

trated, and the oil crystallized from methanol as a yellow solid, 0.47 g. (12%), m.p. $>300^{\circ}$ dec. The analytical sample was a light yellow powder, m.p. $>340^{\circ}$ dec.

Anal. Calcd. for $C_{19}H_{16}BrN$: C, 67.46; H, 4.77; N, 4.14. Found: C, 67.31; H, 4.95; N, 4.20.

The perchlorate was prepared from the filtrate remaining

after crystallization of the crude bromide, yield 0.60 g. (14%) of light yellow solid m.p. $>320^{\circ}$ dec. The analytical sample was prepared from ethanol as light yellow irregular crystals, m.p. $>320^{\circ}$ dec.

Anal. Calcd. for $C_{19}H_{16}ClNO_4$: C, 63.78; H, 4.51; N, 3.92. Found: C, 63.33; H, 4.65; N, 4.14.

Studies in the Sandalwood Oil Series. III. Chain Effect on Terpene Transformations

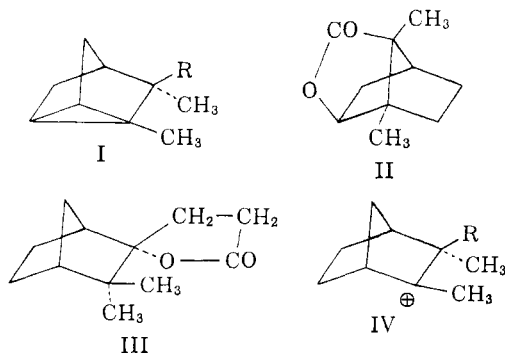
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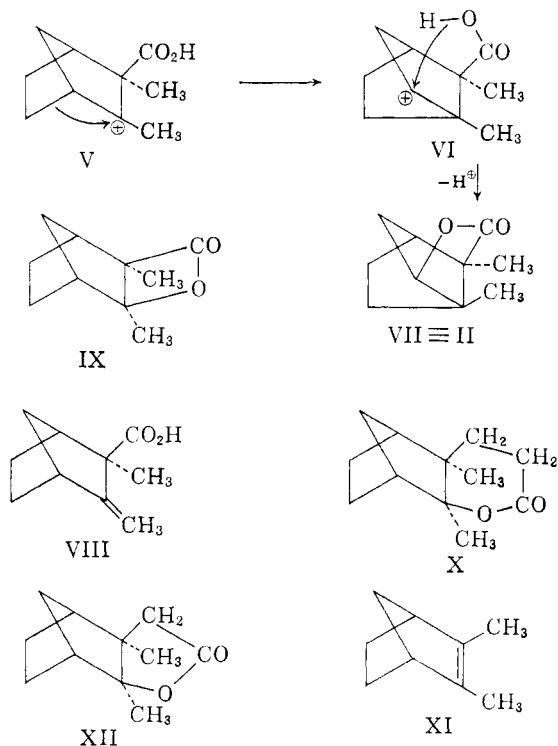
The carboxyl chain of some molecules has been found to be responsible for causing rearrangements and controlling their course. This chain effect, which operates during reactions involving carbonium ions, is illustrated with examples from Sandalwood oil chemistry.

A previous study² in this series has revealed the fact that two homologous compounds behave differently under the same experimental conditions. Thus teresantalic acid (I. $R = CO_2H$) and tricycloekasantalic acid [I. $R = (CH_2)_2-CO_2H$], or their methyl esters, give, on refluxing with formic acid, lactones of dissimilar structures, II and III, respectively.²⁻⁵ This paper deals with an investigation into the cause of this unusual behavior.



