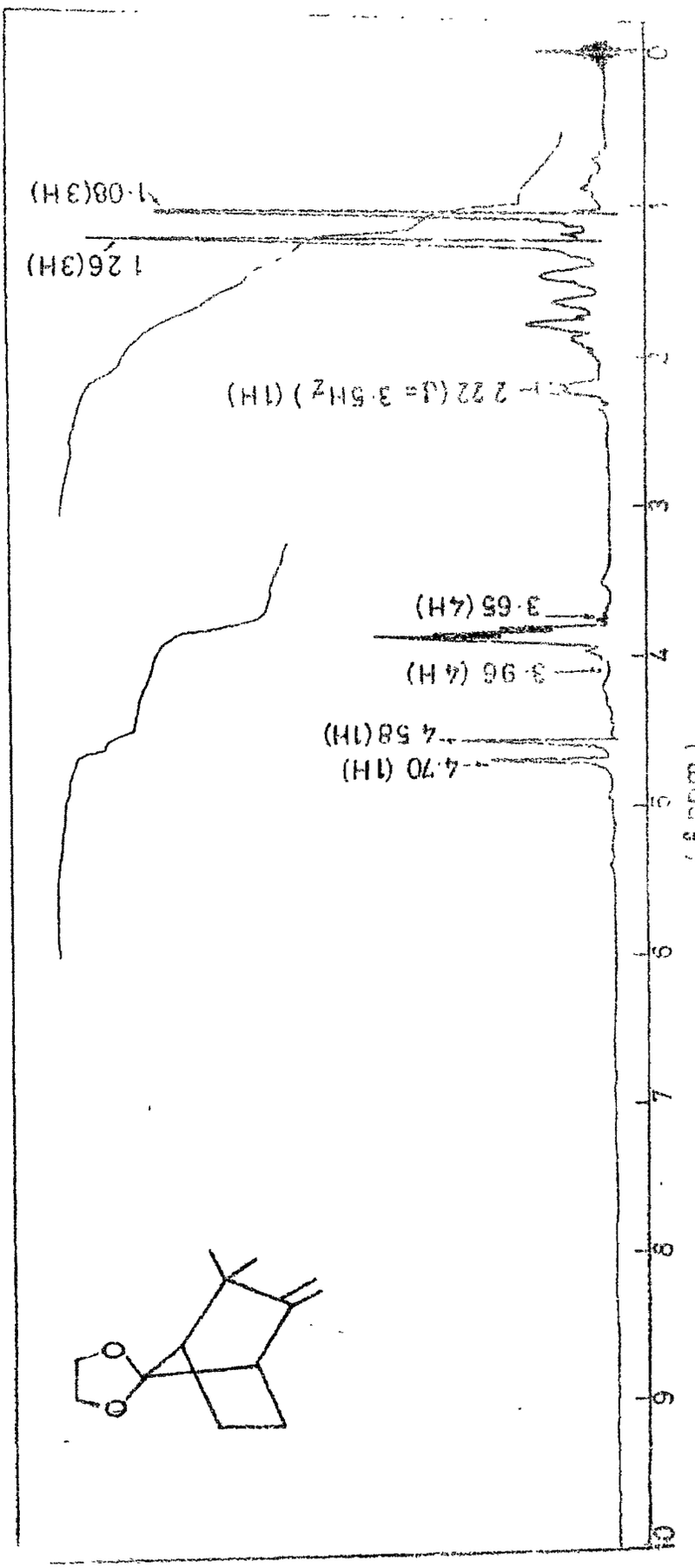


FIG.19: PMR SPECTRUM OF 7,7-ETHYLENEDIOXYCAMPHENE (2S)

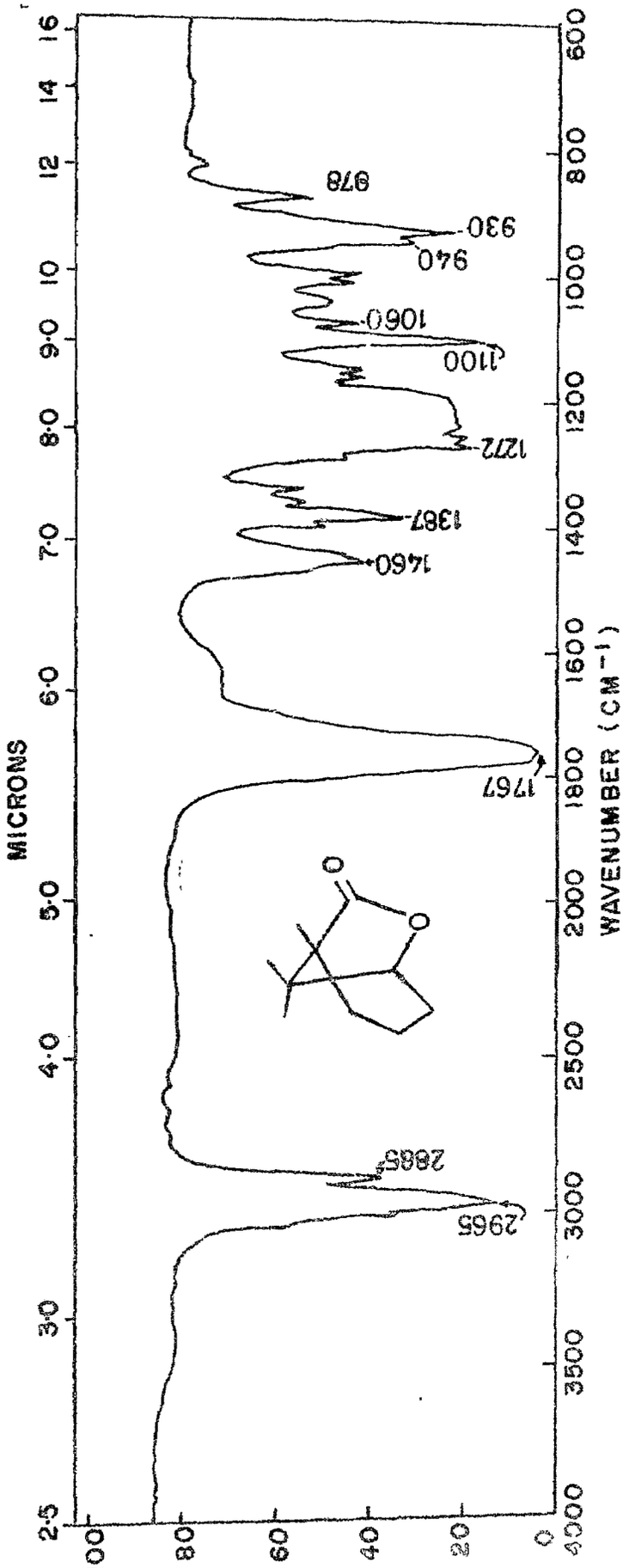


FIG. 20: IR SPECTRUM OF LACTONE(32)

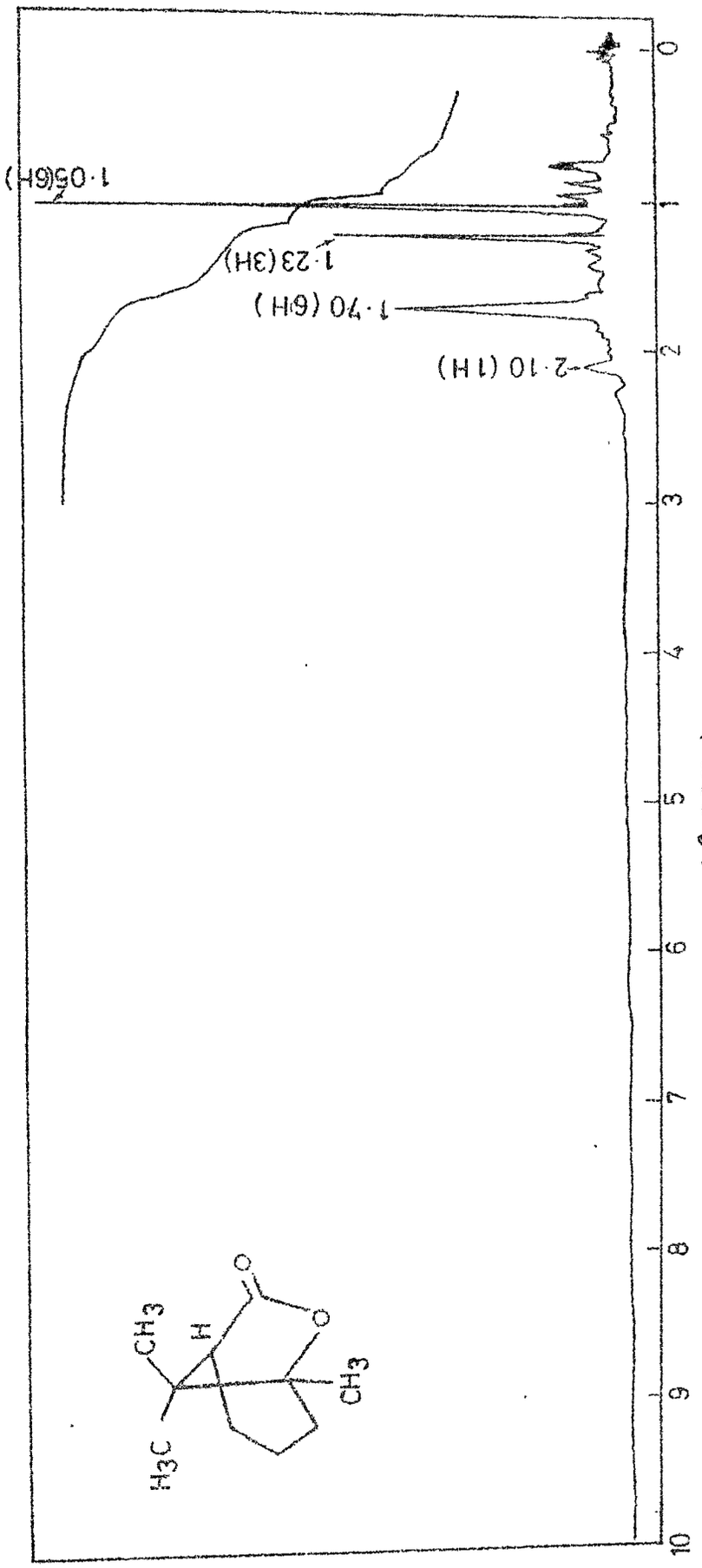


FIG. 21 : PMR SPECTRUM OF LACTONE (32)

