hexanone ring in I and III is present in a chair conformation essentially free of bond-angle distortion.

### Experimental

**3-Keto-*trans*-2-*o*-tolylcyclohexylacetic Acid (I).**—The synthesis of this compound has been reported by Klibansky and Ginsburg[6] through a Michael addition of potassium dibenzyl malonate with 3-keto-2-*o*-tolylcyclohexene. The method used in the present work varies from the method of Klibansky and Ginsburg only in using catalytic hydrogenation in the debenzylation step, a method described[7] for the synthesis of the phenyl analog. The keto acid was obtained in 51% yield starting with 10 g. of 3-keto-2-*o*-tolylcyclohexene. It was found to crystallize in polymorphic forms. Crystallization from benzene gave a crystalline material, m.p. 62–65°, while crystallization from isopropyl alcohol gave m.p. 101–102° (m.p. 102–103° was reported from heptane[6]). There were considerable differences in the finger-print region of the infrared spectra of the two polymorphs when determined in the solid state in potassium bromide pellets, but their infrared spectra were identical when measured in carbon tetrachloride solution, 0.3 *M* in 0.1-mm. pathway cell. The low-melting form gave a neutralization equivalent of 246.8. The calculated value is 246.29.

*Anal.* Calcd. for $C_{15}H_{18}O_3$ (m.p. 101–102°): C, 73.14; H, 7.37. Found: C, 73.16; H, 7.43.

The methyl and ethyl esters, II and III, were prepared by direct esterification catalyzed by sulfuric acid: II, m.p. 84–85°, crystallized from benzene (lit.[6] m.p. 77–78° from ethanol); III, m.p. 38–39°, crystallized from hexane.

*Anal.* Calcd. for $C_{16}H_{20}O_3$ (II): C, 73.82; H, 7.74. Found: C, 74.14; H, 7.56.

*Anal.* Calcd. for $C_{17}H_{22}O_3$ (III): C, 74.42; H, 8.08. Found: C, 74.84; H, 8.28.

***cis*-3-Hydroxy-*trans*-2-*o*-tolylcyclohexylacetic Acid (IV).**—A solution of 3.0 g. (0.012 mole) of 3-keto-*trans*-2-*o*-tolylcyclohexylacetic acid (I) in 10 ml. of 5% sodium hydroxide was added, with stirring, to 0.45 g. (0.012 mole) of sodium borohydride in 10 ml. of a saturated sodium carbonate solution. After stirring for several minutes, the resulting milky mixture cleared up. The reaction was stirred for 24 hr. at room temperature. Dilute sulfuric acid was then added dropwise to destroy the excess sodium borohydride. The mixture was then extracted with ether and the ether phase was extracted with 10% sodium bicarbonate solution. The basic aqueous solution was then acidified and extracted repeatedly with ether. The ether phase was washed with water and dried over anhydrous sodium sulfate. Removal of the solvent yielded 2.1 g. of solid material and a small amount of oily substance. Recrystallization of the solid material from a boiling solution of benzene with enough isopropyl alcohol to clarify the solution gave 1.9 g. (63.5%) of a white crystalline material, m.p. 146–147°. The neutralization equivalent of the hydroxy acid IV was found to be 248.5 (calculated 248.31).

*Anal.* Calcd. for $C_{15}H_{20}O_3$: C, 72.55; H, 8.12. Found: C, 72.46; H, 8.08.

The infrared spectrum of the hydroxy acid had two bands in the carbonyl region, 1720 and 1690 cm.$^{-1}$, when determined in the solid state in potassium bromide pellet, but when measured in carbon tetrachloride solution a single carbonyl band was present at 1720 cm.$^{-1}$. This implies that in the crystalline state all carbonyl oxygen atoms of the carboxyl groups are not associated through identical hydrogen bonds.