In the formation of III from tricycloekasantalic acid [I. $R = (CH_2)_2-CO_2H$] the intermediate carbonium ion [IV. $R = (CH_2)_2-CO_2H$] undergoes a Nametkin type of rearrangement.² The formation of II from teresantalic acid (I. $R = CO_2H$) involves a Wagner-Meerwein rearrangement as the following considerations will show. (1) Acid-catalyzed fission of the cyclopropane ring of teresantalic acid (I. $R = CO_2H$) leads to the carbonium ion (V).^{6,7} (2) That V rearranges to VI would be evident from the fact⁸ that the same lactone

(VII \equiv II) is obtained from *apo*-camphene-carboxylic acid (VIII). In the absence of these rearrangements, the intermediate carbonium ions (V) and [IV. $R = (CH_2)_2-CO_2H$] would have led to



lactones (IX and X, respectively). However, they both yield γ -lactones (II and III, respectively). Therefore, the preferential formation of a γ -lactone, and hence the length of the carboxyl chain of these acids, is responsible for the observed rearrangements. In V the carboxyl chain (counting from the center of carbonium ion) is short, for the formation of a γ -lactone, by one carbon atom. It can either lead to a relatively less stable β -lactone (IX) or undergo decarboxylation and give rise to santene (XI). Alternatively, it can lengthen the

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

(3) F. W. Semmler and K. Bode, *Ber.*, **40**, 4465 (1907).

(4) T. Hasselstrom, *J. Am. Chem. Soc.*, **53**, 1907 (1931).

(5) F. W. Semmler, *Ber.*, **41**, 1488 (1908).

(6) A. Bhati, *Perfumery Essent. Oil Record*, **53**, 15 (1962).

(7) P. de Mayo, "The Mono- and Sesqui-terpenoids," Interscience Publishers, Inc., New York, N. Y., 1959, p. 128.

(8) Y. Asahina, M. Ishidate, and T. Momose, *Ber.*, **68**, 83, 559 (1935).

carboxyl chain by undergoing a Wagner-Meerwein arrangement, and form the stable lactone (VII \equiv II). In IV [R = (CH₂)₂-CO₂H] the carboxyl chain is longer, by one carbon atom, than is required for the formation of a γ -lactone. The necessary shortening of the chain is achieved by this ion undergoing the Nametkin rearrangement. If the length of the carboxyl chain were one of the factors that controls the occurrence and course of rearrangement prior to lactonization, then *nor*-tricycloekasantalic acid [I. R = CH₂-CO₂H] should give the lactone (XII) without any rearrangement, for in this case the carboxyl chain (*cf.* IV. R = CH₂-CO₂H) is of the right length for the formation of a γ -lactone (XII). This actually has been found to be so.

The *nor*-tricycloekasantalic acid used in the present investigation was prepared by the Barbier-Wieland degradation of tricycloekasantalic acid.⁹ Ethyl tricycloekasantalate gave, on treatment with phenyl magnesium bromide, the carbinol [I. R = (CH₂)₂-C(OH)(C₆H₅)₂] which was smoothly dehydrated with acetic anhydride to the corresponding unsaturated hydrocarbon [I. R = CH₂-CH = C(C₆H₅)₂]. This latter compound gave, on ozonolysis, free *nor*-tricycloekasantalic acid and *nor*-tricycloekasantal along with benzophenone and a solid byproduct which was found to be a 1,2-diol, C₂₄H₂₈O₂. The *nor*-tricyclosantalal was oxidized to the corresponding acid by alkaline silver oxide.¹⁰ Methyl *nor*-tricycloekasantalate, prepared from the corresponding silver salt and methyl iodide, on refluxing with formic acid, gave a neutral product which, after hydrolysis and relactonization, afforded a compound, m.p. 162–163°, infrared band (KBr)¹¹ at 1760 cm.⁻¹, indicating that it was a γ -lactone. This was further confirmed from the fact that on hydrolysis with alcoholic sodium hydroxide it gave the sodium salt of the corresponding hydroxy carboxylic acid which relactonized on acidification. On reduction with lithium aluminum hydride, the lactone gave a crystalline diol, C₁₁H₂₀O₂, m.p. 112–113°. On dehydration with acetic anhydride, the diol gave an unsaturated carbinol which was found to possess an *exo*-cyclic double bond. On the basis of these data the lactone possesses the structure (XII).