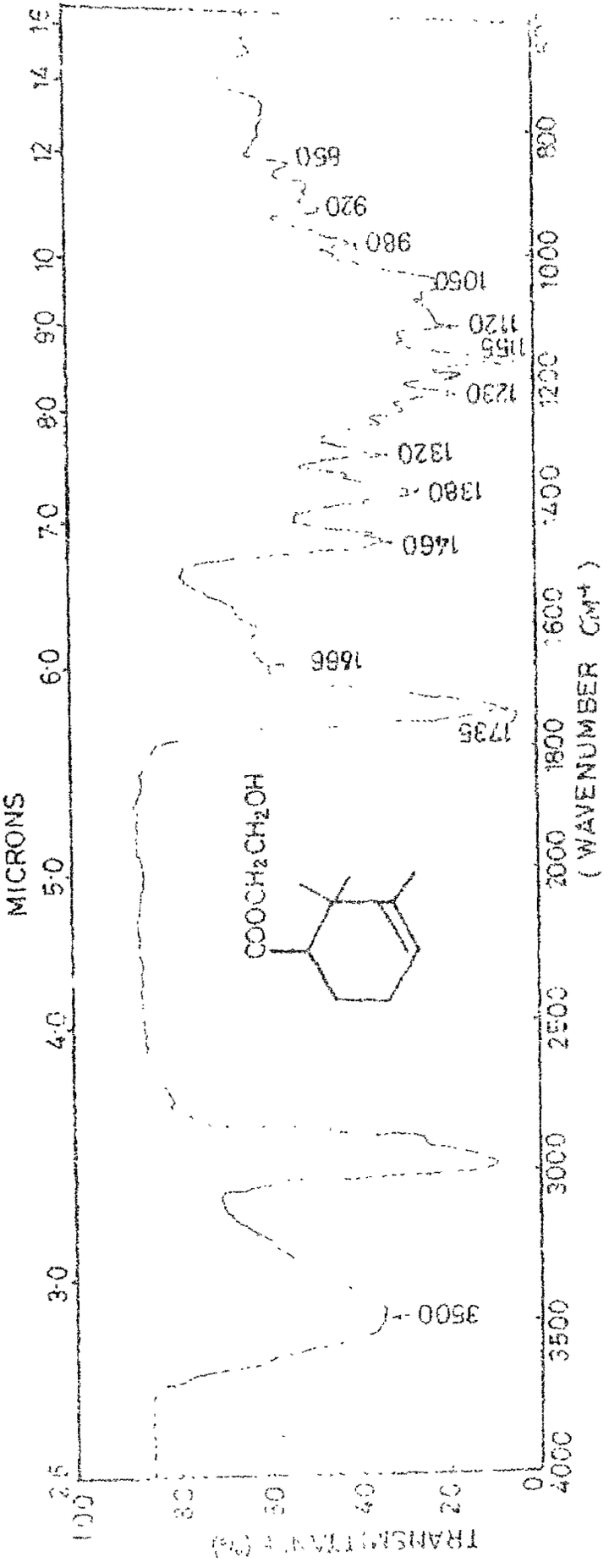


FIG. 21A: IR SPECTRUM OF HYDROXYETHYL ESTER 30

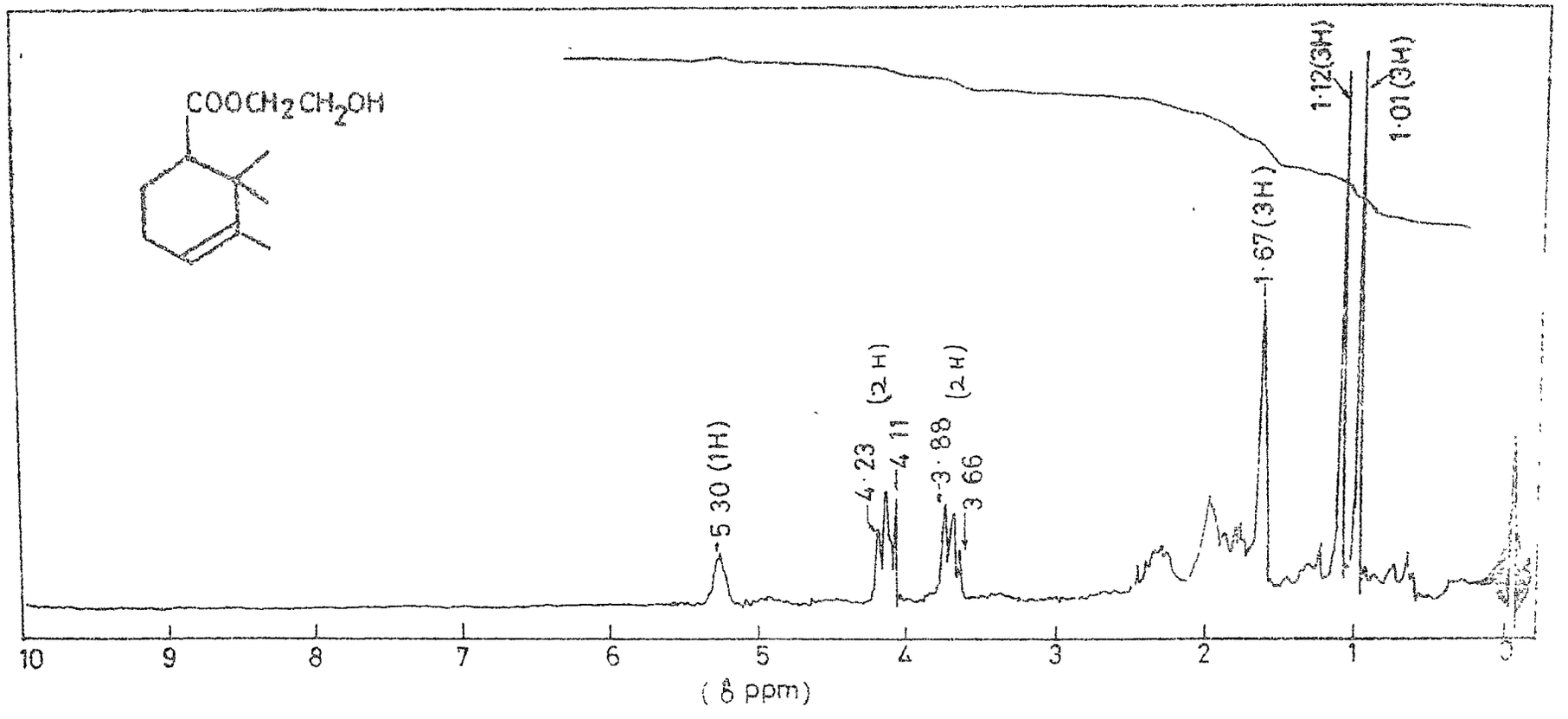


FIG.22:PMR SPECTRUM OF HYDROXY ETHYL ESTER 30

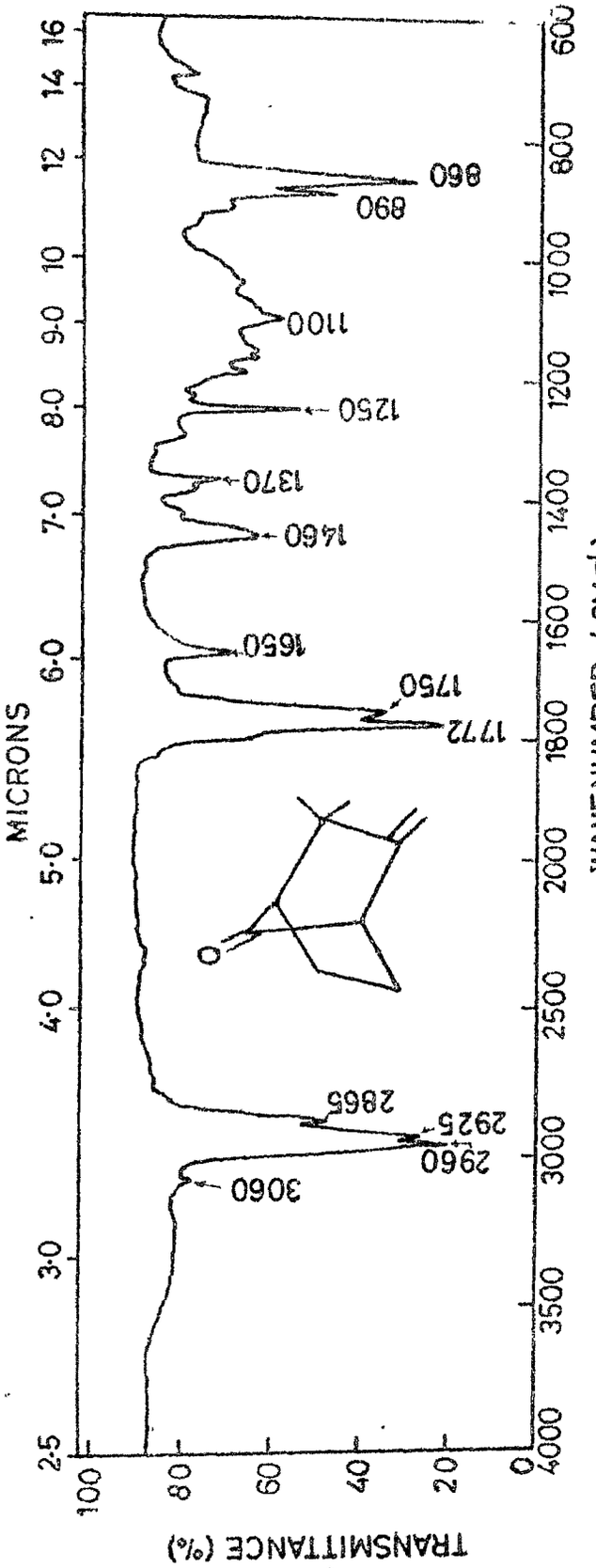


FIG. 23 : IR SPECTRUM OF 7-KETOCAMPHENE(16)