**Methyl *cis*-3-Acetoxy-*trans*-2-*o*-tolylcyclohexylacetate (VI).**—The methyl ester V was prepared by direct esterification of IV with methanol. The ester was a viscous liquid, b.p. 136–140° at 1.25 mm., which did not crystallize. Gas chromatography analysis on a 5-ft. Dow silicone QF-1 column showed only one component. The hydroxy methyl ester V was acetylated by refluxing with acetic anhydride in pyridine for 1 hr. A solution of 0.75 g. (0.003 mole) of V in 5 ml. of pyridine and 2 ml. of acetic anhydride yielded 0.6 g., 69%, of colorless crystalline product after recrystallization from hexane with m.p. 101.5–102.5°.

*Anal.* Calcd. for $C_{18}H_{24}O_4$: C, 71.03; H, 7.94. Found: C, 71.00; H, 7.86.

***trans*-2-*o*-Tolyl-*cis*-3-(2-hydroxyethyl)cyclohexanol (VII) and *trans*-2-*o*-Tolyl-*cis*-3-(2-acetoxyethyl)acetoxycyclohexane (VIII).**—The diol VII was prepared by lithium aluminum hydride reduction of the keto ester II, the hydroxy acid IV, and the acetoxy methyl ester VI. The reactions were carried out in anhydrous ether by adding an ether solution of the compound to the lithium aluminum hydride–ether mixture at such a rate as to cause gentle refluxing of the ether. The mixture was then stirred at room temperature: 2 hr. for II, 24 hr. for IV, and 16 hr. for VI. The excess lithium aluminum hydride was destroyed by addition of ethyl acetate followed by water. The mixture was poured into water, acidified to dissolve the aluminum hydroxide, and extracted with ether. The ether solution was washed successively with sodium bicarbonate solution and water, then dried over anhydrous sodium sulfate. Removal of the solvent gave a very viscous material which could not be induced to crystallize. No elementary analysis was determined on the diol since the same crystalline diacetoxy derivative was readily obtained from the diol produced from the reduction of II, IV, and VI.

The diacetoxy derivative (VIII) was obtained by heating the diol VII at reflux temperature with an excess of acetic anhydride in pyridine. The product, m.p. 85–86.5°, was recrystallized from petroleum ether. The infrared spectrum of the solid in potassium bromide pellet had a sharp carbonyl stretching band at 1725 cm.$^{-1}$ and showed no hydroxyl stretching band.

*Anal.* Calcd. for $C_{19}H_{26}O_4$: C, 71.67; H, 8.23. Found: C, 71.89; H, 8.29.

All melting points were determined with a Kofler micro hot stage. The n.m.r. spectra were obtained with a Varian HR-60 spectrometer.

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[7] E. D. Bergman, D. Ginsburg, and R. Pappo, *Org. Reactions*, **10**, 179 (1959).

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## The Synthesis of a Model Perhydroazulene Derivative

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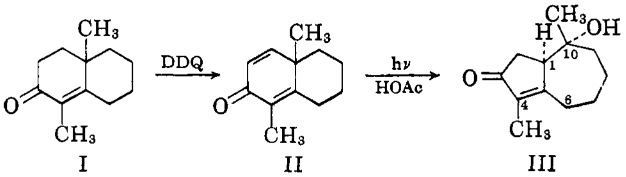
*Received April 13, 1964*

The photochemical rearrangement of 4-methyl-substituted (steroid numbering), cross-conjugated cyclohexadienones in aqueous acidic media to give perhydroazulene derivatives is well known.[1] We wish to report the synthesis of the model 5–7-fused ring system III in *ca.* 80% yield by irradiation of the cross-conjugated cyclohexadienone II,[2] related to santonin, in 45% aqueous acetic acid.

The cyclohexadienone II was obtained by treatment of the octalone I[3] with 2,3-dicyano-5,6-dichlorobenzoquinone in benzene according to the general procedure of Burn, Kirk, and Petrow.[4] On irradiation of II in 45% aqueous acetic acid at room temperature, chromatography of the product on silica gel, and evaporation of the elution solvents, III was obtained as an oil which crystallized on standing. This material showed absorption at 243 mμ and at 2.90, 5.95, and 6.17 μ. These



I II III

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[1] P. de Mayo and S. T. Reid, *Quart. Rev.* (London), **15**, 393 (1961).

