cyclopentadienide anion would be anticipated. This interpretation was supported by the agreement between the emission spectrum and the cyclopentadienide absorption spectrum.

A small concentration of cyclopentadiene radicals was shown to be present by the appearance of a line assigned to this radical;[8] however, the radical does not account for the major portion of the spectrum. Extensive decomposition of the 1,3-cyclopentadiene molecule did not take place since fragment spectra characteristic of this type of decomposition were not observed. The possibility that the spectrum could be attributed to a cation molecule was eliminated by the failure of more stable cations to afford characteristic molecular spectra.

The related indene molecule presents a situation analogous to that in 1,3-cyclopentadiene. Indene gives an intense visible emission spectrum which is related to the indenide anion absorption in the same manner as was observed for the cyclopentadiene system.

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The Structures of the Photolysis Products of Carvonecamphor

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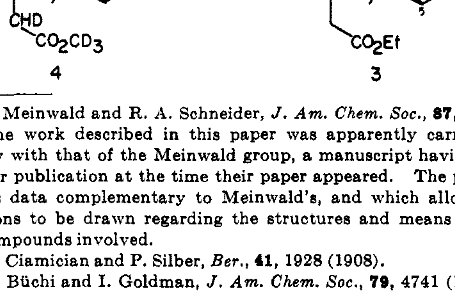
Evidence is presented which establishes the structure **3** for the ultimate product of the irradiation of carvone in ethanolic solution. Degradation of **3** to the ketone **9** provides a substance which on the basis of infrared and nuclear magnetic resonance spectra establishes both the ring structure and stereochemistry of the photoproduct. Independent syntheses of the hydrocarbons **18** and **19** are described, and the values of the chemical shifts of the bridge methyl groups in these compounds are used to support the stereochemistry assigned to **3**.

A recent publication by Meinwald and Schneider[1] concerning the synthesis and reactions of carvonecamphor prompts us to submit our own observations in this area.[2]

We had observed that, upon irradiation in ethanol, carvone (**1**) was converted through the intermediacy of the known[3,4] tricyclic ketone **2** to a saturated bicyclic ester. The corresponding methyl ester was formed on irradiation of carvone in methanol solvent. When the photolysis of **2** was carried out in perdeuteriomethanol, an ester was obtained which contained no deuterium in the ring portion of the molecule, in agreement with data obtained by Meinwald in similar experiments.[1] On the basis of mechanistic reasoning,[5] the perdeuteriomethanol ester was assigned structure **4** and the ethyl ester structure **3**. In this communication we describe further experiments which define absolutely the ring structure and stereochemistry of these esters.



It was felt that definitive evidence for the stereochemistry of **3** could be obtained on the basis of long-range spin coupling between the proton on C_5 and the *endo*-C_6 proton,[6] if indeed **3** represents the correct stereochemistry of the compound. Unfortunately, the signals for both of the protons are obscured by those of the two methyl groups; so it was decided to degrade **3** in the hope of obtaining compounds in which these signals would be open to observation, and at the same time provide a basis for comparison with synthetic materials.

Schmidt degradation[7] of the acid **5**, obtained either by hydrolysis of **3**, or by direct irradiation of **1** in aqueous solution, gave a high yield of the amine **6**, which was converted to the exocyclic olefin **8** by pyrolysis of the amine oxide[8] of the tertiary amine **7**.[9] Oxidation of the olefin to the corresponding ketone **9** was effected in good yield by means of a potassium permanganate–sodium periodate mixture.[10,11] The infrared spectrum of this ketone showed an absorption maximum at 5.67 μ, a value to be expected for a strained cyclopentanone ring.[12] Several attempts were made to reduce the

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[1] J. Meinwald and R. A. Schneider, *J. Am. Chem. Soc.*, **87**, 5218 (1965).

[2] The work described in this paper was apparently carried out concurrently with that of the Meinwald group, a manuscript having been completed for publication at the time their paper appeared. The present paper describes data complementary to Meinwald's, and which allows the same conclusions to be drawn regarding the structures and means of formation of the compounds involved.

[3] G. Ciamician and P. Silber, *Ber.*, **41**, 1928 (1908).

[4] G. Büchi and I. Goldman, *J. Am. Chem. Soc.*, **79**, 4741 (1957).

[5] G. Quinkert, *Angew. Chem.*, **77**, 229 (1965); O. L. Chapman, "Advances in Photochemistry," Vol. I, Interscience Publishers, Inc., New York, N. Y., 1963, p 365.

[6] J. Meinwald and A. Lewis, *J. Am. Chem. Soc.*, **83**, 2769 (1961).

[7] H. Wolff, *Org. Reactions*, **3**, 307 (1946).

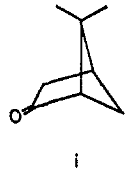
[8] A. C. Cope and E. Ciganek, *Org. Syn.*, **39**, 40 (1959).

[9] M. L. Moore, *Org. Reactions*, **5**, 301 (1949).

[10] R. U. Lemieux and E. von Rudloff, *Can. J. Chem.*, **33**, 1701 (1955).