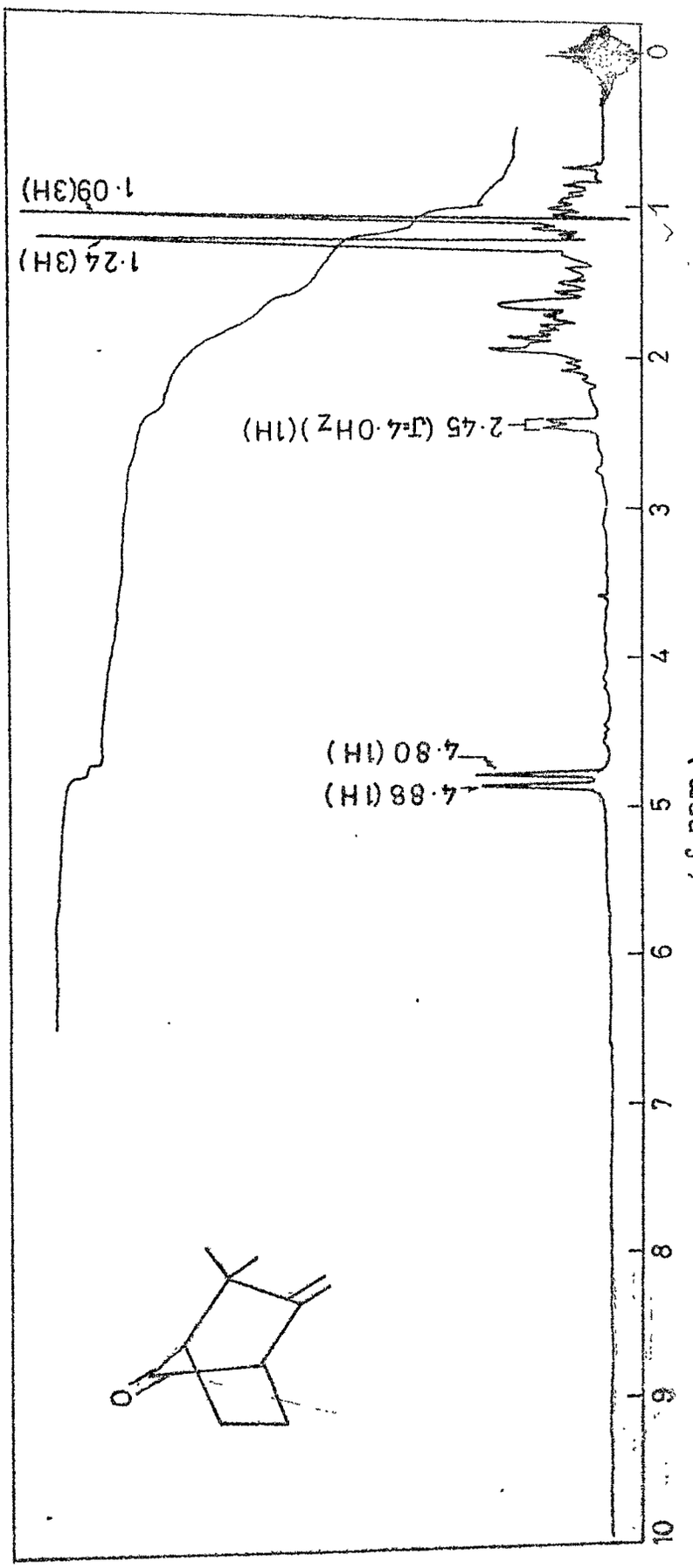


FIG.24: PMR SPECTRUM OF 7-KETOCAMPHENE (16)

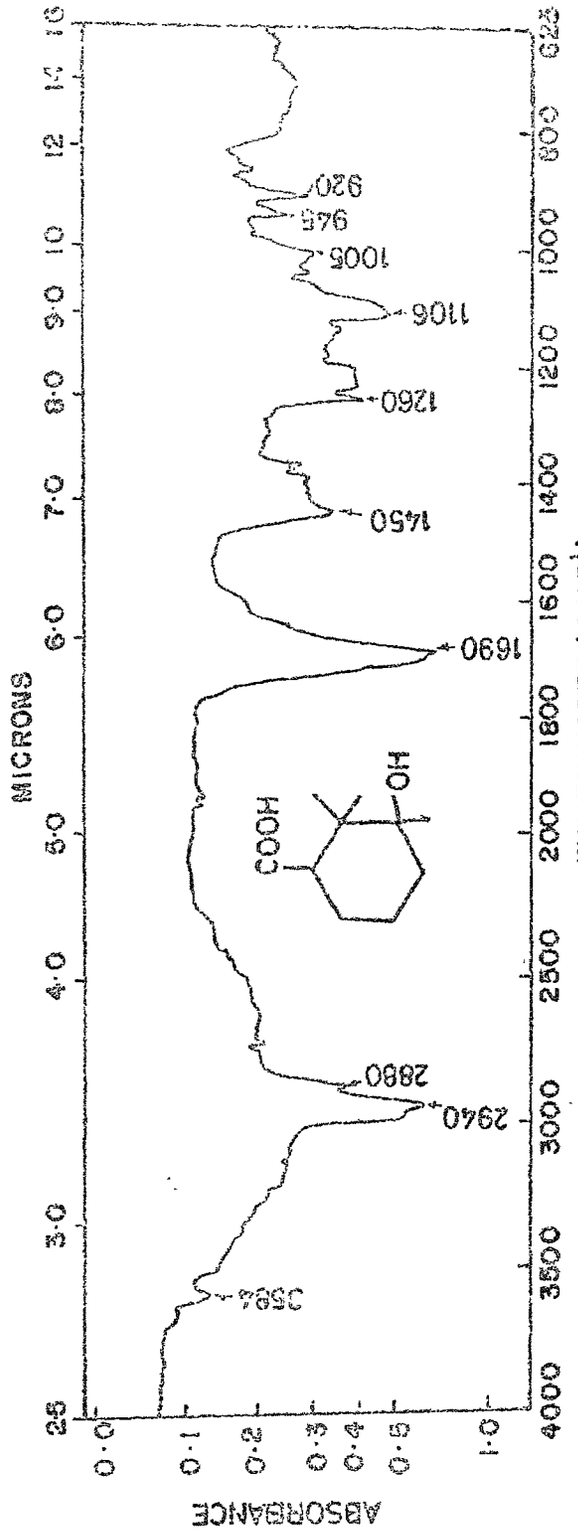


FIG.25: IR SPECTRUM OF 2,2,3-TRIMETHYL-3-HYDROXYCYCLOHEXANE CARBOXYLICACID (33)

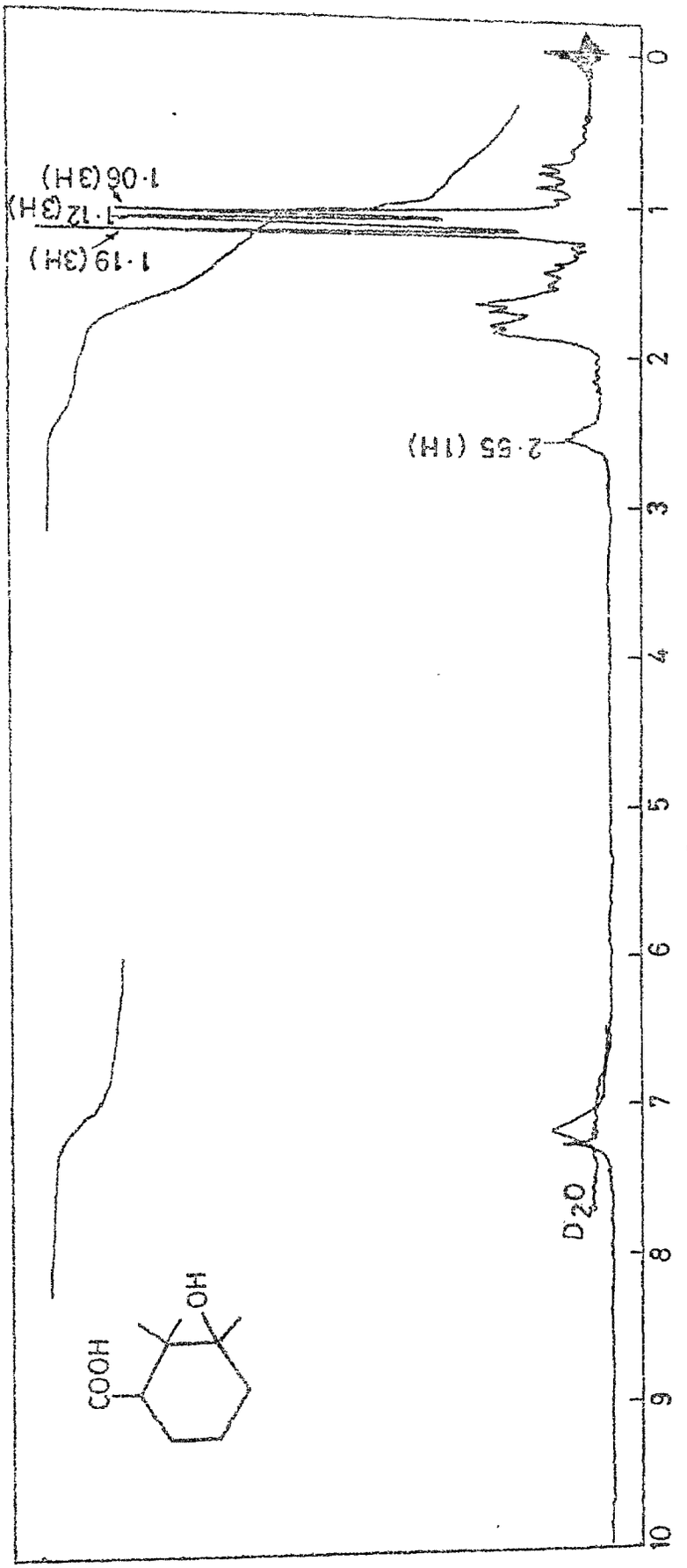


FIG 26 : PMR SPECTRUM OF 2,2,3-TRIMETHYL-3-HYDROXYCYCLOHEXANE CARBOXYLICACID (33)

