Isolation of 16 *via* NBS Bromination of 2-Methyl-4,5-dihydrofuran with Peroxide.—To a 500-ml flask fitted with stirrer and condenser was added 25 g (0.03 mol) of 2-methyl-4,5-dihydrofuran in 200 ml of benzene. To this was added a small amount of benzoyl peroxide and then, with stirring, 53 g (0.3 mol) of N-bromosuccinimide (NBS) slowly, keeping the temperature below 35°. After stirring for 1 hr at room temperature, the mixture was cooled to 10°, filtered, diluted to 600 ml with ethyl acetate in a 1-l. flask, and treated with 79 g of triphenylphosphine in 200 ml of ethyl acetate, dropwise. The temperature was then brought to reflux and held for 24 hr. Filtration gave a solid which had mp 270–271° dec and was shown to be **16** by its infrared spectrum, tlc, and mixture melting point.

Hydrolysis of 21.—To a 250-ml flask fitted with stirrer and reflux condenser was added 7.0 g (0.017 mol) of **21** in 100 ml of aqueous ethanol. To this was added 0.9 g (0.017 mol) of KOH in aqueous ethanol. The mixture was refluxed for 12 hr, added to 500 ml of H_2O, and extracted with ether. The ether was washed, dried, and concentrated to give a 1.1 g (65% yield) of a mixture of 15/85 2-methyl-4,5-dihydrofuran and 2-methylfuran, respectively, as shown by vpc.

Registry No.—**3**, 18138-76-6; **4a**, 18138-77-7; **4b**, 18138-78-8; **4c**, 18138-79-9; **5a**, 2429-96-1; **9c**, 18138-81-3; **9d**, 18138-82-4; **9e**, 18138-83-5; **10a**, 2430-16-2; **11**, 18138-85-7; **16**, 18138-86-8; **17a**, 18138-87-9; **18**, 18138-88-0; **21**, 18153-52-1.

Acknowledgment.—This work was supported, in part, by a grant (PRF 2032-Al) from the Petroleum Research Fund of the American Chemical Society, by a Public Health Service Predoctoral Fellowship (to E. T. Shaffer), and by a Public Health Service Grant (9R01 CA 11000-04) for which we are most grateful.

Notes

Bridged Ring Compounds. XVI.[1] Stereoselectivity in Epoxidation of Bicyclic Anhydrides[2]

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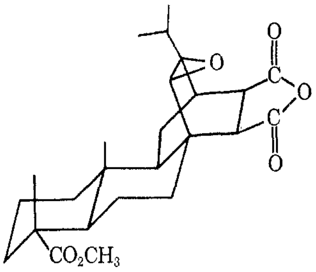
Recently, we reported that, both on ozonlysis and on treatment with trifluoroperacetic acid, methyl maleopimarate gave the *syn*-epoxide I.[3] It was suggested that the stereospecificity observed might be due to formation of an intermediate cyclic peroxide, followed by intramolecular epoxidation. Such an explanation was first proposed by Henbest[4] for the *cis* epoxidation of *cis*-Δ^4-tetrahydrophthalic anhydride. However, others[5] have argued that in the latter case the observed stereospecificity arises because the cyclohexene ring in *cis*-Δ^4-tetrahydrophthalic anhydride exists as an "equatorial half-boat" (II) and *exo* attack occurs just as in norbornenyl anhydrides. Norbornenyl anhydrides and imides are reported to yield *exclusively exo*-epoxides.[5,6]



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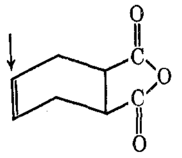
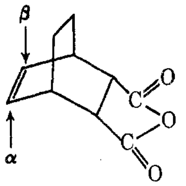
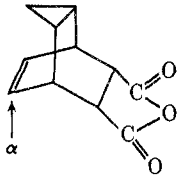


II

In order to obtain more information regarding intramolecular epoxidations we decided to study the epoxidation of bicyclo[2.2.2]-5-octene-2,3-*endo*,*cis*-dicarboxylic anhydride (III). During the course of our investigation, Fray, *et al.*,[7] reported that epoxidation of III paralleled that of bicyclo[2.2.1]-5-heptene-2,3-*endo*,-*cis*-dicarboxylic anhydride; that is, the *exo*-epoxide was exclusively obtained (β attack). On the other hand, anhydride IV gave the *endo*-epoxide (α attack). Fray, *et al.*,[7] therefore, concluded that the stereochemistry of epoxidation of these cyclic compounds is determined solely on steric grounds.