[11] J. Meinwald and P. G. Gassman, *J. Am. Chem. Soc.*, **82**, 2857 (1960).

[12] The ketone i shows λ_{max} 5.69 μ.[11] The absorption maximum of **9** also eliminates the alternative ring systems ii and iii, since a bicyclo[2.2.0]-butanone structure ii would be expected to show λ_{max} ~5.62 μ [W. G. Dauben and R. M. Coates, *ibid.*, **86**, 2490 (1964)], while a bicyclo[3.1.0] hexanone system would show λ_{max} no lower than a normal cyclopentanone (5.73–5.75 μ) [T. Norin, *Acta Chem. Scand.*, **15**, 1676 (1961)].



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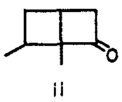
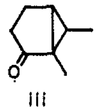
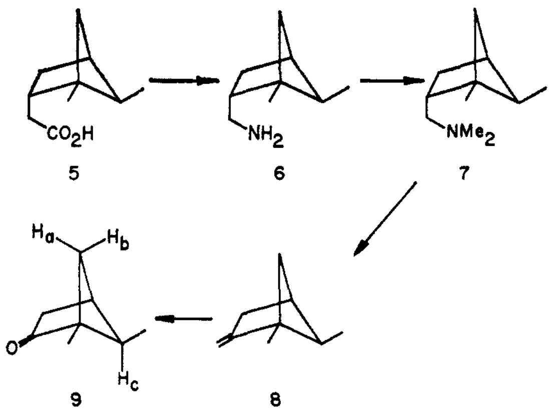


ii



iii

ketone to the corresponding hydrocarbon, none of which was successful. However, the ketone **9** served as a perfect model for analyzing and comparing the nmr spectrum with the epimeric hydrocarbons synthesized below.

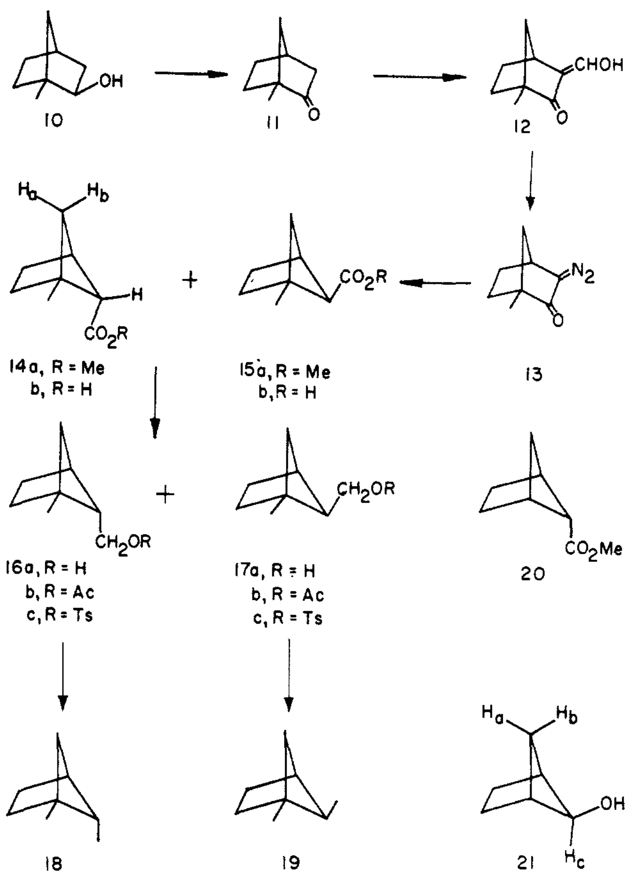


While working on the degradation reactions, we had proceeded to synthesize the two epimeric parent hydrocarbons **18** and **19** to provide further support for the structure of **3**.

Jones oxidation[13] of the alcohol **10**, prepared as described in the literature,[14] gave the ketone **11**, which on treatment with methyl formate and sodium methoxide[15] afforded in high yield the hydroxymethylene ketone **12**. This compound could be conveniently transformed to the diazo ketone **13** on treatment with toluenesulfonylazide in the presence of triethylamine.[16]

Irradiation[17] of a methanolic solution of **13** with a 200-w mercury lamp gave a mixture of the epimeric methyl esters **14a** and **15a**, in which the *endo* ester **14a** predominated to the extent of about 90%. Attempts to separate **14a** and **15a** by means of gas chromatography were only partially successful, and it was found that the composition of the mixture did not alter on treatment with sodium methoxide in methanol. This is in agreement with results obtained from the photolysis of diazonorcamphor,[18] in which the *endo* ester **20** is produced predominantly. In interesting contrast to this result, photolysis of **13** in aqueous dioxane gave a mixture of the carboxylic acids **14b** and **15b**, in which the *endo* to *exo* ratio was approximately 56:44. Evidence for the stereochemistry of the epimer formed in greater amount in the irradiation carried out in methanol was obtained from an examination of the nmr spectrum of material partially purified by gas chromatography. Thus, the *endo* proton on C_6 appears as a doublet, $J = 6.5$ cps, at τ 9.06. This is the signal expected for this proton (H_a) in **14a**, the analogous proton in **15a** should give rise to a triplet signal. Wiberg[19] has shown that proton H_a in the related *exo* alcohol **21** produces a triplet signal resulting from coupling both to H_b and H_c. In the epimeric alcohol, H_a produces a doublet due to geminal coupling only.