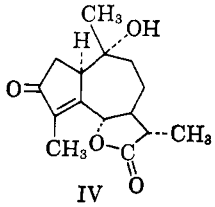
[2] *Cf.* L. Mandell, D. Caine, and G. E. Kilpatrick, *J. Am. Chem. Soc.*, **83**, 4457 (1961), and references therein.

[3] The authors are grateful to Dr. M. R. Willcott, III, and Mr. G. H. Beasley for providing us with a method they developed for the synthesis of I. For other published methods for the synthesis of I, see M. Yanagita and R. Futaki, *J. Org. Chem.*, **21**, 949 (1956), and references therein.

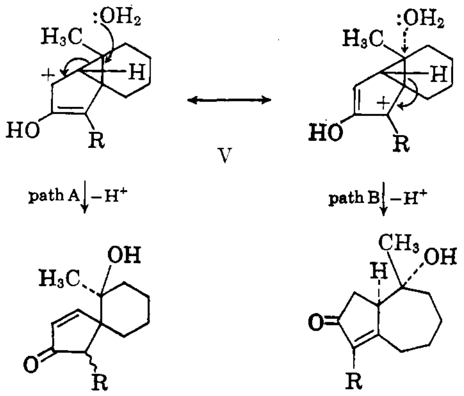
[4] D. Burn, D. N. Kirk, and V. Petrow, *Proc. Chem. Soc.*, 14 (1960).

absorptions correspond closely with those reported for isophotosantonic acid lactone (IV)[5] and for an analogous rearrangement product obtained from 1,2-dehydro-4-methyltestosterone acetate.[6] The n.m.r. spectrum of III showed peaks at $\tau$ 8.35 (multiplet) and 9.09 (singlet) corresponding to the methyl groups at C-4 and C-10, respectively, and no vinyl protons. The signal at $\tau$ 8.35 was broadened and showed fine structure presumably as a result of homoallylic coupling[7] between the C-4 methyl group and the hydrogens at C-1 and C-6. The stereochemistry of III at C-1 and C-10 is assigned by analogy with isophotosantonic lactone.[8a,b]

Formation of III can be depicted as occurring *via* the cleavage of the polar intermediate V (R = CH$_3$) proposed by Zimmerman and Schuster[9] according to path B.



IV



V

VI

VII

Recent comprehensive studies on the photochemistry of C-4-unsubstituted dienones by Kropp and Erman[10] and by Kropp[11] have demonstrated that in aqueous acidic media such compounds yield roughly equal amounts of spiro ketones of the type VI (R = H) and perhydroazulene such as VII (R = H). This result has been rationalized[10,11] by noting that with C-4-unsubstituted cyclohexadienones, cleavage of the intermediate V (R = H) can occur with equal facility by either path A or B. Although small amounts of unidentified products in addition to III were obtained on irradiation of II, none of these showed spectral properties attributable to spiro ketones of the type VI (R = CH$_3$). Thus, as with analogous 4-methylcyclohexadienones,[5,6] rearrangement of II *via* path B predominates.

Barton[12] has pointed out the potential value of the photochemical rearrangement of C-4-substituted, cross-conjugated cyclohexadienones for the synthesis of perhydroazulene sesquiterpenoids, and 8-epiisophotoartemisic lactone acetate has been converted to geigerin acetate[8b] and O-acetylisophotosantonic lactone to epicyclocolorenone.[13] The high yield observed in the photochemical conversion of II to III further illustrates the value of this reaction for the synthesis of 5–7-fused ring systems having the structural features exhibited by III.[14]