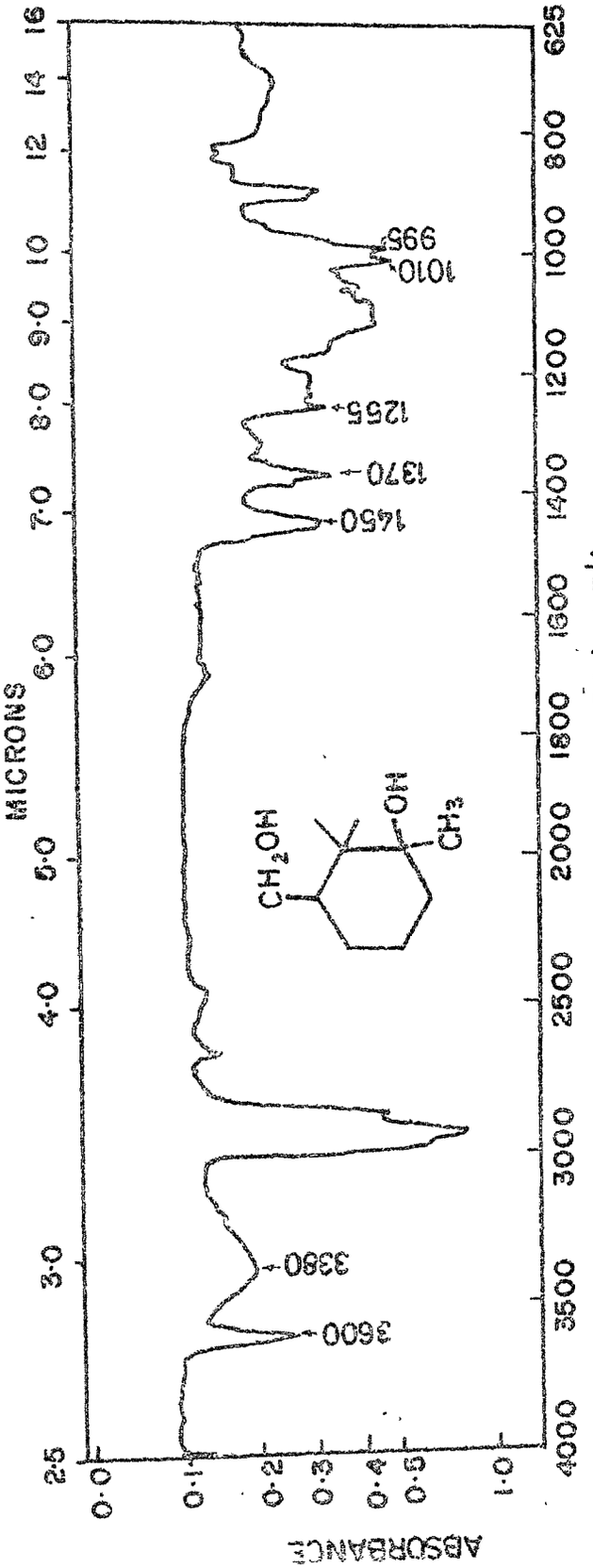


FIG:27, IR SPECTRUM OF 1,2,2-TRIMETHY-3-HYDROXYMETHYLCYCLOHEXANOL(34)

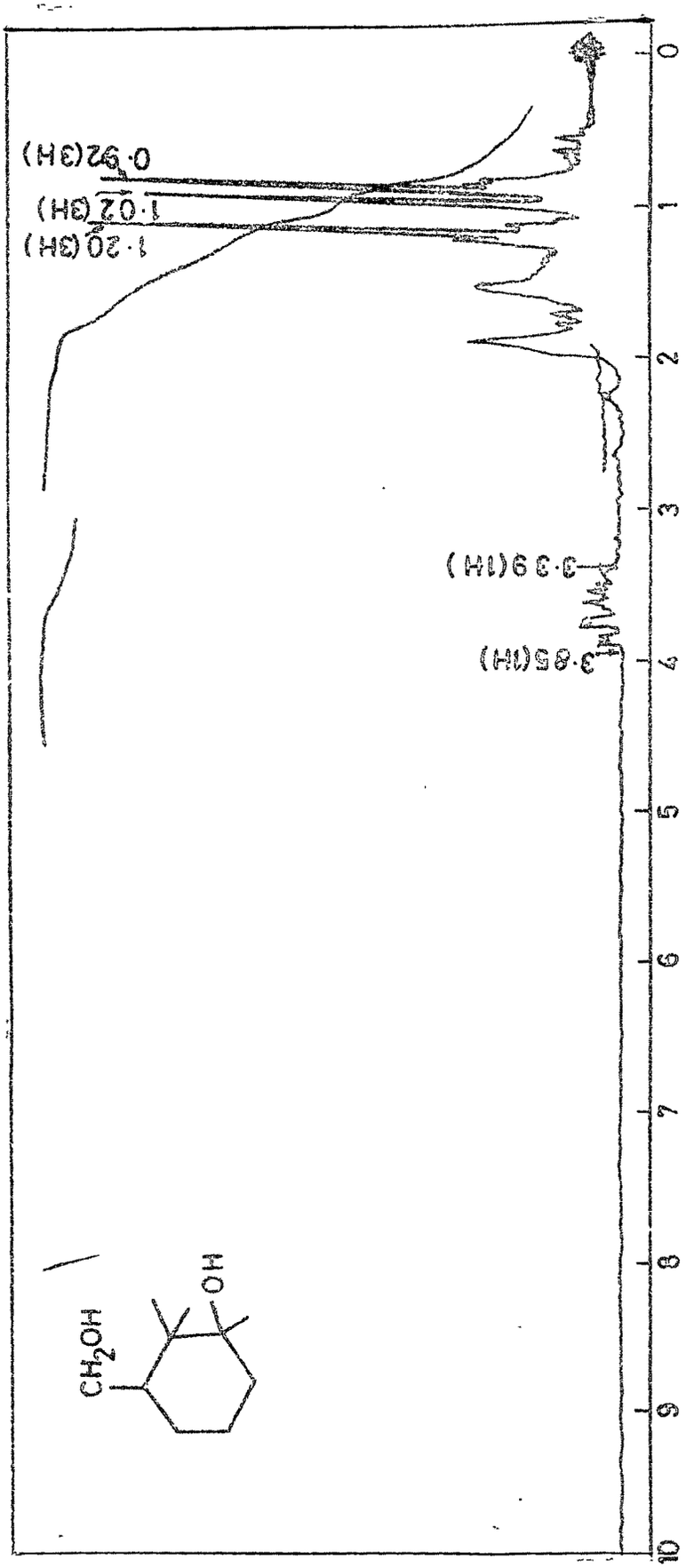


FIG.28: PMR SPECTRUM OF 3-HYDROXYMETHYL-1,3,3-TRIMETHYL-CYCLOHEXANOL (34)