SCHEME I



The hydrocarbon **18** was obtained starting from the mixture of esters formed upon irradiation of **13** in methanol. Reduction with lithium aluminum hydride afforded the corresponding mixture of alcohols **16a** and **17a**, which were converted to the mixture of tosylates. Reduction of this mixture with lithium aluminum hydride gave the hydrocarbon **18**, contaminated with a small amount of **19**. The hydrocarbon **19** was obtained in a similar manner from the mixture of acids formed from **13** on photolysis in aqueous dioxane. Reduction with lithium aluminum hydride followed by acetylation gave a mixture of the acetates **16b** and **17b**, from which **17b** could be separated easily by preparative gas chromatography. Application of the reduction–tosylation–reduction sequence afforded the hydrocarbon **19** in low yield. (See Scheme I.)

Nmr Comparison.—A study of the nmr spectra of some of the compounds encountered, both in the degradation of **3** and in the syntheses of the hydrocarbons **18** and **19**, gives much useful information which is decisive in establishing the configuration at C_5 in the photoproducts. While all of the compounds obtained from carvone showed an apparent quintuplet, due to a single proton, in the τ 8.4–8.5 region, the signals for both H_a and H_b were obscured by the methyl signals, and neither their chemical shift nor their multiplicity could be determined. This problem was finally resolved on examination of the nmr spectrum of the ketone **9**. In this compound, the signals due to H_a and H_c are shifted to lower field by the presence of the carbonyl group, both appearing in regions of the spectrum which are free from interference due to other signals. Proton H_c gives rise to a quintuplet, $J = 7$ cps, centered at

[13] R. G. Curtis, I. Heilbron, E. R. H. Jones, and G. F. Woods, *J. Chem. Soc.*, 457 (1953).

[14] N. J. Toivonen, E. Siltanen, and K. Ojala, *Ann. Acad. Sci. Fennicae Ser. A.*, **II**, No. 64 (1955).

[15] W. S. Johnson and H. Posvic, *J. Am. Chem. Soc.*, **69**, 1361 (1947).

[16] M. Rosenberger, P. Yates, J. B. Hendrickson, and W. Wolf, *Tetrahedron Letters*, 2285 (1964).

[17] L. Horner and E. Spietschka, *Chem. Ber.*, **88**, 934 (1955).

[18] K. B. Wiberg, B. R. Lowry, and T. H. Colby, *J. Am. Chem. Soc.*, **83**, 3998 (1961).

[19] K. B. Wiberg, B. R. Lowry, and B. J. Nist, *ibid.*, **84**, 1594 (1962).

τ 8.04, while a clear triplet, $J = 7$ cps, is seen for H_a at τ 8.44. The quintuplet nature of the τ 8.04 signal was verified by a double-resonance experiment. Decoupling of H_c from the adjacent methyl group collapses the quintuplet to a doublet, $J = 7$ cps, demonstrating the coupling between H_c and an additional proton, presumably H_a.

Additional evidence for the *exo* stereochemistry of the C_5 methyl group in **3** can be obtained from the chemical shifts of the corresponding methyl groups in the hydrocarbons **18** and **19**. In **18**, in which the *endo* stereochemistry is established by the mode of genesis from **14a**, this methyl group appears as a doublet at τ 9.42. In the *exo* epimer **19**, the methyl doublet appears at τ 8.96. Since all of the compounds obtained either by photolysis of carvonecamphor in different solvents or in the degradation of **3** show the methyl doublet signal in the range of τ 8.65–8.95, the above data support the *exo* stereochemistry for these compounds. Examination of the nmr spectra of alcohols **16a** and **17a**, and acetates **16b** and **17b** suggests that this phenomenon may be general, in that *endo* hydrogens are shifted upfield from the corresponding *exo* hydrogens in the epimeric compound by about 0.5 ppm. This appears to hold not only for protons of methyl and methylene groups, but also to protons attached directly to the ring.[6,20]

Experimental Section[21]

Irradiation of Carvone. A. In Ethanol.—A solution of 1.003 g *d*-carvone, $[\alpha]^{25}D$ 51.6°, in 150 ml absolute ethanol was irradiated under nitrogen with a 200-w high pressure mercury lamp. Aliquots were removed periodically and subjected to gas chromatographic analysis. After 3 hr two new peaks were seen, in a ratio of approximately 1:5, comprising about 10% of the mixture. The reaction was stopped after 20 hr, at which time only a trace of carvone remained, and the smaller of the two new peaks had disappeared. The solvent was removed *in vacuo*, and the residue chromatographed with 30 g of silica gel. Elution with 10% ether in pentane gave 530 mg of the ethyl ester **3**, which after further purification by gas chromatography gave material with $n^{25}D$ 1.4525, $[\alpha]^{25}D$ −51.5° [4.76, EtOH], λ_{max} 5.75 μ (neat), and nmr signals (60 Mc) at τ 9.07 (3 H, singlet), 8.94 (3 H, doublet, $J = 6.5$ cps), 8.73 (3 H, triplet, $J = 7.2$ cps), 7.6–8.5 (7 H), and 5.84 (2 H, quartet, $J = 7.2$ cps). In addition, integration intensities indicated the presence of two protons in the region of τ 8.8–9.1. The mass spectrum gave a parent peak at *m/e* 196.

Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 73.31; H, 10.31.

B. In Methanol.—Irradiation of 98.5 g of *d*-carvone in 4 l. absolute methanol with a 450-w mercury lamp gave, after distillation, 61.0 g (51%) of the methyl ester corresponding to **3**. Material purified by gas chromatography showed $n^{25}D$ 1.4548, $[\alpha]^{25}D$ −47.5° (*c* 4.91, EtOH), λ_{max} 5.77 μ (CH_2Cl_2), and nmr signals at τ 9.10 (3 H, singlet), 8.97 (3 H, doublet, $J = 6.5$), 8.8–9.0 (2 H), 8.45 (1 H, quintuplet, $J = 6.5$), 7.5–8.2 (6 H), and 6.35 (3 H, singlet).

Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.96. Found: C, 72.53; H, 10.02.

C. In Aqueous Ethanol.—Irradiation of 1.06 g *d*-carvone in 135 ml 50% aqueous ethanol with a 200-w mercury lamp was carried out until the complete disappearance of carvone, about 22 hr. Part of the solvent was removed by distillation, and the residue extracted with ether. Extraction of the ether solution with sodium carbonate solution gave, after acidification, 0.47 g of the acid **5**. Crystallization from formic acid gave material with mp 50–52°, $[\alpha]^{25}{}_{5461}$ −89.3° (*c* 1.82, EtOH), λ_{max} 5.85 μ, and an nmr spectrum essentially identical with them ethyl ester's, except for the absence of the τ 6.35 methoxyl signal and a signal for the carboxyl proton at τ 1.0. The infrared and nmr spectra of this material were identical with those of the acid obtained by alkaline hydrolysis of **3**.

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.33; H, 9.63.

D. In Ethanol with 350-mμ Lamps.—A solution of 1.134 g *d*-carvone in 100 ml absolute ethanol in a round quartz flask was irradiated with a circular array of mercury lamps with wavelength maximum of 350 mμ. Periodic gas chromatographic analysis indicated the slow formation of a new compound with retention time identical with the transient peak observed in the broad spectrum irradiation, with very little of the ester **3** being formed. After 108 hr, the mixture was composed of 39% of the new compound, 14% ester, and 47% unreacted carvone. Purification by gas chromatography gave a crystalline compound, mp 101–102° after one sublimation, $[\alpha]^{25}D$ +75° (*c* 1.50, EtOH). Reported for carvonecamphor were mp 101–104°, $[\alpha]^{25}D$ +86.9°.[4] The infrared spectrum showed λ_{max} 5.80 μ (CH_2Cl_2) and other peaks corresponding to those reported.[4] The nmr spectrum showed singlet signals due to two methyl groups at τ 8.86 and 8.97.

Irradiation of Carvonecamphor. A. In Ethanol.—A solution of 42.9 mg carvonecamphor in 5.0 ml absolute ethanol in a quartz flask was irradiated with a 100-w mercury lamp for 160 min. The product, isolated by gas chromatography, was identified as the ester **3** by means of infrared spectra and gas chromatographic retention time.

B. In Tetradeuteriomethanol.—A solution of 46.4 mg carvonecamphor in 2.0 ml CD_3OD contained in a 5-ml quartz flask was irradiated under an argon atmosphere with a 100-w mercury lamp. After 267-min irradiation no detectable carvonecamphor remained. The solvent was distilled and the entire product was isolated in pure form by gas chromatography to give 32.2 mg (60%) of the ester **4**. The infrared spectrum showed four small bands in the region 4.4–4.8 μ, as well as the ester carbonyl peak at 5.75 μ. The nmr spectrum was superimposable with that of the methyl ester above τ 8.2. The spectrum also showed the loss of one proton in the region of τ 7.7, attributable to the methylene group adjacent to the carbomethoxy group, and the complete absence of a signal due to a methoxyl group. The mass spectrum showed a parent peak of 186, corresponding to the introduction of four deuterium atoms into the methyl ester. Additionally, the methyl ester and most of the other compounds prepared in this work, show a large P − 29 peak, corresponding to the loss of an ethyl group, which can most reasonably arise by loss of C_5 and the attached methyl group accompanied by rearrangement. That no deuterium has been incorporated at C_5 is shown by the absence of a P − 30 peak in the deuterio ester.