## Experimental[15]

**1,4a-Dimethyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (I).**[3]—To a solution prepared from 52.5 g. (0.47 mole) of 2-methylcyclohexanone (b.p. 162–164°) in 450 ml. of freshly distilled dimethyl sulfoxide was added 13.25 g. (0.55 mole) of sodium hydride as a 53% oil dispersion and 0.30 g. of hydroquinone. The reaction mixture was stirred under nitrogen until the evolution of hydrogen had ceased (*ca.* 15 min.) and a solution of 1-diethylamino-3-pentanone methiodide (prepared from 25.0 g., 0.16 mole, of 1-diethylamino-3-pentanone and 25.0 g., 0.18 mole, of methyl iodide) in 25 ml. of dimethyl sulfoxide was added dropwise with stirring over 25 min. When the addition was complete the bright yellow reaction mixture was immediately diluted with 200 ml. of water and acidified to pH 3 with dilute hydrochloric acid. The aqueous solution was extracted with three 100-ml. portions of ether and the combined ethereal extracts were washed with saturated sodium bicarbonate to neutralize the excess acid, and with saturated sodium chloride solution. The ethereal solution was dried over anhydrous magnesium sulfate and the solvent was removed under reduced pressure. Distillation of the residue gave 11.5 g. (40%) of I: b.p. 85–90° at 0.25 mm. (lit.[3] b.p. 99–100° at 1 mm.); $\lambda_{max}$ 5.98 and 6.20 $\mu$; n.m.r. spectrum (carbon tetrachloride), $\tau$ 8.79 (s,[16a] 3,[16b] CH$_3$-4a) and 8.33 (s, 3, CH$_3$-1).

**1,4a-Dimethyl-5,6,7,8-tetrahydro-2(4aH)-naphthalenone (II).**—A solution of 6.00 g. (0.034 mole) of I and 8.85 g. (0.039 mole) of 2,3-dicyano-5,6-dichlorobenzoquinone in 200 ml. of dry benzene was refluxed under nitrogen for 42 hr. After about one-half the solvent had been removed under reduced pressure, the mixture was cooled to 10° and the precipitate of quinol was removed by filtration. The filtrate was then evaporated to dryness and the residue was chromatographed on 150 g. of alumina. Elution with 1000 ml. of pentane, 1000 ml. of 5% ether–pentane, and 500 ml. of 15% ether–pentane gave mixtures of the starting material I and the dienone II as shown by infrared analysis and thin layer chromatography. Elution with an additional 500 ml. of 15% ether–pentane and 1000 ml. of 30% ether–pentane gave 2.25 g. (40%) of pure dienone II: infrared and ultraviolet absorptions identical with those previously reported[2]; n.m.r. spectrum (carbon tetrachloride), $\tau$ 3.30 and 3.93 (2d, 2, $J_{AB}$ = 10 c.p.s., CH-4 and CH-3), 8.17 (s, 3, CH$_3$-1), and 8.77 (s, 3, CH$_3$-4a).

**3,8β-Dimethyl-4,5,6,7,8,8aα-hexahydro-8α-hydroxy-2(1H)-azulenone (III).**—The irradiation of II was carried out with a Hanovia 450-w. high-pressure mercury vapor lamp in an apparatus similar to that described by Kropp and Erman[10] except that a quartz water-jacketed immersion well was used to house the lamp. A solution of the dienone II, 1.50 g. (0.0085 mole), in 225 ml. of 45% aqueous acetic acid was irradiated for 90 min. while stirred vigorously with a stream of nitrogen. The temperature of the reaction mixture was kept at 20–25° by adjusting the

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[5] D. H. R. Barton, P. de Mayo, and M. Shafiq, *J. Chem. Soc.*, 929 (1957).

[6] K. Weinberg, E. C. Utzinger, D. Arigoni, and O. Jeger, *Helv. Chim. Acta*, **43**, 236 (1960).

[7] J. T. Pinhey and S. Sternhall, *Tetrahedron Letters*, **No. 4**, 275 (1963).

[8] (a) J. D. M. Asher and G. A. Sim, *Proc. Chem. Soc.*, 111 (1962); (b) D. H. R. Barton, T. Miki, J. T. Pinhey, and R. J. Wells, *ibid.*, 112 (1962).

[9] H. E. Zimmerman and D. I. Schuster, *J. Am. Chem. Soc.*, **84**, 4527 (1962).

[10] P. J. Kropp and W. F. Erman, *ibid.*, **85**, 2456 (1963).

[11] P. J. Kropp, *ibid.*, **85**, 3779 (1963).

[12] D. H. R. Barton, *Helv. Chim. Acta*, **42**, 2605 (1959).

[13] G. Buchi and H. J. E. Loewenthal, *Proc. Chem. Soc.*, 280 (1962).