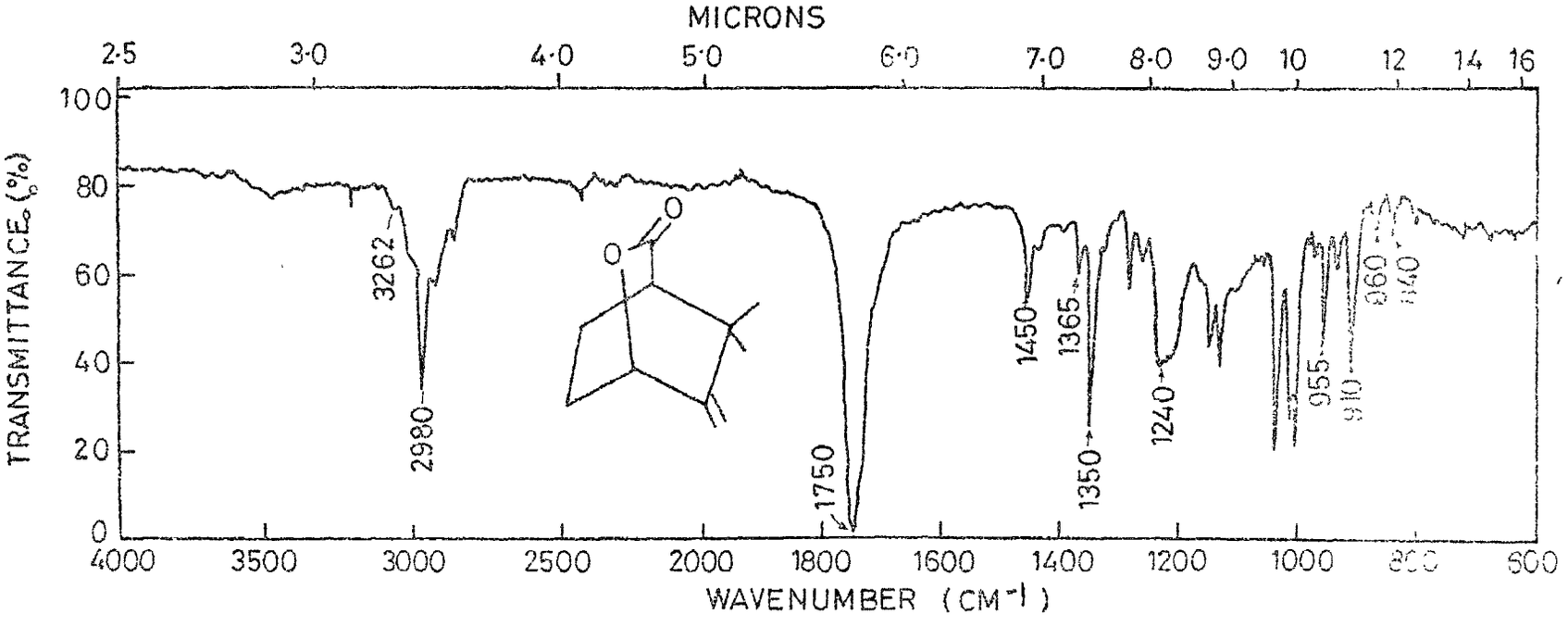


FIG. 29 : IR SPECTRUM OF LACTONE 36

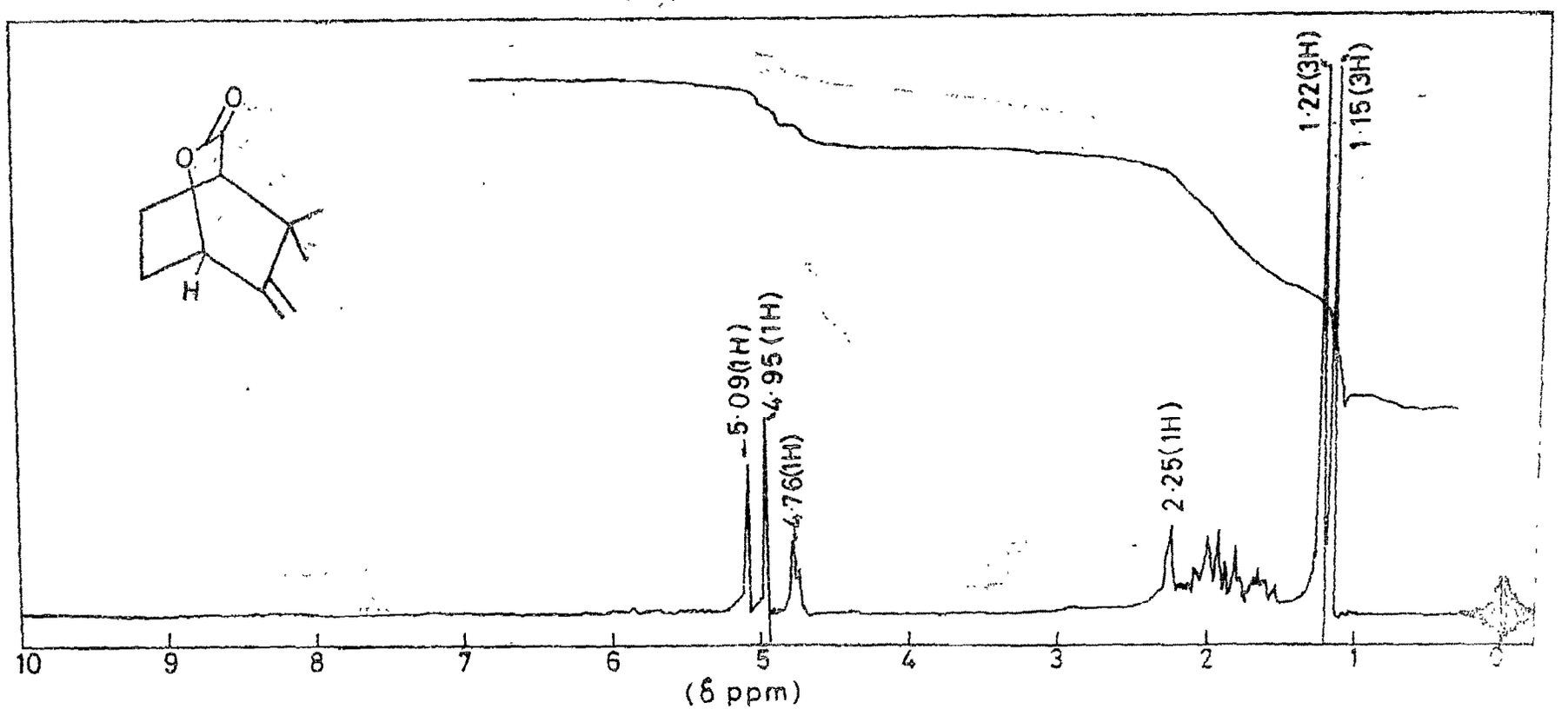


FIG.30: PMR SPECTRUM OF LACTONE (36)

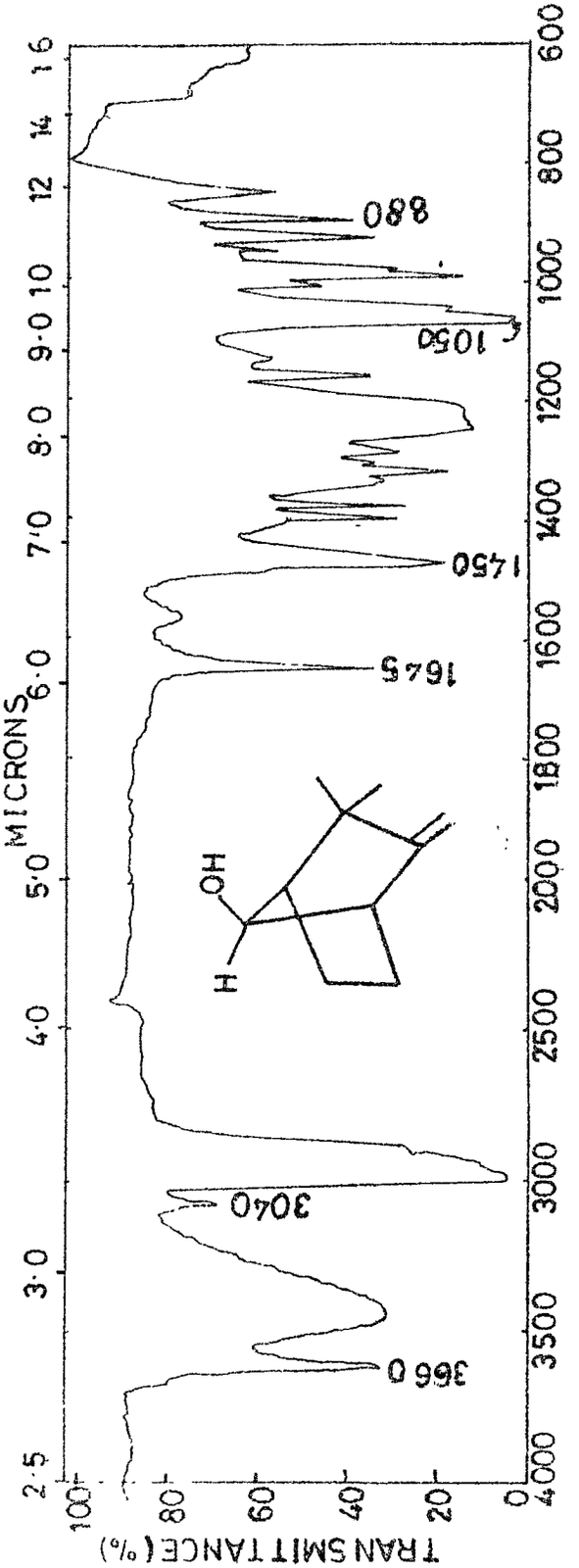


FIG. 31: IR SPECTRUM OF 7-SYN-HYDROXYCAMPHENE (5)

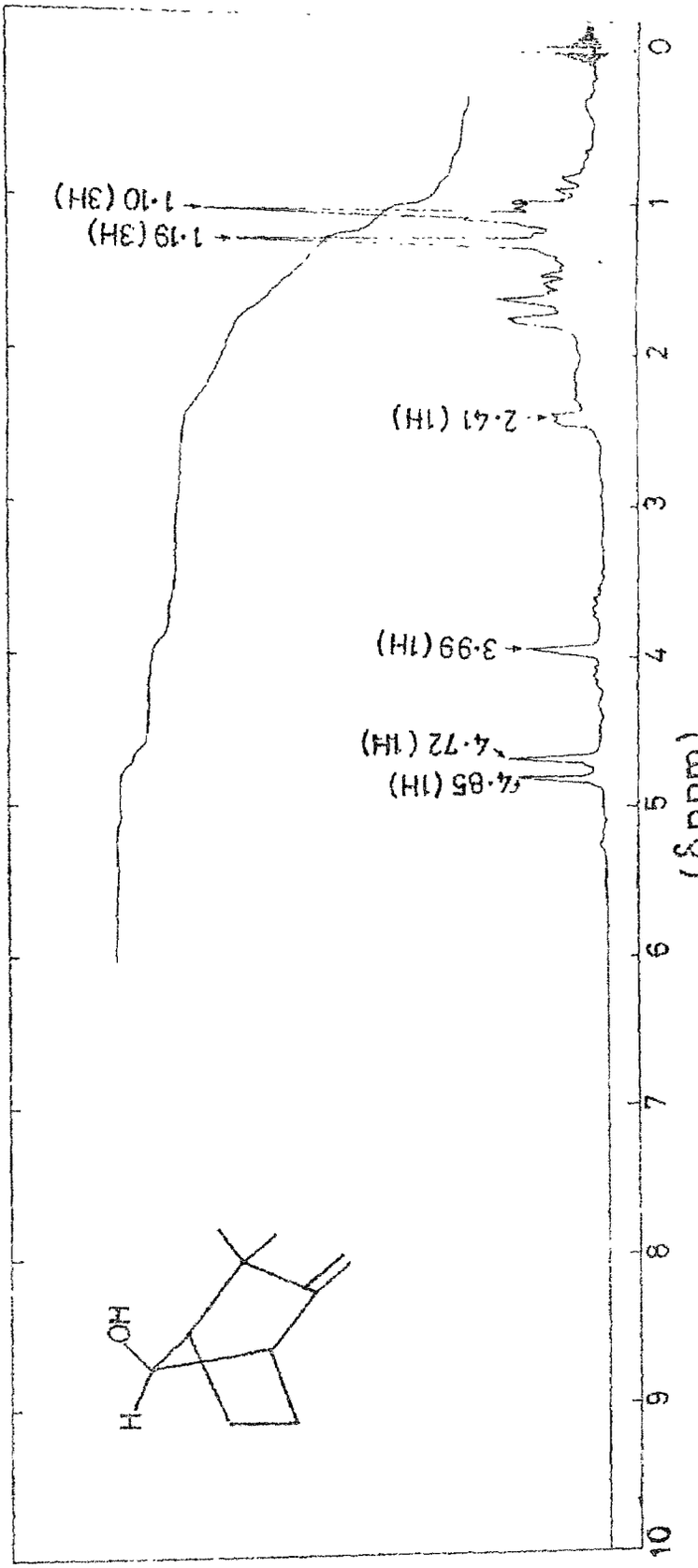


FIG. 32: PMR SPECTRUM OF 7-SYN-HYDROXYCAMPHENE (5)