N,N-Dimethyl(1,5R-dimethylbicyclo[2.1.1]hexyl-2S-methyl)amine (7).—To a stirred mixture of 8.25 g of acid **5** and 35 ml concentrated sulfuric acid kept at 53° in an oil bath was added 6.40 g sodium azide in small increments over 1.5 hr.[7] After stirring at the same temperature for an additional 45 min the mixture was poured onto crushed ice and extracted with ether. The aqueous solution was diluted somewhat with water, made strongly basic with potassium hydroxide, and extracted thoroughly with ether to give 6.44 g of the primary amine **6**. The crude product was treated with 11.6 ml of 36% formaldehyde solution and 23 ml of formic acid at reflux for 9 hr.[8] The solution was cooled, poured into water, made acidic with 6 *N* HCl, and extracted with ether. The aqueous solution was made alkaline and extracted with ether to give 5.65 g of crude **7**. Distillation gave 2.82 g (35%), bp 70–71° (10.2 mm), $n^{25}D$ 1.4571, $[\alpha]^{25}{}_{5461}$ −69.0 (*c* 2.74, EtOH), λ_{max} 3.6 μ, and nmr signals at τ 9.03 (3 H, singlet), 8.95

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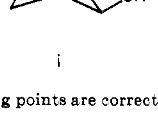
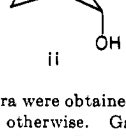
[20] R. Srinivasan, *J. Am. Chem. Soc.*, **83**, 4923 (1961). Examination of reported spectra for bicyclo[2.1.1]hexane compounds reveals only one apparent reversal to this trend, in the epimeric alcohols i and ii, and the corresponding tosylates.[19]



i



ii

[21] Melting points are corrected. Nmr spectra were obtained on a Varian Associates HA-100 spectrometer unless noted otherwise. Gas chromatographic analyses were performed on an Aerograph A-90P instrument using Carbowax 20M packed columns in the range of 60–200°. Microanalyses were performed by the Spang Microanalytical Laboratory, Ann Arbor, Mich. Infrared spectra were obtained on a Perkin-Elmer Infracord spectrometer, ultraviolet spectra were obtained from a Cary Model 14 spectrometer, and mass spectra were obtained from an Atlas CH-4 spectrometer.

(3 H, doublet, $J = 7$), *ca.* 8.9 (2 H), 8.40 (1 H, quintuplet, $J = 6.5$), 8.1 (3 H, broad), 7.98 (1 H, broad), 7.78 (8 H).

Anal. Calcd for $C_{11}H_{21}N$: C, 78.97; H, 12.65; N, 8.37. Found: C, 78.89; H, 12.54; N, 8.31.

The picrate had mp 152.5–153°, after recrystallization from ethanol.

Anal. Calcd for $C_{17}H_{24}N_4O_7$: C, 51.51; H, 6.10; N, 14.14. Found: C, 51.60; H, 6.24; N, 14.15.

1,5R-Dimethyl-2-methylenebicyclo[2.1.1]hexane (8).—To a cooled solution of 2.55 g **7** in 10 ml methanol was added 3.5 ml of 30% hydrogen peroxide solution with stirring, under argon.[9] The ice bath was removed and the solution was allowed to warm to room temperature and stirred for 7 hr. Another 2.0 ml peroxide solution was then added and the solution stirred overnight. The excess peroxide was decomposed with Pt on charcoal until the solution gave a negative starch–iodide test. The solution was filtered and evaporated at 35° and 15-mm pressure The residue was heated at 125° and 45-mm pressure for 2.5 hr, the olefin being collected in two Dry Ice–isopropyl alcohol traps. The trap system was rinsed with ether, extracted with water and dried. Distillation of the ether gave 1.42 g (72%) nearly pure olefin, which showed only one peak on the gas chromatogram. Material purified by gas chromatography showed λ_{max} 6.02 and 11.48 μ, mol wt 122 (mass spec), and nmr signals at τ 8.91 (3 H, singlet), 8.86 (3 H, doublet, $J = 6.5$), ~8.9 (1 H), 8.43 (1 H, quintuplet, $J = 6.5$), 7.7–7.9 (4 H), 5.35 and 5.27 (2 H).

Anal. Calcd for C_9H_{14}: C, 88.45; H, 11.55. Found: C, 88.58; H, 11.57.

1,5R-Dimethylbicyclo[2.1.1]hexan-2-one (9).—To a solution of 0.27 g of $KMnO_4$, 7.0 g $NaIO_4$, and 5.0 g K_2CO_3 in 200 ml water was added 1.173 g of olefin **8** in 2 ml dioxane.[11] The mixture was stirred vigorously at room temperature for 22 hr. Extraction with ether gave 1.00 g light yellow oil containing some ether and dioxane, with no evidence for the presence of olefin. Material purified by gas chromatography showed λ_{max} 5.67 μ (CCl_4), and nmr signals at τ 8.98 (3 H, singlet), 8.68 (3 H, doublet, $J = 6.5$), 8.44 (1 H, triplet, $J = 6.5$), 8.06 (1 H, quintuplet, $J = 6.5$), 7.77 (2 H), and 7.57 (2 H).