[14] NOTE ADDED IN PROOF.—After this work had been submitted for publication we learned that Dr. Paul J. Kropp had performed a similar synthesis of III. *Cf.* P. J. Kropp, *J. Org. Chem.*, **29**, 3110 (1964).

[15] Ultraviolet spectra were determined in 95% ethanol, using a Cary Model 14 spectrophotometer, and infrared spectra were determined in chloroform solution on a Perkin-Elmer Infracord spectrophotometer. Nuclear magnetic resonance spectra were obtained in carbon tetrachloride or deuteriochloroform solution with a Varian Model A-60 spectrometer, using tetramethylsilane as an internal standard. Melting points and boiling points are uncorrected. Microanalyses were performed by Galbraith Laboratories, Inc., Knoxville, Tenn.

[16] (a) Multiplicity (s = singlet, d = doublet, and m = multiplet); (b) integration.

rate of flow of cold water through the quartz water jacket. The reaction mixture was then diluted with an equal volume of toluene, which dissolved a yellow polymeric material formed during the irradiation and concentrated to dryness under reduced pressure. Chromatography of the residue on activated silica gel gave, on elution with 500 ml. of hexane and 1000 ml. of 1:4 ether–hexane, a small amount of solid and an oily polymeric material which had no well-defined spectral characteristics.

Further elution with 1000 ml. each of 1:3 and 1:2 ether–hexane gave 0.20 g. of an unidentified oil which thin layer chromatography showed to be composed of one component. The n.m.r. spectrum of this material showed no vinyl protons which appeared to rule out the possibility of its being a spiro compound of the type VI ($R = CH_3$).

Finally, elution with 1000 ml. each of 2:1, 3:1, and 4:1 ether–hexane and with 1000 ml. of ether gave 1.34 g. (81%) of III as an oil which crystallized on standing, m.p. 96.5–98.0°. Recrystallization from diethyl ether gave colorless needles: m.p. 97.2–99.0°; $\lambda_{\max}$ 243 mμ (ε 13,300) and $\lambda_{\max}$ 2.90, 5.95, and 6.17 μ; n.m.r. spectrum (deuteriochloroform), τ 8.35 (m, 3, $CH_3$-3) and 9.09 (s, 3, $CH_3$-8).

*Anal.* Calcd. for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.31; H, 9.37.

**Acknowledgment.**—Support of this research by a Frederick Gardner Cottrell grant-in-aid from the Research Corporation is gratefully acknowledged.

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## Photochemical Rearrangements of Cross-Conjugated Cyclohexadienones. V. A Model for the Santonin Series[1]

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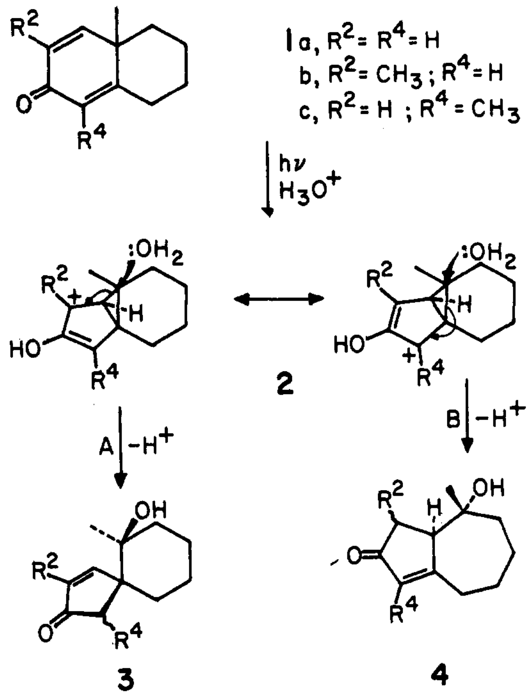
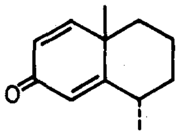
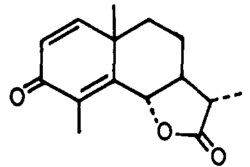
*Received May 25, 1964*