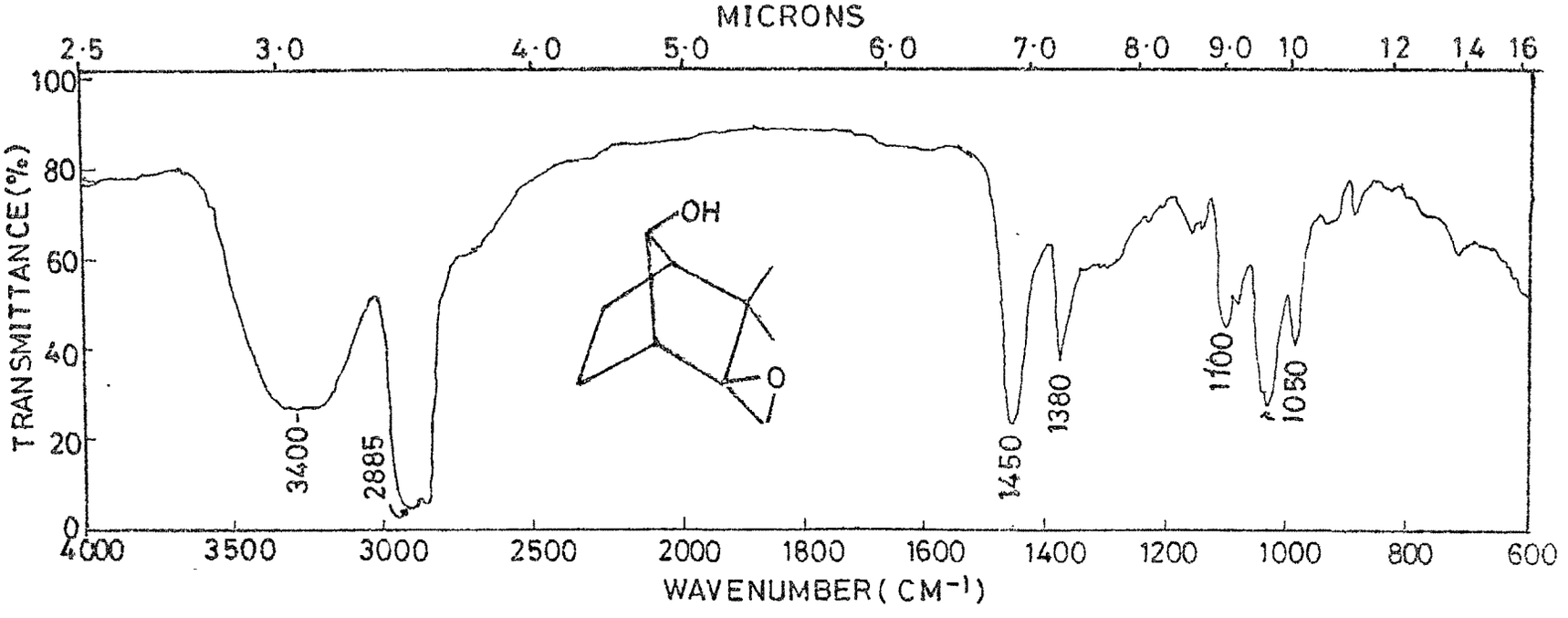


FIG.32A:IR SPECTRUM OF 7-SYN-HYDROXY-2,10-EXO-EPOXYCAMPHANE(12)

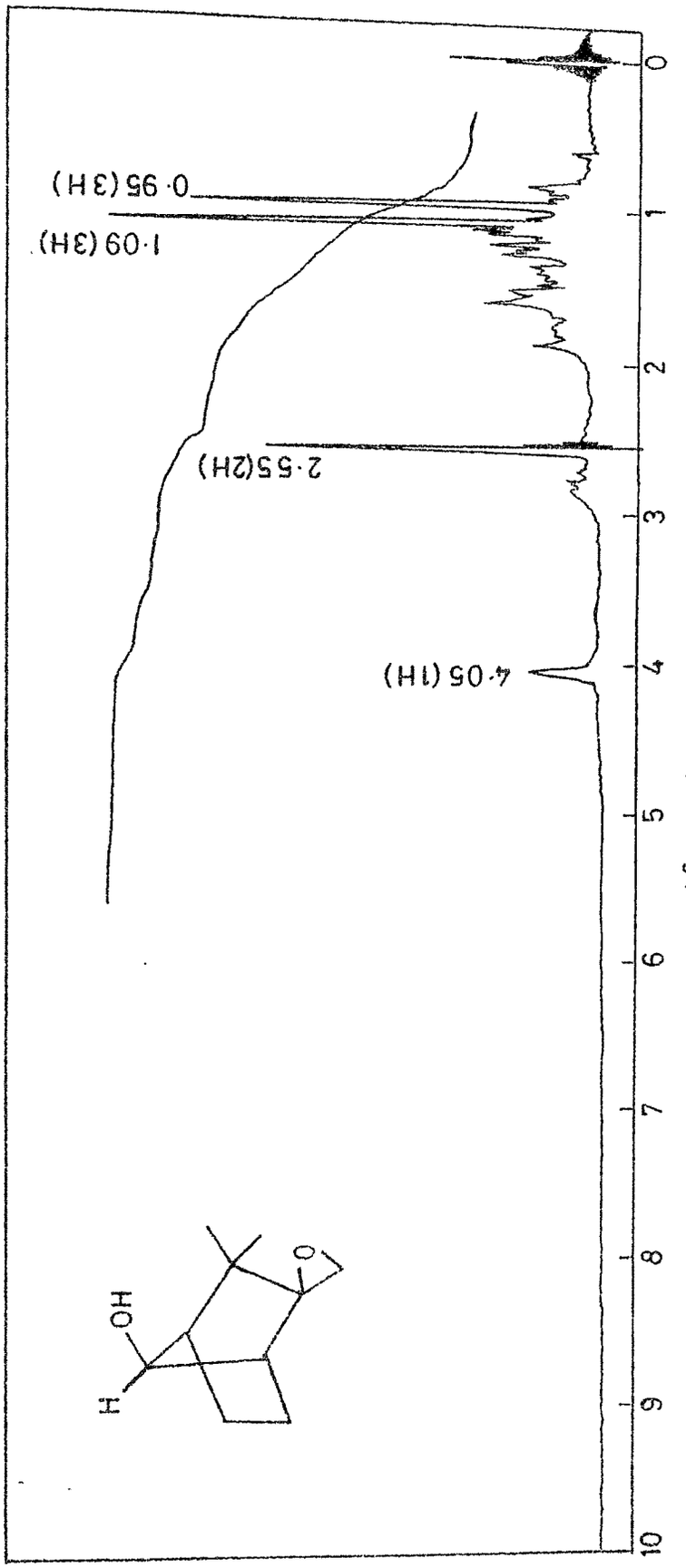


FIG. 33: PMR SPECTRUM OF 7-SYN-HYDROXY-2,10-EXO-EPOXYCAMPHANE (12)

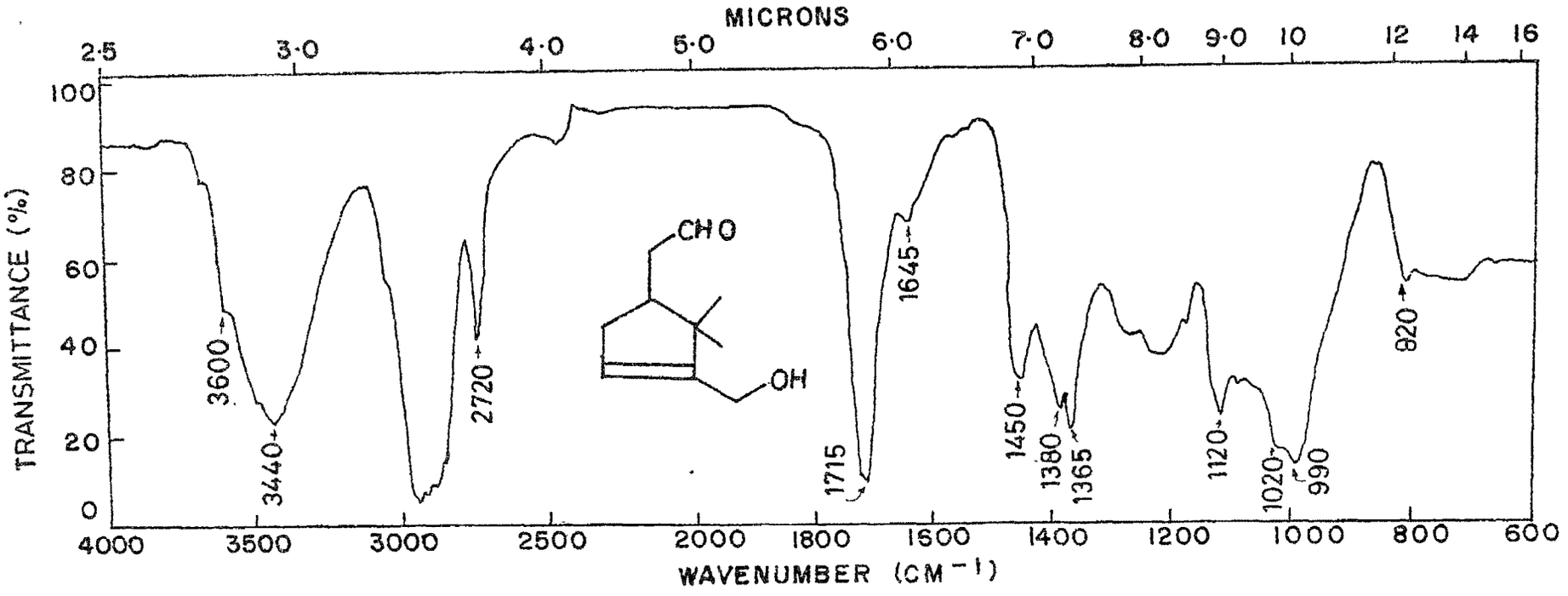


FIG:34, IR SPECTRUM OF 2-(2,2-DIMETHYL-3-HYDROXYMETHYL CYCLOPENT-3-EN-1-YL) ACETALDEHYDE (36)

