

pressure and the product isolated by extraction into ethyl acetate (2 × 25 ml.). The ethyl acetate extracts were washed with 2% sodium hydroxide solution. The alkaline extracts were acidified and extracted with ethyl acetate. There was obtained 426 mg. of light brown oily acid which was crystallized from ether to product 236 mg. of material, m.p. 73–74°, with prior softening; infrared spectrum: 3.04 (broad) (OH) and broad ascending band 3.6–4.3 (OH of -COOH) and 5.86 μ (COOH) (mull). Two further crystallizations from ether gave an analytical sample of the diol acid XXXVIII, m.p. 77.0–77.8°.

Anal. Calcd. for $C_{15}H_{24}O_4$: C, 67.13; H, 9.02. Found: C, 67.43; H, 8.74.

The Action of Concentrated Hydrochloric Acid on Photosantonic Acid. (a) **Acidic Portion.**—A suspension of 280 mg. of photosantonic acid hydrate in 14 ml. of concentrated hydrochloric acid was stirred at room temperature for 20 hours and then diluted with 42 ml. of ice-water and extracted with ethyl acetate. The ethyl acetate was washed with two portions of 5% potassium carbonate solution. Acidification and isolation with ether gave 206 mg. of yellow oil. A concentrated chloroform solution of 188 mg. of this oil was placed on a column of acetone-washed silicic acid. Elution with chloroform gave 27 mg. of a yellow oil, intense λ_{max} 268 $m\mu$, followed by 100 mg. of solid with an ultraviolet spectrum characteristic of "dehydrophotosantonic acid" (weak peaks at 265–266 and 274 $m\mu$). Recrystallization of this material from benzene-hexane gave 37 mg. of material, m.p. 128.0–129.5°, mixture melting point with pure material, 132.2–134.2°. Elution of the column with 1–2% methanol-chloroform gave 50 mg. of yellow oil, intense λ_{max} 242 $m\mu$.

After 12 hours stirring with concentrated hydrochloric acid the approximate proportions of acids were 40 (λ_{max} 268 $m\mu$):68 (dehydrophotosantonic acid):32 (λ_{max} 242 $m\mu$).

(b) **Neutral Portion.**—The neutral material from four runs at 1, 2, 4.5 and 8 hours (using 1.129 g. of photosantonic acid hydrate), 321 mg., was recrystallized from ethyl

acetate-cyclohexane yielding 85 mg. of the dilactone XX as white needles, m.p. 218.5–220°; infrared spectrum: bands at 5.65 (broad) (2 γ -lactones) and 6.17 μ (C=C). Further crystallization gave an analytical sample, m.p. 224.7–225.3°.

Anal. Calcd. for $C_{18}H_{20}O_4$: C, 68.16; H, 7.63. Found: C, 68.51; H, 7.76.

Ozonization of the Dilactone XX.—Ozone (from a Welsbach Laboratory Ozonator) was passed through a cooled solution of 50 mg. of the dilactone in 5 ml. of acetic acid for 30 minutes. The solution was steam distilled into an aqueous solution of methone (1 hour). The pH of the distillate was adjusted to about 4.5 by the addition of 5% sodium hydroxide solution. After standing overnight at 10° the precipitate was removed by filtration and dried to constant weight. There was obtained 26.1 mg. (47%) of the methone derivative of formaldehyde, m.p. 186.5–190°, mixture m.p. 189–191.5°. The pot residue was extracted several times with chloroform. Evaporation left 45 mg. of nearly white crystals, m.p. 198–203°; infrared spectrum: bands at 5.65 μ (broad) (2 γ -lactones) and 5.86 μ (-C=O). The analytical sample was prepared by several recrystallizations from ethyl acetate-cyclohexane, m.p. 215.5–217.5° dec.

Anal. Calcd. for $C_{14}H_{18}O_6$: C, 63.14; H, 6.81. Found: C, 63.10; H, 6.73.

The norketone (10 mg.) was dissolved in water (0.1 ml.) and dioxane (0.2 ml.) and the solution made basic on addition of 3 *N* NaOH (0.2 ml.). Potassium iodide-iodine reagent was added until color persisted, followed by warming to 60° and the further addition of the reagent until the brown color lasted a full minute. Addition of 3 *N* NaOH to remove any persisting brown color and warming for 2 minutes followed by dilution with water (1 ml.) gave after standing, iodoform (7 mg., m.p. 120°, 45%), confirmed by m.p. and mixed m.p.