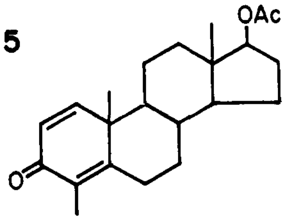
The principal course of the photochemical rearrangements of cross-conjugated cyclohexadienones of type **1** in aqueous, acidic media is hydroxy ketone formation; normally either a spiro ketone (**3**), a perhydroazulenone (**4**), or a mixture of the two is formed. In previous papers of this series, we reported that the type of hydroxy ketone photoproduct produced is influenced by the presence or absence of alkyl substituents on ring A of the dienone. Thus the 2-methyldienone **1b** (steroid numbering system) gave almost exclusively a spiro ketone (**3b**),[1] whereas the unsubstituted dienone **5** gave both a spiro ketone (type **3a**) and a perhydroazulenone (type **4a**) in approximately equal amounts.[2] Comparison of these results with the previous findings that the 4-methyldienones santonin (**6**)[3] and the steroid **7**[4] were converted predominantly to a perhydroazulenone (type **4c**) led to the conclusion that a cyclopropyl intermediate (**2**) is a common precursor to both types of product (with the direction of cleavage being controlled principally by the electronic effects of the substituents at C-2 and C-4).[2]



However, recent findings that the lactone ring of santonin markedly influences some of its photochemical[5a] and related chemical properties[5b] made it of interest to demonstrate that a bicyclic 4-methyldienone, lacking the additional rings of **6** and **7**, exhibits analogous behavior. This has now been found to be the case with the model dienone **1c**.


**5**


**6**



**7**

The dienone **1c**[6] was prepared by oxidation of the octalone **8**[6a,c,7] with 2,3-dichloro-5,6-dicyanobenzoquinone. Irradiation of **1c** in 45% acetic acid gave in 65–70% yield a hydroxy ketone to which the perhydroazulenone structure **4c** could be assigned on the basis of spectral data and by analogy to the formation of similar products from **6** and **7**. No evidence for the formation of any significant amount of the spiro ketone **3c** could be detected.

The hydroxy ketone **4c** exhibited typical absorption at 5.92 (conjugated C=O) and 6.14 μ (C=C) and at 242 mμ (ε 14,400). The n.m.r. spectrum verified the absence of any olefinic protons and showed the

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[1] For part IV, see P. J. Kropp, *J. Am. Chem. Soc.*, in press.

[2] P. J. Kropp and W. F. Erman, *ibid.*, **85**, 2456 (1963).

[3] D. H. R. Barton, P. de Mayo, and M. Shafiq, *J. Chem. Soc.*, 929 (1957); D. Arigoni, H. Bosshard, H. Bruderer, G. Büchi, O. Jeger, and L. J. Krebaum, *Helv. Chim. Acta*, **40**, 1732 (1957); J. D. M. Asher and G. A. Sim, *Proc. Chem. Soc.*, 111 (1962).

[4] K. Weinberg, E. C. Utzinger, D. Arigoni, and O. Jeger, *Helv. Chim. Acta*, **43**, 236 (1960).

[5] (a) *Cf.* discussion in P. J. Kropp, *J. Am. Chem. Soc.*, **85**, 3779 (1963); (b) unpublished data from these laboratories.

[6] (a) F. D. Gunstone and R. M. Heggie, *J. Chem. Soc.*, 1437 (1952); (b) P. R. Hills and F. J. McQuillin, *ibid.*, 4060 (1953); (c) M. Yanagita and R. Futaki, *J. Org. Chem.*, **21**, 949 (1956); (d) M. Yanagita, S. Inayama, M. Hirakura, and F. Seki, *ibid.*, **23**, 690 (1958); (e) L. Mandell, D. Caine, and G. E. Kilpatrick, *J. Am. Chem. Soc.*, **83**, 4457 (1961).

[7] F. J. McQuillin, *J. Chem. Soc.*, 528 (1955); J. K. Chakrabarti, P. Dutt, and P. C. Dutta, *ibid.*, 4978 (1956); M. Yanagita, M. Hirakura, and F. Seki, *J. Org. Chem.*, **23**, 841 (1958).