If the carboxyl chain is increased enormously, as in dihydro- α -santalyl acetic acid [I. R = (CH₂)₃-CH(CH₃)-(CH₂)₂-CO₂H] then the chances of lactonization and rearrangement would be nil. In fact this acid yields, on treatment with acids, the normal fission product.^{12,6} The chain effect

depends not only on the length of the carboxyl chain but also on its mode of folding and configuration. It is discussed fully elsewhere with additional examples.¹³

Experimental¹⁴

Ethyl tricycloekasantalate was prepared from tricycloekasantalic acid (18.6 g.), m.p. 76.5°, [α]_D²⁵ +13.09° (ethanol, *c*, 3.514), by treating its silver salt with ethyl iodide (16.5 g.) in dry benzene. Yield: 17.09 g. (80%). It possesses b.p. 110–111°/1.5 mm.; *n*_D²⁵, 1.4715; [α]_D²⁵ +12.27° (chloroform, *c*, 3.26).

Anal. Calcd. for C₁₄H₂₂O₂: C, 75.63; H, 9.97. Found: C, 75.70; H, 9.41.

Diphenyl *nor*-Tricycloekasantalyl Carbinol [I. R = (CH₂)₂-C(OH)(C₆H₅)₂].—A solution of ethyl tricycloekasantalate (16.5 g.) in ether (50 ml.) was added gradually to an ice-cold ethereal solution of phenyl magnesium bromide (prepared from 4.75 g. of magnesium, 30.2 g. of bromobenzene, and 50 ml. of ether). A vigorous reaction took place and a white complex separated. After 30 min. more ether (50 ml.) was added and the mixture refluxed for 4 hr., then cooled and decomposed with ice and dilute sulfuric acid. The resultant viscous oil (27.0 g.), isolated by extraction with ether, gave on distillation under reduced pressure (1.2 \times 10⁻² mm.) the following fractions: forerun (1.75 g.) which consisted of diphenyl, (i) b.p. up to 168° (4.5 g.); (ii) 168–184° (4.4 g.), and (iii) 184–186° (14.92 g.). Fractions (i) and (ii) consisted mostly of the dehydrated product. Fraction (iii) was the expected carbinol. It has *n*_D^{19.5} 1.5828.

Anal. Calcd. for C₂₄H₂₈O: C, 86.70; H, 8.49. Found: C, 86.57; H, 8.23.

α,α -Diphenyl- β -teresantalyl-ethylene [I. R = CH₂-CH=C(C₆H₅)₂].—The above mentioned fraction (iii) (12 g.) was refluxed with freshly distilled acetic anhydride (30 ml.) for 2 hr. The anhydride was distilled off and the residue heated with water (50 ml.) in a steam bath for 15 min. The resultant material was taken up in ether and the extract washed successively with water, dil. sodium carbonate, and water again. The ethereal solution, so obtained, gave, on drying and removal of ether, an oil which gave, upon distillation, a colorless liquid (9.6 g.), b.p. 180–185°/1.5 mm.; *n*_D²⁵ 1.5855. Yield, 85%.

Anal. Calcd. for C₂₄H₂₆: C, 91.67; H, 8.33. Found: C, 90.81; H, 8.35.

The dehydrated product was found to contain 1.035 double bond, and give a brown coloration with tetranitromethane.

Fractions (i) and (ii) were combined and similarly treated. The resultant compound from its b.p. and *n*_D²⁵ was found to be the same unsaturated hydrocarbon. The over-all yield was 23.82 g., 96%.

Ozonolysis of α,α -Diphenyl- β -teresantalylethylene [I. R = CH₂-CH=C(C₆H₅)₂].—A stream of ozonized air was passed through a solution of the unsaturated hydrocarbon (10.5 g.) in ethyl acetate (150 ml.) at 0° until the reaction mixture gave a faint yellow coloration with tetranitromethane. The residue, left after the removal of solvent at ca. 25°/20 mm., was gradually heated with water (50 ml.) in a water bath, the temperature of which was raised to ca. 97° during an hour, and then maintained there for another 3 hr. The mixture was cooled and extracted with ether (100 ml.), and the extract shaken with dil. sodium carbonate (50 ml.). The alkaline solution gave, on acidification, crude *nor*-tricycloekasantalic acid (0.55 g.), m.p. 90–92°. The neutral ethereal solution gave, on drying and removal of ether, an oil which furnished the following fractions: (i)

(9) *Cf.* preliminary communication, A. Bhati, *Current Sci.* (India), **22**, 341 (1953).