MADISON, WISC.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, SMITH COLLEGE]

The Structure of the Crystalline Cadinol from Citronella Oil

BY MILTON D. SOFFER, MARLENE BREY AND JANE FOURNIER

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The action of methylmagnesium iodide on the epoxide of the crystalline cadinol from citronella oil, followed by treatment with palladium-carbon under conditions inducing the elimination of the isopropyl group gives 1,2,5-trimethylnaphthalene, indicating in the light of previous evidence that the structure of the cadinol from citronella oil is represented by formula I.

In a recent communication¹ we have reported the conversion of the crystalline cadinol isolated by Plattner and Markus² from citronella oil to the reference compound agathalene, 1,2,5-trimethylnaphthalene. These reactions (I–IV) when taken together with the conversion² of the sequiterpene alcohol to cadinene dihydrochloride (V)³ provide evidence that the structure of the natural product is represented by formula I.

More recently Motl, Sykora, Herout and Šorm⁴ have reported the conversion of the same cadinol through a useful extension of the epoxide-Grignard-dehydrogenation method^{5,6–7} to 5-methylcadalene (VI), indicating the same gross structure, I.

(1) M. D. Soffer, M. Brey and J. Fournier, *Chemistry & Industry*, 19 (1958).

(2) P. A. Plattner and R. Markus, *Helv. Chim. Acta*, **25**, 1674 (1942).

(3) W. P. Campbell and M. D. Soffer, *This Journal*, **64**, 417 (1942).

(4) O. Motl, V. Sykora, V. Herout and F. Šorm, *Coll. Czechoslov. Chem. Commun.*, **23**, 1297 (1958).

(5) I. Ruzicka and L. Sternbach, *Helv. Chim. Acta*, **23**, 124 (1940).

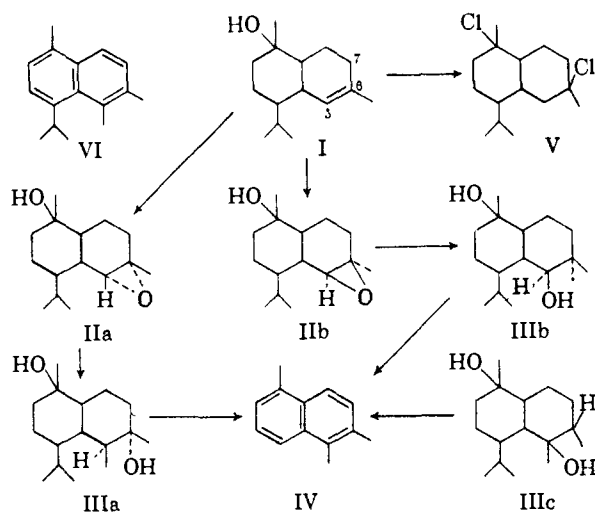
(6) M. D. Soffer, C. Steinhardt, G. Turner and M. E. Stebbins, *This Journal*, **66**, 1520 (1944).

In the present work, treatment of the crystalline cadinol with perbenzoic acid gave a product melting over a wide range (65–90°) which was assumed to be a mixture of stereoisomeric epoxides (IIa,b), but since it was thought that both isomers might serve as precursors to the same final degradation product no separation was attempted. The action of methylmagnesium iodide produced a new mixture of products, m.p. 196–204° from which in separate experiments one well defined dihydroxytetrahydro-methylcadinene, $C_{16}H_{28}(OH)_2$, m.p. 211–212.5°, could be isolated in about 30% yield. In previous applications of the method the isomers were usually not separated and it was assumed^{3,5–8} that in analogy with the Grignard addition to the oxides of acyclic olefins⁹ the reaction would produce pre-

(7) L. H. Briggs and W. I. Taylor, *J. Chem. Soc.*, 1338 (1947); L. H. Briggs, N. S. Gill, F. Lyons and W. I. Taylor, *ibid.*, 1098 (1949).

(8) M. Ehrenstein, *J. Org. Chem.*, **8**, 83 (1943).

(9) S. Winstein and R. B. Henderson in R. C. Elderfield's "Heterocyclic Compounds," John Wiley and Sons, Inc., New York, N. Y., Vol. I, 1950, p. 32; N. G. Gaylord and E. I. Becker, *Chem. Revs.*, **49**, 413 (1951); M. S. Kharasch and O. Reinmuth, "Grignard Reac-



dominantly a gross structure of the type IIIa rather than IIIb; but if the reaction proceeds under conformational control¹⁰ either of the two diaxial adducts (IIIa and b) would be formed, depending mainly upon the stereochemistry of the epoxide.^{11,12} Introduction of the methyl group at C₅ could also take place through the carbinols IIIc arising from the isomerization of the epoxide to the C₅-ketone^{8,9,11} in the Grignard reaction.