Anal. Calcd for $C_8H_{12}O$: C, 77.37; H, 9.74. Found: C, 77.24; H, 9.65.

The ketone formed an orange-red 2,4-dinitrophenylhydrazone derivative, mp 154.5–155°.

Anal. Calcd for $C_{14}H_{16}N_4O_4$: C, 55.25; H, 5.30; N, 18.41. Found: C, 55.26; H, 5.33; N, 18.28.

1-Methylnorcamphor (11).—The *exo* alcohol **10** was synthesized as described by Toivonen.[14] The crude alcohol from 81.1 g of norcamphor, which showed no carbonyl band in the infrared spectrum, was dissolved in 500 ml acetone and oxidized at 0–5° with 230 ml of 8 *N* CrO_3 in sulfuric acid.[13] The excess oxidant was destroyed with isopropyl alcohol and the solvent removed under vacuum. The residue was taken up in ether, extracted with saturated Na_2CO_3 solution and water, and dried over $MgSO_4$; the solvent was stripped. Distillation through an 18-in. spinning-band column gave 32.7 g (36%) of ketone **11**. The residue, 36.5 g, was shown by gas chromatography to contain about 50% ketone, 25% starting alcohol, and 25% of an unidentified compound. The ketone showed bp 61° at 13.5 mm and $n^{26}D$ 1.4630 (lit.[22] 67° at 18 mm and $n^{20}D$ 1.4674).

1-Methyl-3-hydroxymethylenenorcamphor (12).—A mixture of 20.0 g 1-methylnorcamphor and 21.3 g ethyl formate was added dropwise to a stirred slurry of 8.7 g NaOMe in 200 ml benzene at 0–5° over a 30 min period.[15] The ice bath was removed and the mixture stirred overnight at room temperature. The mixture was extracted with 1 *N* NaOH, dried, and the solvent evaporated to give about 12 g starting ketone. The alkaline extract was acidified with 6 *N* HCl, extracted with ether, and the ether solution dried over Na_2SO_4. Distillation of the residue after removal of the ether gave 10.0 g (41% conversion) of **12**, bp 51° (0.5 mm), λ_{max} 3.64, 5.68, 5.80, 5.88, and 6.15 μ (CCl_4), and nmr signals (60 mc) at τ 8.80, 8.35, 6.98, 3.20 and −0.70.

1-Methyl-3-diazonorcamphor (13).—To a solution of 12.86 g hydroxymethylene ketone **12** and 17.2 g triethylamine in 150 ml ether, cooled in an ice bath, was added an ether solution of 16.65 g toluene sulfonyl azide[23] over 3 hr.[16] The solution was allowed to warm to room temperature during an additional 3 hr stirring, poured into water, and extracted with ether. After drying, removal of solvent gave 14.0 g orange oil, containing some Et_3N. The oil was heated slowly *in vacuo* until the volatile impurities were removed, at which point decomposition began so that further purification was impractical. The residue, 10.6 g, showed strong absorption in the infrared at 4.78 and 5.92 μ, apparently due to a ketonic impurity.

Methyl-1-methylbicyclo[2.1.1]hexane-5-*exo*- and 5-*endo*-carboxylates (14a and 15a).—A solution of 1.69 g of the diazo ketone **13** in 150 ml methanol was irradiated with a 200-w mercury arc using Vycor glassware.[17] After the disappearance of the diazo band in the infrared, about 3.5 hr, the methanol was removed by distillation through a spinning-band column. Distillation of the residue through a small column gave 350 mg colorless oil, bp 50–52°, which appeared to be a mixture of two compounds in a ratio of about 9:1 on gas chromatographic analysis. Only a trace of the minor component could be obtained pure, which showed λ_{max} 5.77 μ. The major component showed λ_{max} 5.75 μ (CCl_4), $n^{26}D$ 1.4472, and nmr signals at τ 9.06 (1 H, doublet, $J = 6.5$), 8.80 (1 H, complex), 8.72 (3 H, singlet), 8.1–8.7 (4 H), 7.86 (1 H, doublet, $J = 2$), 7.40 (1 H, complex), and 6.40 (3 H, singlet). An additional small peak at τ 6.34 suggests the presence of about 5–10% of *exo* ester.

Anal. Calcd for $C_9H_{14}O_2$: C, 70.10; H, 9.15. Found: C, 69.87; H, 9.09.

1-Methyl-5-hydroxymethylbicyclo[2.1.1]hexane (16a and 17a).—A solution of 0.980 g of the ester mixture (**14a** and **15a**) in ether was added to a slurry of 0.48 g $LiAlH_4$ in ether. After stirring overnight the mixture was decomposed with saturated Na_2SO_4 solution, filtered through celite, dried over $MgSO_4$, and the solvent removed to give 0.926 g clear oil with no carbonyl band in the infrared. The gas chromatogram consisted essentially of one peak. Purification by gas chromatography gave material with λ_{max} 2.95 and 9.78 μ, and nmr signals at τ 9.04 (1 H, doublet, $J = 6.5$), 8.89 (1 H, complex), 8.81 (3 H, singlet), 8.3–8.75 (6 H), 7.62 (1 H, broad), and 6.60 (2 H, doublet, $J = 7$). An additional small doublet at τ 6.14, $J = 7$ cps, suggests the presence of 5–10% *exo*-hydroxymethyl compound.