III



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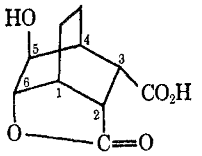
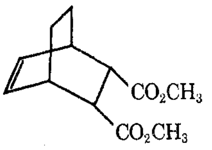


V

We have found that epoxidation of III under conditions similar to those reported by Fray[7] does in fact yield appreciable amounts of the *endo*-epoxide (Table I). Fray, *et al.*,[7] isolated the *exo*-epoxide of III in 48% yield by crystallization and apparently did not account for the remaining products.



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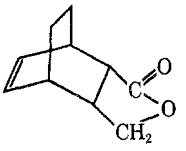
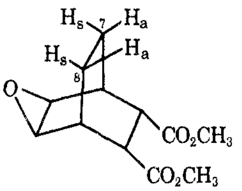


VII



VIII

All of the products mentioned in Table I were isolated in pure form and analytical and spectral data support

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[1] Bridged Ring Compounds. XV: R. L. Hale and L. H. Zalkow, *Tetrahedron*, in press.

[2] Presented at the 19th Southeastern Regional Meeting of the American Chemical Society, Nov 1–3, 1967, Atlanta, Ga.

[3] L. H. Zalkow, M. V. Kulkarni, and N. N. Girotra, *J. Org. Chem.*, **30**, 1679 (1965).

[4] H. B. Henbest, *Proc. Chem. Soc.*, 159 (1963)

[5] A. P. Gray and D. E. Heitmeier, *J. Org. Chem.*, **30**, 1226 (1965).

[6] J. A. Berson and S. Suzuki, *J. Amer. Chem. Soc.*, **80**, 4341 (1958).

[7] G. I. Fray, R. J. Hilton, and J. M. Teire, *J. Chem. Soc., C*, 592 (1966).

TABLE I

EPOXIDATION WITH TRIFLUOROPERACETIC ACID[a]

Alkene	Starting material, %	% products endo-Epoxide	exo-Epoxide	V
III[b]	0	24	45	29
III[c]	0	26	2	70
III[d]	48	5	41	6
III[e]	47	6	3	34
VI[b]	0	21	2	66
VII	25	0	75	

[a] Generated *in situ:* W. D. Emmons and A. S. Pagano, *J. Amer. Chem. Soc.*, **77**, 89 (1955). Run in methylene chloride in presence of anhydrous sodium sulfate. [b] Refluxing (30 min) in methylene chloride, then room temperature for 12 hr. The total product was treated with diazomethane in ether–methanol and analyzed by vpc using a 10% SE-30 column. [c] The solid product obtained as in footnote *b* was allowed to stand at room temperature open to atmosphere for 4 weeks before esterification and vpc analysis. [d] Reaction run at 0° and treated as in footnote *b*. [e] Reaction run at 0° then allowed to stand 4 weeks at room temperature.

the assigned structures. The nmr spectra of the dimethyl esters of the *endo*- and *exo*-epoxides obtained from III are particularly characteristic. Thus the *syn* and *anti* protons at C-7 and C-8 in the *endo*-epoxide are magnetically equivalent, whereas in the *exo*-epoxide (see VIII) the *anti* protons (H_a) give signals at ~40 cps higher field (in $CDCl_3$) than the *syn* protons (H_s), as expected.[8]

The data presented in Table I show that the *exo*-epoxide from III is converted into lactone V even on standing in the solid state at room temperature. Therefore a more meaningful comparison is provided by the ratio

$$\frac{\%\ endo\text{-epoxide}}{\%\ exo\text{-epoxide} + \text{lactone}} \equiv \frac{\alpha \text{ attack}}{\beta \text{ attack}}$$

Thus it can be seen that the dimethyl ester VI gives about the same ratio (1:3) as does the anhydride III on epoxidation in refluxing methylene chloride, but at 0° the ratio for III drops to ~1:7.

No epoxidation of III occurred using 30 or 90% hydrogen peroxide in the absence or presence of *p*-toluenesulphonic acid but trifluoroacetic acid and 90% hydrogen peroxide gave similar results to those obtained generating trifluoroperacetic acid by the Emmons[9] procedure as used in Table I. As the concentration of III in methylene chloride was varied from 1×10^{-1} to 5×10^{-2} to 2.5×10^{-2} *M* the α to β ratio varied from 1:3 to 1:3.5 to 1:5 using trifluoroacetic acid and 90% hydrogen peroxide. This variation in α:β ratio is, however, too small to be significant.