In the next step the whole diol, therefore, was dehydrated and dehydrogenated directly using an active preparation of palladium-carbon at 300–330°. It could be expected that these conditions would in addition induce the elimination of the isopropyl group^{13,14} which would offer the advantage that the resulting methyl homologs of 1,6-dimethylnaphthalene appeared in some cases to be better defined reference compounds¹⁵ than the corresponding homologs of cadalene. In these reactions it could be assumed that the non-quaternary methyl groups would remain intact¹⁴ and that in the particular case of 5-methylcadalene (VI) the elimination of the isopropyl group would be enhanced by the presence of the methyl groups in the C₅- and C₆-positions.^{14,16}

tions of Non-Metallic Substances," Prentice-Hall, Inc., New York, N. Y., 1954, pp. 961 ff.

(10) D. H. R. Barton and R. C. Cookson, *Quart. Revs. (London)*, **10**, 44 (1950).

(11) Compare the formation of the 5 α -hydroxy-6 β -methyl- and 6 β -hydroxy-5 α -methyl-3 β -cholestanol from cholesterol α - and β -oxides, respectively [L. F. Fieser and J. Rigaudi, *THIS JOURNAL*, **73**, 4660 (1958); R. B. Turner, *ibid.*, **74**, 5362 (1952); Y. Urishibara and M. Chuman, *Bull. Chem. Soc. Japan*, **22**, 69 (1949); C. A., **44**, 1124e (1950); M. Chuman, *J. Chem. Soc. Japan, Pure Chem. Sect.*, **70**, 253 (1949); C. A., **45**, 6051d (1951)].

(12) Our diol mentioned above may be the same as that obtained by Šorm and co-workers (m.p. 209–210°) to which the gross structure IIIb was assigned.⁴ From the foregoing discussion the C₄-hydroxyl is probably axial and the relative configuration of the oxide from which the diol was derived (m.p. 120–121°)⁴ and that of its stereoisomer (m.p. 84.5–85.5°)⁴ would be represented by IIb and IIa, respectively.

(13) R. P. Linstead, K. O. A. Michaelis and S. L. S. Thomas, *J. Chem. Soc.*, 1139 (1940).

(14) W. Cocker, B. E. Cross and J. McCormick, *ibid.*, 72 (1952); W. Cocker, B. E. Cross, J. T. Edward, D. S. Jenkinson and J. McCormick, *ibid.*, 2355 (1953).

(15) P. A. Plattner, E. Heilbronner and U. Frohlicher, *Helv. Chim. Acta*, **32**, 2479 (1949).

(16) The formation of these hydrocarbons from diol IIIb would require a "retropinacolone" (Meerwein) type rearrangement during the reaction: cf. P. A. Plattner in "Newer Methods of Preparative Organic Chemistry," Interscience Publishers, Inc., New York, N. Y., 1948, p. 21.

The dehydrogenation product, 1,2,5-trimethylnaphthalene, was isolated in the form of its trinitrobenzene derivative, m.p. 160–160.5° (reported 159.5–160°,¹⁷ 159–160°¹⁸) and was identified by the characteristic ultraviolet absorption spectra of the regenerated hydrocarbon¹⁶ and by the m.p. and the mixed m.p. (139–140°) of the picrate (reported, 137°,¹⁷ 138°,¹⁹ 139–140°^{18,20}) prepared from the latter. The identification is further supported by the fact that the melting points of these derivatives of 1,2,5-trimethylnaphthalene are in each case distinctly higher than those recorded for the corresponding derivatives of all the other isomeric hydrocarbons containing the 1,6-dimethyl residue of cadalene.

Motl, Sykora, Herout and Šorm⁴ have reported that the TNB derivative of their dehydrogenation product, 5-methylcadalene, has a quite different melting point (112–112.5°) from that recorded in the literature (160–161°) for the synthetic hydrocarbon.²¹ We have had occasion to examine an authentic sample of this derivative noting that the conditions used in the final step in the synthesis of the hydrocarbon (Se, 320°) might be expected to induce at least partial elimination of the isopropyl group,^{3,14,22} and that the reported melting points of three of its four derivatives²¹ correspond closely to those of 1,2,5-trimethylnaphthalene (*i.e.*, for the two hydrocarbons, respectively, TNB 160–161°, 160–160.5°; TNT 87–88°, 90–90.5°¹⁷; styphnate, 130–131°, 130–131°.²³ It was found by mixed m.p., analyses and the absorption spectra of the regenerated hydrocarbon¹⁶ that this TNB derivative is in fact that of 1,2,5-trimethylnaphthalene. On the other hand, the picrate (m.p. 102.5–103.5°)²¹ which we have also examined, gave good analyses²⁴ and is clearly different from that of 1,2,5-trimethylnaphthalene. The synthetic liquid hydrocarbon, in spite of its satisfactory carbon-hydrogen analyses, must have been a mixture of the two naphthalenes.²⁴