(10) M. Delepine and P. Bonnet, *Comp. rend.*, **149**, 39 (1909); *J. Chem. Soc. Abs.* (i), **96**, 632 (1909).

(11) This measurement was kindly made by Samuel P. Sadtler and Son, Inc., Philadelphia, Pa., through the courtesy of Professor D. K. Banerjee, for which the author is grateful.

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

(13) A. Bhati, *Perfumery Essent. Oil Record*, **53**, 383 (1962).

(14) All m.p. are uncorrected. Petroleum ether refers to the fraction, b.p. 40–60°. Anhydrous sodium sulfate was used for drying solutions. Analyses are by Mr. B. R. Seetharamiah to whom the author is grateful.

b.p. 80–85°/5 mm. (1.4 g.); (ii) b.p. 90–140°/5 mm. (3.03 g.); (iii) b.p. 140–150°/3 mm. (2.20 g.) and (iv) b.p. 210–213°/3 mm. (3.60 g.). Fractions (i) and (ii) gave the usual tests for aldehyde and also a semicarbazone (shiny white plates from dil. ethanol), m.p. 223–224°.

Anal. Calcd. for $C_{12}H_{18}N_3O$: C, 65.12; H, 8.65; and N, 18.99. Found: C, 65.24; H, 8.30; and N, 19.20. Fraction (iii), which solidified on cooling, was found to be benzophenone from its m.p. and mixed m.p. with an authentic sample. Fraction (iv) gave, on trituration with petroleum ether, under ice-cooling, a flocculant precipitate (0.66 g.). It was washed thoroughly with the same solvent, dried over anhydrous calcium chloride at ca. 25°/2 mm. It melts at 116°.

Anal. Calcd. for $C_{24}H_{38}O_2$: C, 82.72; H, 8.10; M.w. 348. Found: C, 82.08; H, 8.34; M.w. 346.4 (Rast).

It gave a positive test¹⁵ for a 1,2-diol¹⁶ and, therefore, it is the corresponding glycol [I. R = $CH_2-CH(OH)-C(OH)-(C_6H_5)_2$]. The mother liquor, left after removal of the flocculant solid, gave, on removal of solvent, the unchanged hydrocarbon (2.8 g.).

Oxidation of *nor*-Tricycloekasantalal with Alkaline Silver Oxide.—A 3% barium hydroxide solution (125 ml.) was gradually added over 2 hr. to a stirred homogeneous mixture prepared from the above mentioned fraction (i) (1.2 g.), aldehyde-free ethanol (150 ml.) and 10% aqueous silver nitrate (32 ml.). The mixture was stirred for another 2 hr., allowed to stand overnight, and then filtered. The filtrate was concentrated to a small bulk and then extracted with ether in order to remove any adhering organic material. The alkaline solution gave, on acidification and subsequent extraction with ether, a white solid (0.95 g.), m.p. 90–92°. Fraction (ii) (3.1 g.) gave, on similar oxidation, the same solid (1.35 g.). The total yield of the acid was thus (0.55 + 0.95 + 1.35 = 2.85 g.) ca. 64% on the basis of the unsaturated hydrocarbon. The acid crystallized from petroleum ether in rhombic plates, m.p. 93°, $[\alpha]_D^{25} -23.1^\circ$ (ethanol, c, 1.712).

Anal. Calcd. for $C_{11}H_{16}O_2$: C, 73.30; H, 8.95; neut. equiv., 180. Found: C, 73.59; H, 8.90; neut. equiv., 179.4.

It is interesting to note that during the Barbier-Wieland degradation of tricycloekasantalic acid, there is a reversal in the sign of optical rotation.

Methyl *nor*-Tricycloekasantalate (I. R = $CH_2-CO_2-CH_3$).—*nor*-Tricycloekasantalic acid (2.0 g.) was converted into its silver salt (2.7 g.) which gave, on treatment with methyl iodide (2.5 g.) in dry benzene (100 ml.), the corresponding methyl ester (1.6 g.), b.p. 102–104°/11 mm., $n_D^{24} 1.4720$.