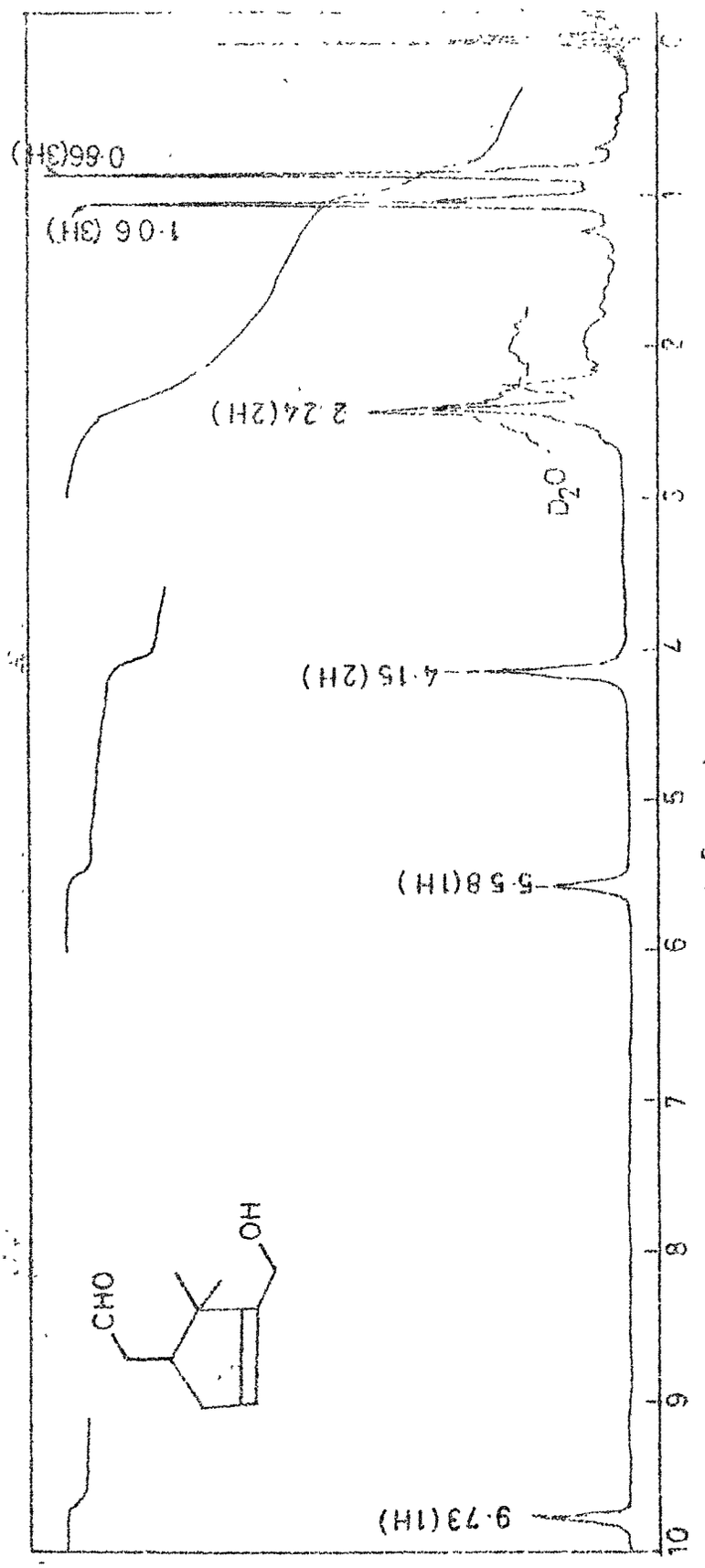


FIG. 35: PMR SPECTRUM OF 2-[2,2-DIMETHYL-3-HYDROXYMETHYLCYCLOPENT-3-EN-1-YL]ACETALDEHYDE (3S)

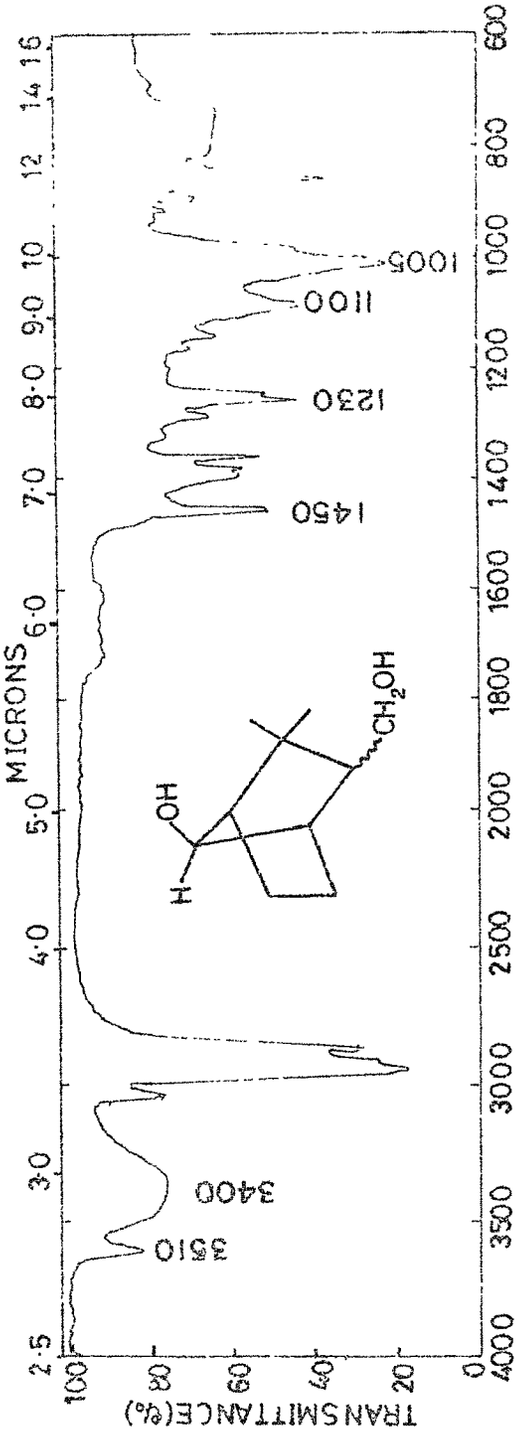
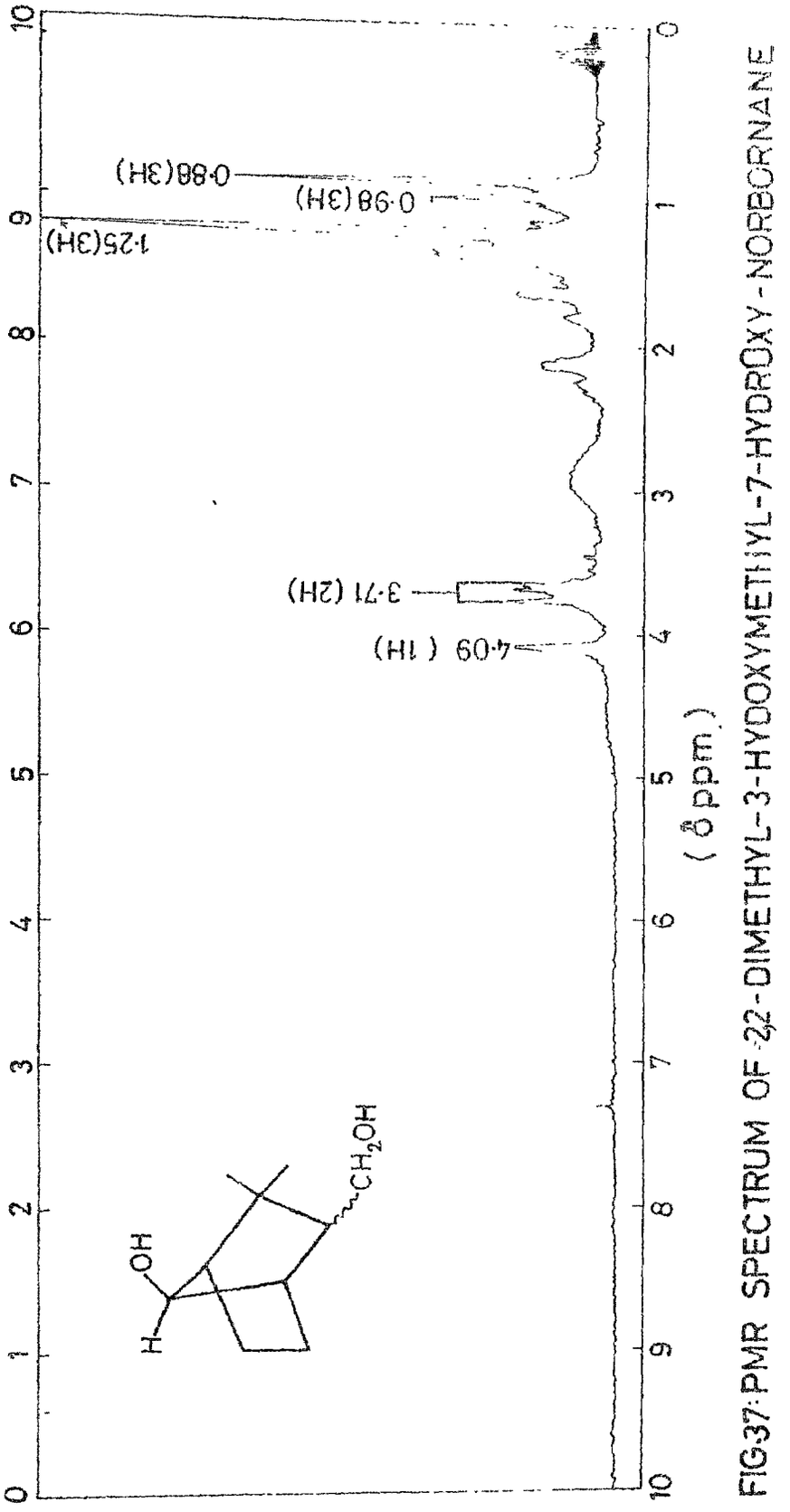
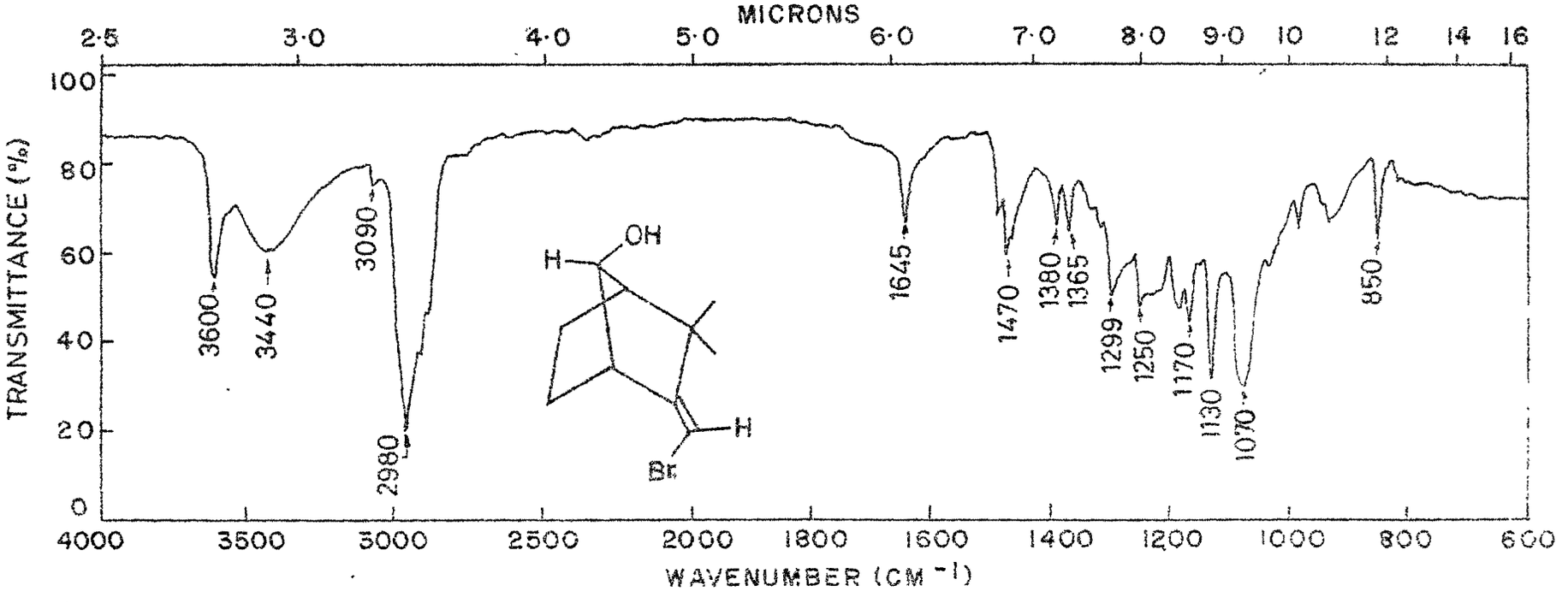