In view of the evidence presented here we see no need to invoke the previously mentioned mechanism involving participation of the anhydride moiety even though *endo*-epoxide is produced in the epoxidation of anhydride III. Apparently, the activation energy for β epoxidation (*exo*) is lower than for α epoxidation (*endo*) as illustrated in Table I by the decrease in *endo*- to *exo*-epoxide ratio as the temperature is decreased. This is what one would expect if the stereochemistry of epoxidation is determined solely on steric grounds. Under the conditions utilized, lactone VII gives solely β epoxidation because of steric interaction of the inside hydrogen atom in the methylene group of the γ-lactone ring.

Experimental Section

Melting points were taken on a Thomas–Hoover apparatus and are uncorrected. Analyses were performed by Dr. Alfred Bernhardt, Mülheim, Germany. Infrared spectra were recorded with a Perkin-Elmer Model 237-B spectrophotometer. Nuclear magnetic resonance spectra were obtained with a Varian A-60 spectrometer using TMS as an internal standard ($\delta = 0$). Gas–liquid partition chromatographic analyses were with an F & M Biomedical 400 gas chromatograph with a hydrogen flame detector using glass columns ($^1/_8$ in. × 6 ft) packed with 10% SE-30 on Gas-Chrom Q; the column temperature was 200° and the helium flow rate was 88 ml/min. All gas chromatographic analyses were run on methyl ester derivatives obtained by treating the reaction products with diazomethane in ether–methanol. Under the above conditions, VI, the *exo*-epoxydimethyl ester, the *endo*-epoxydimethyl ester (VIII), and the lactone methyl ester (ester of V) had the following retention times: 1.3, 1.8, 2.6, and 3.6 min.

Preparation of Authentic Samples of 3-Oxatricyclo[3.2.2.0$^{2,4\text{-}exo}$]nonane-5,6-*cis*,*endo*-dicarboxylic Anhydride and 3-Oxatricyclo[3.2.2.0$^{2,4\text{-}endo}$]nonane-5,6-*cis*,*endo*-dicarboxylic Anhydride and the Corresponding Dimethyl Esters.—To a mixture of 8.9 g (0.05 mol) of III and 28 g (0.20 mol) of anhydrous disodium hydrogenphosphate in 150 ml of methylene chloride was added a solution of trifluoroperacetic acid prepared by the dropwise addition at 0° of 19 ml (0.09 mol) of trifluoroacetic anhydride to a suspension of 2.1 ml (0.07 mol) of 90% hydrogen peroxide in 25 ml of methylene chloride. After addition was complete, the reaction mixture was stirred at room temperature for 24 hr.

The solution was filtered and the solid thus obtained was further washed with methylene chloride. The combined filtrate was washed with water, dried over anhydrous magnesium sulfate, and concentrated to give the crude product. Additional product was obtained by dissolving the above solid in a 5% sodium carbonate solution followed by extraction with methylene chloride. The total collected product weighed 7.0 g. Recrystallization from acetone gave, first, square crystals of 3-oxatricyclo[3.2.2.0^{exo}]nonane-5,6-*endo*,*cis*-dicarboxylic anhydride, which sintered at 208 and 217° and melted at 221–223° (lit.[7] mp 207–208°): ν_{max}^{KBr} 1830, 1775, 1250, 1215, 1080, 950, 915 cm^{-1}; nmr (CF_3CO_2H), δ 1.43 (d, $H_{7a,8a}$, $J = 11$ cps), 1.92 (bd, $H_{7s,8s}$, $J = 11$ cps), 2.96 (2 H, $W_{1/2}$ 9 cps), 3.44 (2 H, $W_{1/2}$ 4 cps), 3.64 (2 H, $W_{1/2}$ 6 cps).

Anal. Calcd for $C_{10}H_{10}O_4$: C, 61.91; H, 5.20. Found: C, 61.87; H, 5.20.

Treatment of the above anhydride with diazomethane in methanol–ether gave dimethyl ester VIII: mp 93–94° from ether; ν_{max}^{KBr} 1733, 1235, 1205, 1167 cm^{-1}; nmr ($CDCl_3$), δ 1.18 (2 H, bd, $J = 11$ cps), 1.88 (2 H, bd, $J = 11$ cps), 2.50 (2 H, $W_{1/2}$ 8 cps), 3.05 (2 H, $W_{1/2}$ 3 cps), 3.44 (2 H, $W_{1/2}$ 8 cps), 3.60 (6 H).