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Experimental²⁵

α -²⁶Cadinol *p*-Nitrobenzoate.—Commercial citronella oil of Javanese origin (1521 g.) was stripped of volatile material

(17) L. Ruzicka, K. Hoffman and H. Schellenberg, *Helv. Chim. Acta*, **19**, 1931 (1936).

(18) W. Cocker, B. E. Cross, S. R. Duff, J. T. Edward and T. F. Holly, *J. Chem. Soc.*, 2540 (1953).

(19) L. Ruzicka and F. Lardon, *Helv. Chim. Acta*, **29**, 912 (1946).

(20) D. H. R. Barton, J. F. McGhie, M. K. Pradhan and S. A. Knight, *J. Chem. Soc.*, 876 (1955).

(21) S. Dev, *J. Indian Chem. Soc.*, **25**, 69 (1948).

(22) L. Ruzicka, L. Bhmann and E. Morgeli, *Helv. Chim. Acta*, **16**, 325 (1933).

(23) L. Ruzicka and A. H. Lamberton, *ibid.*, **23**, 1338 (1940).

(24) No analyses were reported²¹ on the synthetic hydrocarbon derivatives and they were not correlated by interconversion. It is relevant in the discussion that C and H analyses distinguish homologous hydrocarbons in this series only weakly, and that the same is true for N (but not for C) in the case of the derivatives.

(25) Melting points are corrected; boiling points are not. We are indebted to Elinor Hedden and Roberta Kurtz for aid in certain parts of this work.

(26) We are following here the designation suggested by Šorm and co-workers.⁴

(b.p. 24° (19 mm.) to 99° (9.5 mm.)) and the remainder, 849 g., was freed from 39 g. of tarry residue by a rapid distillation through a Claisen flask at 0.7 mm., before fractionation through a 6-plate modified Widmer column. The cadinol-containing fractions, 54.5 g., b.p. 97–112° (0.2 mm.), were best recognized by their indices of refraction (n_D^{20} 1.4982–1.4988), which were higher than those of the preceding fractions (739 g., b.p. 49–97° (0.2 mm.), n_D^{20} 1.4574–1.4946) and of the fractions following (9.2 g., b.p. 112–155° (0.2 mm.), n_D^{20} 1.4890–1.4942).

The cadinol fraction was treated with 85 g. of *p*-nitrobenzoyl chloride in 350 ml. of anhydrous pyridine according to the procedure of Plattner and Markus² and the oily neutral fraction was chromatographed on 1200 g. (100 cm.) of alumina (Alcoa). After thorough removal of non-crystalline material with petroleum ether (b.p. 35–60°), elution with 5:1 ether-petroleum ether gave a semi-crystalline product (18.9 g.) which was recrystallized four times from absolute ethanol; 3.41 g., m.p. 137–138°, $[\alpha]_D^{24}$ –83.1 (chf., *c* 1.1) (reported m.p. 136°,² 138°,⁴ 139°;⁴ $[\alpha]_D$ –67.4°,⁴ –77°;⁴ –6.76°;² the last value² should probably be –67.6°). The substance crystallizes in delicate glistening leaflets from 95% ethanol and in long well formed needles from absolute ethanol or petroleum ether.

Anal. Calcd. for $C_{22}H_{23}NO_4$ (371.46): C, 71.13; H, 7.87. Found: C, 71.35, 71.13; H, 7.91, 7.99.

α -Cadinol.—A mixture of 2.42 g. of the foregoing ester and a solution of 5 g. of potassium hydroxide in 50 ml. of methanol was refluxed under nitrogen for four hours, diluted with water, and worked up for the neutral fraction in the usual manner. On removal of solvent the oily residue solidified in feathery snow-white crystals, 1.43 g., m.p. 74–74.5°. A small sample sublimed at 0.06 mm. (bath temp. 55°), had m.p. 74.5–75° (reported 72.5°,² 74.5°⁴).

Dihydroxytetrahydromethylcadinene (IIIa, b or c).—A solution of 0.88 g. of α -cadinol in 20 ml. of dry chloroform was mixed at 5° with 100 ml. of a 0.2 *M* chloroform solution of perbenzoic acid. The mixture was allowed to stand at 5° for three hours when periodic titrations of aliquots indicated that the reaction was complete (95%). After the treatment described,^{1,6} removal of chloroform through a short column at reduced pressure left a soft crystalline solid, 0.91 g., m.p. 65–90°, which could be crystallized only inefficiently from petroleum ether, and was considered to be a mixture of the stereoisomeric epoxides.