1,5-*endo*-Dimethylbicyclo[2.1.1]hexane (18).—To a solution of 0.670 g of alcohols **16a** and **17a** in *ca.* 5 ml pyridine was added 1.11 g toluene sulfonyl chloride. After standing overnight at 0°, the solution was poured onto crushed ice and extracted with ether. The ether solution was extracted twice with 1 *N* HCl, water, twice with saturated $NaHCO_3$, dried over $MgSO_4$, and evaporated to give 1.324 g (90%) of the tosylate. The tosylate, λ_{max} 7.34 and 8.48 μ, crystallized from pentane, but melted on approaching room temperature. An ether solution of the crude tosylate was added to a slurry of 0.5 g $LiAlH_4$ in 50 ml ether under Ar, and the mixture heated at reflux 4.5 hr. After decomposition with saturated Na_2SO_4 solution, the solution was extracted with 1 *N* HCl, saturated Na_2CO_3, and water. After drying over $MgSO_4$, the ether was distilled through a spinning-band column. The residue consisted of a mixture of ether and a very volatile compound in a 2:1 ratio. The hydrocarbon was isolated by gas chromatography to give 223 mg (43%), λ_{max} 3.35, 6.9, 7.28, and 7.6 μ (CCl_4), and nmr signals at τ 9.42 (3 H, doublet, $J = 6.5$), 9.05 (2 H, broad), 8.97 (3 H, singlet), 8.4–8.9 (5 H), 7.84 (1 H, broad).

Anal. Calcd for C_9H_{14}: C, 87.19; H, 12.81. Found: C, 86.88; H, 12.91.

1-Methylbicyclo[2.1.1]hexane-5-*exo*- and -*endo*-carboxylic Acids (14b and 15b).—A solution of 10.9 g of the diazo ketone **13** in 195 ml of 7:1 dioxane–water was flushed with nitrogen, then irradiated with a 200-w mercury lamp until the complete disappearance of the diazo band in the infrared (about 21 hr). The solvent was removed *in vacuo*, and the residue taken up with saturated sodium carbonate solution. After extraction with ether to remove neutral by-products, acidification gave 2.9 g of a mixture of carboxylic acids. Short-path distillation gave material with λ_{max} 5.86, and an nmr spectrum which suggested the presence of two compounds in nearly equal amount, the quaternary methyl groups appearing at approximately equal intensities at τ 8.65 and 8.71.

Anal. Calcd for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.72; H, 8.79.

1-Methyl-5-*exo*- and -*endo*-acetoxymethylbicyclo[2.1.1]hexanes (16b and 17b).—The mixture of acids **14b** and **15b** was reduced with 0.85 g lithium aluminum hydride in ether to give 1.44 g of the alcohols **16a** and **17a**. Gas chromatography showed that **16a** amounted to about 60% of the mixture. The crude mixture was acetylated with 5 g acetic anhydride and a small amount of

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(22) H. Toivonen, *Suomen Kemistilehti*, **33b**, 66 (1960).

(23) W. von E. Doering and C. H. DePuy, *J. Am. Chem. Soc.*, **75**, 5955 (1953).

pyridine. Removal of the acetic anhydride *in vacuo* gave 1.71 g of the acetates, easily separable on a Carbowax 20M gas chromatography column. Planimeter measurement of peak areas showed the two acetates to be present in a 56:44 ratio. The purified *endo* isomer **16b** showed λ_{max} 5.75 and 8.1 μ, $n^{25}D$ 1.4449, and nmr signals at τ 8.98 (1 H, doublet, J = 6.5), 8.80 (3 H, singlet), 7.96 (3 H, singlet), and 6.15 (2 H, doublet, J = 7).

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.43; H, 9.63.

The *exo* isomer **17b** showed λ_{max} 5.76 and 8.11 μ, and nmr signals at 8.87 (3 H, singlet), ~8.9 (1 H), 7.96 (3 H, singlet), and 5.68 (2 H, doublet, J = 7.5).

Anal. Found: C, 71.90; H, 9.55.

1,5-*exo*-Dimethylbicyclo[2.1.1]hexane (19).—The acetate **17b** (196 mg), purified by preparative gas chromatography, was reduced with excess lithium aluminum hydride. The resultant alcohol was converted to the tosylate and reduced in the same manner as described for **16a** to 18.1 mg of gas chromatographically pure hydrocarbon **19**. This material showed a molecular weight of 110 by mass spectroscopy and nmr signals at τ 7.95 (1 H, doublet, J = 2 cps), 8.18 (1 H, broad), 8.41 (2 H, singlet), 8.48 (2 H, singlet), 8.96 (3 H, doublet, J = 6.5), 8.98 (3 H, singlet), and ~9.0 (1 H). Insufficient material could be recovered for microanalysis.