Continued crystallization from acetone gave diminishing amounts of the square crystals of the *exo*-epoxide until finally the mother liquor gave needlelike crystals of 3-oxatricyclo[3.2.2.0^{endo}]nonane-5,6-*endo*,*cis*-dicarboxylic anhydride: mp 183–185°; ν_{max}^{KBr} 1860, 1835, 1785, 1250, 1100, 970, 915 cm^{-1}.

Anal. Calcd for $C_{10}H_{10}O_4$: C, 61.91; H, 5.20. Found: C, 61.99; H, 5.17.

Treatment of the above anhydride with diazomethane in ether–methanol gave the *endo*-epoxydimethyl ester which had mp 89–90° after recrystallization from ether: ν_{max}^{KBr} 1724, 1224 and 1188 cm^{-1}; nmr ($CDCl_3$), δ 1.61 (4 H, $W_{1/2}$ 4 cps), 151–168 cps (a broad signal upon which a sharp signal is superimposed, total area corresponds to 4 H), 3.22 (2 H, $W_{1/2}$ 7 cps), 3.64 (6 H).

Preparation of V Methyl Ester.—A solution containing 3 g of *m*-chloroperbenzoic acid (85%) in 25 ml of methylene chloride was added to 2.6 g of VI dissolved in 25 ml of methylene chloride. After stirring at room temperature for 48 hr, the solution was washed with 10% sodium nitrite solution, then 10% sodium carbonate solution, and finally dried over magnesium sulfate. Removal of the solvent gave 1.62 g of neutral material which appeared to be predominantly one product by tlc and the nmr spectrum of this material indicated a minimum of 90% V methyl ester, mp 64–66°. After drying at 60° (29 mm) under vacuum for 5 hr the melting point was 89–91° (lit.[7] mp 93–94°); ν_{max}^{KBr} 3472, 3370, 3210, 1775, 1730 cm^{-1}; nmr (benzene), δ 3.95 (H_5, $J_{5,6} = 4.5$ cps), 4.38 (H_6).

When III was treated with *m*-chloroperbenzoic acid as described above, V was obtained directly, mp 221–223° (lit.[7] mp

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(8) K. Tori, K. Aono, K. Kitahonoki, R. Muneyuki, and Y. Takano, *Tetrahedron Lett.*, 2921 (1966).

(9) See Table I, footnote *a*.

203–204.5°). These compounds retain solvent very tenaciously and this accounts for the variation in melting points observed. However, the infrared and nmr spectra verify the structures: ν_{max}^{KBr} 3425, 2941, 1770 and 1709 cm^{-1}. Treatment of V with ethereal diazomethane gave the above-mentioned V methyl ester.

Epoxidation of Lactone VII.—To a mixture of 0.82 g of VII[10] (mp 90–91°) and 2.8 g of anhydrous sodium sulfate in 50 ml of methylene chloride was added a solution of trifluoroperacetic acid prepared, as described above, from 1.25 ml of trifluoroacetic anhydride and 0.25 ml of 90% H_2O_2 in 10 ml of methylene chloride. After addition was complete, the solution was refluxed for 30 min. Filtration followed by removal of solvent gave 0.9 g of product, the glpc of which showed 25% unreacted VII and 75% *exo*-epoxide. Slow recrystallization from ether gave pure *exo* epoxide: mp 175–176°; ν_{max}^{KBr} 1755, 1185 cm^{-1}; nmr [$CD_3C(=O)CD_3$], δ 1.08 (bd, J = 10 cps, H_{7a},H_{8a}), 1.50 (d, J = 10 cps, H_{7s},H_{8s}).

Anal. Calcd for $C_{10}H_{12}O_3$: C, 66.72; H, 6.72. Found: C, 66.59; H, 6.54.

Sample Epoxidation Experiment as Used in Table I.—The following typical experimental procedure was used for those experiments recorded in Table I because under these conditions a quantitative recovery of organic material was obtained. When disodium hydrogenphosphate was used, a quantitative recovery of organic material could never be obtained despite repeated washings of the solid disodium hydrogenphosphate precipitate with methylene chloride. When *m*-chloroperbenzoic acid was used as an epoxidizing agent the gas chromatographic analysis was complicated by by-products, presumably arising from the *m*-chloroperbenzoic acid, which, however, gave esssentially the same ratio of *exo*:*endo* epoxides with III as obtained from trifluoroperacetic acid as determined by nmr analysis of the corresponding methyl esters.