Lactone of *nor*-Tricycloekasantalic Acid (XII).—Methyl *nor*-tricycloekasantalate (1.5 g.) was heated with 90% formic acid (13 ml.) at 110–115° for 75 min. The mixture, which was colorless in the beginning, acquired a faint violet coloration toward the end. It was cooled and poured into ice (ca. 50 g.) and the liberated solid was taken up in pet. ether (100 ml.) and the extract washed with water (2 × 25 ml.). The washings were added to the acidic layer and the mixture was neutralized with alkali, and then distilled. The fore-run was found to contain methanol, which was converted into formaldehyde and thence into the dimedone derivative; m.p. and mixed m.p. with an authentic sample

was 188°. The petroleum ether extract was shaken with 5% sodium carbonate (2 × 25 ml.). The alkaline washings gave, on acidification, a small amount (0.1 g.) of a viscous acidic product which was not examined. The neutral petroleum ether solution gave, on drying and removal of the solvent, a yellowish solid (1.01 g.), m.p. 154–158°, with previous shrinking from 140°. The product was refluxed with 10% ethanolic sodium hydroxide (15 ml.) for 15 hr. Ethanol was distilled off and the alkaline residue diluted with water (25 ml.) and extracted with ether. The clear alkaline solution was cooled in ice and then acidified with 4 *N* hydrochloric acid. The liberated material was taken up in ether (100 ml.) and then shaken with 5% sodium carbonate (2 × 50 ml.). The neutral petroleum ether solution was washed with water, dried, and freed from the solvent when a white solid, m.p. 160–162°, was obtained. On sublimation under reduced pressure it gave a white powder, m.p. 162–163°, which showed in the infrared a CO band at 1760 cm^{-1} ; yield 0.6 g.

Anal. Calcd. for $C_{11}H_{16}O_2$: C, 73.30; H, 8.95. Found: C, 73.21; H, 8.65.

The sodium carbonate extract was acidified under ice-cooling and the liberated product (0.27 g.) was isolated by extraction with ether. On distillation it gave a viscous acidic material which neither absorbed bromine nor gave any coloration with tetranitromethane. It possessed a borneol-like smell and gave the xanthate test for a secondary alcohol. On refluxing with 25% sulfuric acid it gave a small amount of a neutral solid, m.p. 76–78°, which was not further examined.

Reduction of the Lactone (XII) with Lithium Aluminum Hydride.—The lactone (0.55 g.), dissolved in dry ether (50 ml.), was added to a slurry of lithium aluminum hydride (0.8 g.) in ether (100 ml.) at room temperature. The mixture was heated under reflux for 7.5 hr. and then allowed to stand overnight. It was decomposed with ice and dilute hydrochloric acid. The reaction product (0.5 g.), obtained on removal of ether, was a viscous oil which solidified on cooling. A part of it was put on a porous plate, the solid left after absorption of the adhering material melted at 103–105°. The product was a mixture and probably contained some of the unchanged lactone which was removed by refluxing the mixture with alcoholic potassium hydroxide. The neutral product (0.45 g.), so obtained, gave, on crystallization from petroleum ether, shiny white plates, m.p. 112–113°.

Anal. Calcd. for $C_{11}H_{20}O_2$: C, 71.69; H, 10.94. Found: C, 71.70; H, 10.41.

Dehydration of the Diol, M.P. 112–113°.—The diol (0.32 g.) was refluxed with freshly distilled acetic anhydride (15 ml.) for 2 hr. The dehydrated material (0.19 g.) gave, on distillation, a yellowish white oil with a pleasant smell.

Anal. Calcd. for $C_{11}H_{18}O$: C, 79.46; H, 10.92. Found: C, 79.70; H, 10.86.

The substance gave a brown coloration with tetranitromethane, and decolorized a chloroform solution of bromine. On ozonolysis in ethyl acetate solution it gave formaldehyde which was characterized by the dimedone derivative.

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(15) F. Feigl, "Spot Tests in Organic Analysis," Elsevier Publishing Co., Amsterdam, 1956, p. 127.

(16) The formation of this diol in this way might be due either to the direct oxidation of the starting material, or due to an unusual mode of decomposition of the ozonide. In this connection, it is worth mentioning that *d*-limonene gave 1,8-cineol along with other expected products on a similar ozonolysis (A. Bhati, Ph.D. thesis, Agra University, 1952, p. 78).