The Synthesis of 6-Ketononanolides from Chromans[1]

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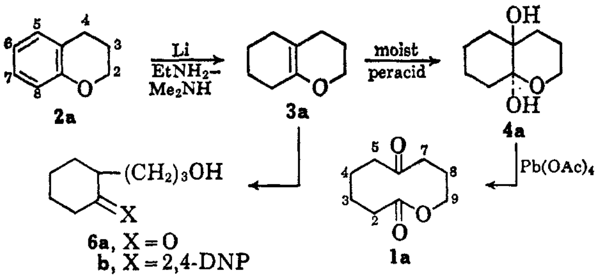
The reduction of chroman with excess lithium in ethylamine–dimethylamine (1:1 by volume) gives 5,6,7,8-tetrahydrochroman **3a**. Reaction of **3a** with perphthalic acid in moist ether gives a *trans* glycol **4a** which is cleaved with lead tetraacetate to give 6-ketononanolide **1a**. A direct conversion of **3a** to **1a** is obtained with an excess of *m*-chloroperbenzoic acid. The use of these methods in the synthesis of substituted 6-ketononanolides and the limitations of the *m*-chloroperbenzoic acid–olefin reactions are discussed.

It is of long-range interest to us to develop convenient syntheses of medium-ring keto lactones which are structurally related to the macrolide antibiotics. We wish to report the synthesis of the 6-ketononanolide system in this paper. The lithium–amine reduction of chromans **2a–2g** gives 5,6,7,8-tetrahydrochromans **3a–3g** which are then oxidized by various methods to give 6-ketononanolides **1a–1g**.

A series of chromans substituted in the aromatic ring was synthesized by the alkylation of the appropriate sodium phenoxide with 3-chloro-1-propanol to give the corresponding 3-phenoxy-1-propanol which was then cyclized by dehydration in boiling benzene with phosphorus pentoxide.[3] A 1.46:1 mixture of 7-methyl- and 5-methylchroman was prepared from *m*-cresol in this manner and then separated by repeated fractional distillation.[4] Impure 2-methylchroman **2f** was prepared according to a modification of the reaction of phenol with butadiene and 100% phosphoric acid as described by Bloch.[5] Since **2f** could not be entirely freed from low-boiling butadiene polymers, it was used in a purity of about 65% in the subsequent reactions.

The reduction of chroman **2a** with about 6.5 equiv of lithium in 1:1 (by volume) of dry ethylamine–dimethylamine gave **3a** in 85% yield based on a purity of 96% (by vpc). Two minor components were present (4% of the total material). The use of ethylamine–dimethylamine as a mixed solvent gave **3a** in higher purity and yield than did ethylamine alone or other amine combinations. Thus the yields and purity (by vpc) in the lithium–amine reduction of **2a** to **3a** were 68% (87% pure) from ethylamine, 22% (93% pure) from 1:1 ethylenediamine–morpholine, and 23% (100% pure) from ethylamine–diethylamine. The impurities noted in the ethylamine–dimethylamine reduction may be (a) one (or both) of the isomers of hexahydrochroman appearing as a single peak with shorter vpc retention time than for **3a** and (b) a double-bond isomer of **3a** with a longer vpc retention time. The identification of these minor components has not yet been carried out. The assignment of the less retentive minor peak to a hexahydrochroman is by analogy to the shorter vpc retention time for the decalin formed as a minor component in the lithium–amine reduction of naphthalene to 1,9- and 9,10-octalin.[6] The structure of **3a** was assigned on the basis of its analysis, nmr and infrared spectra (Experimental Section), and conversion to the 2,4-dinitrophenylhydrazone of 2-(3′-hydroxypropyl)cyclohexanone **6b** (58%).[7]



1a, unsubstituted
b, 4-methyl
c, 2-methyl
d, 5-methyl
e, 3-methyl
f, 9-methyl
g, 2,5-dimethyl
h, 3,5-dimethyl

2–4a, unsubstituted
b, 6-methyl
c, 8-methyl
d, 5-methyl
e, 7-methyl
f, 2-methyl
g, 5,8-dimethyl
h, 5,7-dimethyl

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[3] R. E. Rindfusz, P. M. Ginnings and V. L. Harnack, *J. Am. Chem. Soc.*, **42**, 157 (1920).

[4] Performed by S. S. Ho.

[5] (a) H. S. Bloch and H. E. Mammen, U. S. Patent 2,657,193 (Oct 21, 1953); *Chem. Abstr.*, **48**, 3724 (1954). (b) H. S. Bloch, personal communication.

[6] (a) G. Gonis, Lehigh University, unpublished results. (b) I. J. Borowitz and G. Gonis, *Tetrahedron Letters*, **No. 19**, 1151 (1964).

[7] H. Obara, *J. Chem. Soc. Japan, Pure Chem. Sect*, **82**, 60 (1961).