FIG.36: IR SPECTRUM OF 2,2-DIMETHYL-3-HYDROXYMETHYL-7-HYDROXY-NORBORNANE



FIG·37·PMR SPECTRUM OF 2,2-DIMETHYL-3-HYDOXYMETHYL-7-HYDROXY-NORBORNANE



FIG·38; IR SPECTRUM OF (E)-7-SYN-HYDROXY-10-BROMOCAMPHENE (42)

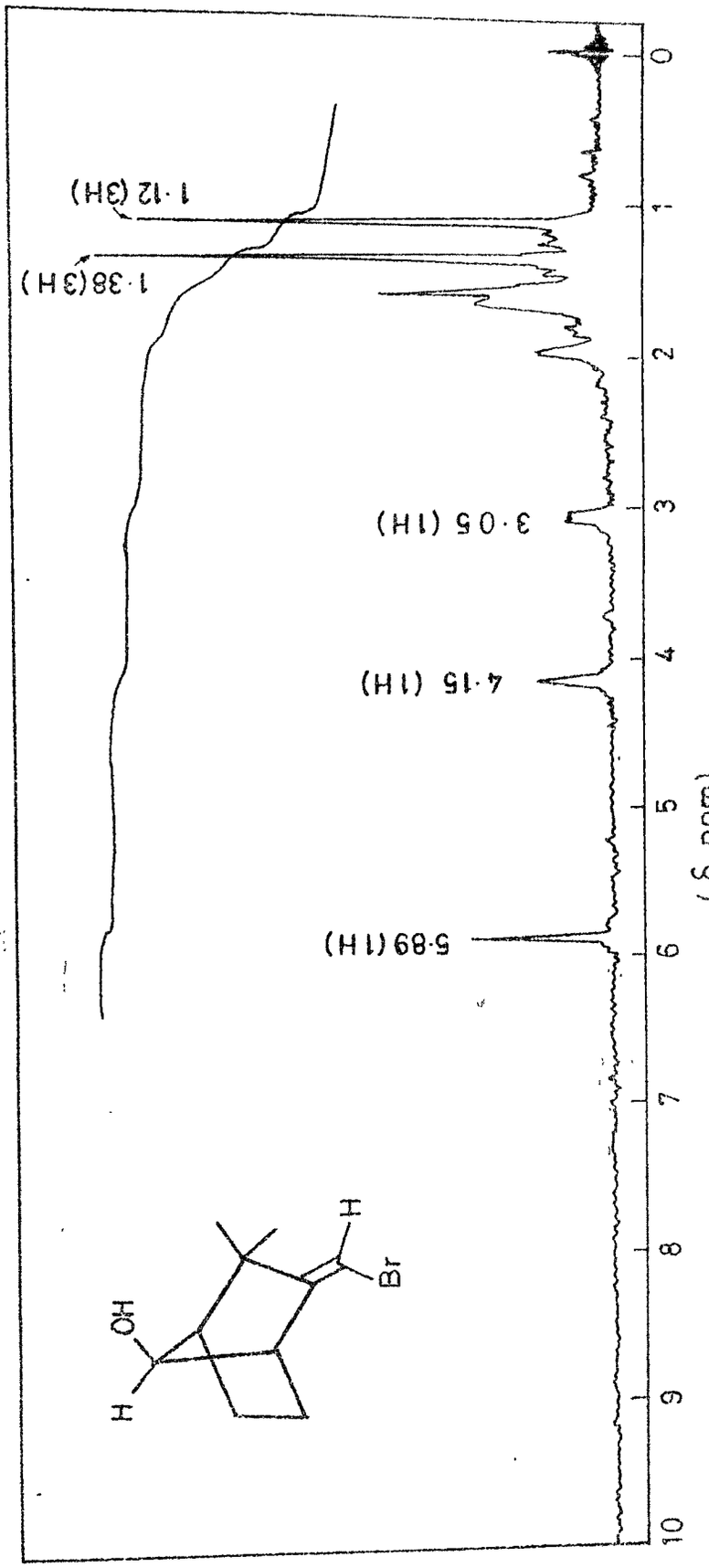


FIG. 39: PMR SPECTRUM OF (E)-7-SYN-HYDROXY-10-BROMOCAMPHENE (42)

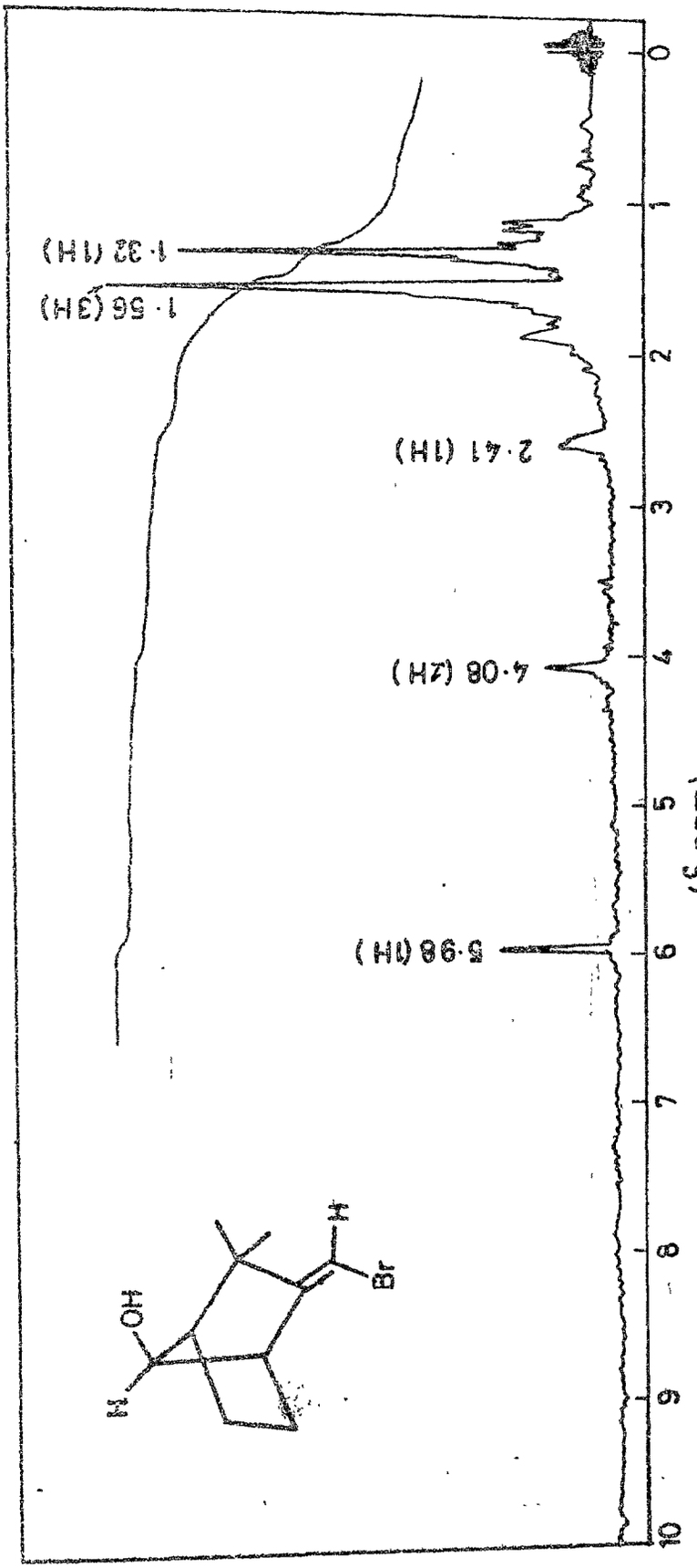


FIG. 40: PMR SPECTRUM OF (Z)-7-SYN-HYDROXY-10-BROMOCAMPHENE (43)