The whole product above (0.90 g.) was stirred and refluxed under nitrogen for 48 hours with the Grignard reagent prepared from 1.65 g. of magnesium, 10.00 g. of methyl iodide and 150 ml. of dry ether. After decomposition with ice and saturated ammonium chloride the washed and dried (sodium sulfate) ether extract yielded 0.87 g. of the crude colorless carbinol, m.p. 196–204°, which was used directly in next step.

In preliminary experiments 0.09 g. of the same product gave on three recrystallizations from aqueous ethanol 0.03 g. of one pure isomer, m.p. 211–212.5°.

Anal. Calcd. for $C_{18}H_{23}(OH)_2$ (254.40): C, 75.53; H, 11.89; active H, 0.79. Found: C, 75.42, 75.31; H, 11.83, 11.53; active H, 0.83, 0.96.

1,2,5-Trimethylnaphthalene.—The crude carbinol was heated in a 30'' tube with 0.45 g. of freshly prepared¹³ 30% palladium-carbon²⁷ at 300–330° until after two hours the evolution of gaseous products subsided. The product was taken up in ether, filtered, washed with 5% sodium hydroxide solution, dried over anhydrous sodium sulfate, passed through a short tube of alumina, and the solvent was removed through a 15'' helix-packed column. The almost colorless oily residue, 0.48 g., gave with 1,3,5-trinitrobenzene in methanol the crude derivative, 0.21 g., m.p. 128–146°, from which the pure product was obtained after five recrystallizations in well defined bright yellow needles, 0.051 g., m.p. 160–160.5°.

Anal. Calcd. for $C_{18}H_{17}O_3N_3$ (383.35): C, 59.53; H, 4.47; N, 10.96. Found: C, 59.66, 59.60; H, 4.64, 4.55; N, 10.96, 11.10.

The ultraviolet absorption spectrum of the hydrocarbon regenerated on alumina (Woelm, basic, activity I) from 2.15 mg. of the TNB derivative by the exact method of Plattner, Heilbronner and Frohlicher¹⁶ was identical with that recorded¹⁶ for 1,2,5-trimethylnaphthalene. Using the same method on a larger scale the hydrocarbon was regenerated from 22 mg. of the TNB derivative eluting with fractionated¹⁶ petroleum ether (b.p. 31–32°) and finally with 1:5 ether-petroleum ether. Removal of the solvent through a 60-plate Heligrad column and treatment with picric acid in methanol gave after one recrystallization the bright orange-red picrate, m.p. 139–140°, unchanged by admixture with an authentic²⁰ sample.

5-Methylcadalene Derivatives.—A sample of the reported trinitrobenzene derivative of synthetic 5-methylcadalene²¹ melted at 160–161° and when mixed with the corresponding derivative of 1,2,5-trimethylnaphthalene, above, melted at 160–160.5°. When a portion of the same sample²¹ was mixed with the corresponding derivative of 2-methylcadalene³ (m.p. 168.5–169°) the m.p. was 138–142°. Similarly the mixed melting point with the T.N.B. derivative of 3-methylcadalene²¹ (m.p. 165–165.5°) was 137–144°.

Anal. Calcd. for $C_{19}H_{17}N_3O_6$ (383.35): C, 59.53; H, 4.47. Found: C, 59.78, 59.59; H, 4.67, 4.44.

The ultraviolet absorption spectrum of the hydrocarbon regenerated¹⁶ as before was identical with that of 1,2,5-trimethylnaphthalene.

The picrate (m.p. 103–104°)²¹ gave good analyses for the derivative of 5-methylcadalene.

Anal. Calcd. for $C_{22}H_{23}N_3O_7$ (441.43): C, 59.86; H, 5.25. Found: C, 60.19, 60.29; H, 5.52, 5.51.

The 7-methylcadalene TNB derivative was prepared from the pure hydrocarbon³ for purposes of comparison and to complete in the literature the series of TNB derivatives of the methylcadalenes.^{3,4,21} The substance crystallized from methanol in yellow-orange needles, m.p. 126–126.5°.

Anal. Calcd. for $C_{22}H_{23}N_3O_6$ (425.43): N, 9.88. Found: N, 9.72.

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(27) R. P. Linstead and S. L. S. Thomas, *J. Chem. Soc.*, 1127 (1940).