To a mixture consisting of 1.78 g of III (0.01 mol) and 5.7 g of anhydrous sodium sulfate in 50 ml of methylene chloride, there was added slowly a solution of trifluoroperacetic acid prepared from 2.5 ml of trifluoroacetic anhydride, 0.5 ml of 90% hydrogen peroxide, and 15 ml of methylene chloride prepared as described above. After addition was complete, the solution was refluxed for 30 min, cooled to room temperature, and filtered, the precipitate was washed with methylene chloride, and the combined filtrate was concentrated on the rotary evaporator. To the residue 25 ml of dry benzene was added and removal of this solvent with the rotary evaporator gave 1.94 g of product. This product was dissolved in methanol and treated with excess ethereal diazomethane. The resulting mixture was analyzed by glpc and gave the results indicated in the first line of Table I.

Registry No.—$C_{10}H_{10}O_4$ (*exo*-epoxide), 5826-30-2; VIII, 17989-97-8; $C_{10}H_{10}O_4$ (*endo*-epoxide), 17989-98-9; dimethyl ester of $C_{10}H_{10}O_4$ (*endo*-epoxide), 18019-45-9; VII (*exo*-epoxide), 17989-99-0.

Acknowledgment.—We thank the University System of Georgia for Quality Improvement Funds in support of this research. We also thank Dr. M. V. Kulkarni for initial experiments.

[10] S. F. Birch, N. J. Hunter, and D. T. McAllan, *J. Org. Chem.*, **21**, 970 (1956).

Reduction of 6-Dichloromethyl-2,6-dimethylcyclohexa-2,4-dien-1-one

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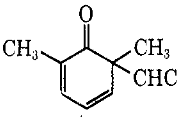
Received June 17, 1968

The chlorinated cyclic ketones available by the "abnormal" Reimer–Tiemann reaction[2] of substituted phenols offer a potentially useful and direct method for the preparation of alicyclic ketones and their derivatives. Yet there has been very little use made of such compounds, perhaps partly owing to difficulties encountered in their reduction.[3] Recently, the reduction of two dichloromethylmethylcyclohexanones has been reported.[4] We sought to apply this method to the preparation of 2,2,6-trimethylcyclohexanone, a useful synthetic intermediate, from 6-dichloromethyl-2,6-dimethylcyclohexa-2,4-dien-1-one, and report our results herewith.

Results and Discussion.—When the dichloromethyldienone **1** is hydrogenated in the presence of 15% KOH–methanol and with 10% Pd–C, two neutral products are isolated. The expected 2,2,6-trimethylcyclohexanone is produced in 12% yield and a monochloro ketone is produced in 14% yield. This ketone is not the expected 2-chloromethyl-2,6-dimethylcyclohexanone **2**, however, but the bicyclic ketone **3**. This structure is supported by the infrared carbonyl absorption at 5.63 μ, characteristic of four-membered ketones.[5] While lactones also absorb in this region, the elemental analysis precludes this structure. The nmr spectrum also supports this structure (see Experimental Section).



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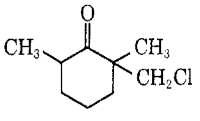

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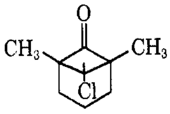

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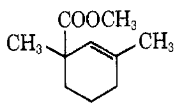

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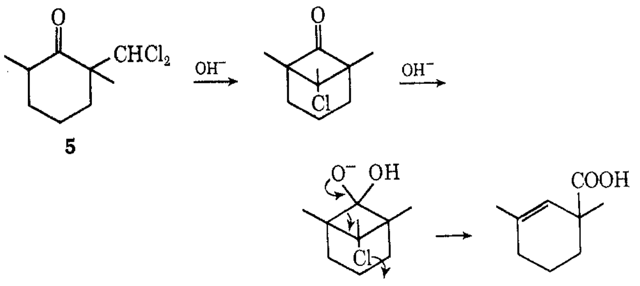
Further confirmation of this structure was found in a product isolated from the aqueous extracts of the original hydrogenation mixture. Upon acidification, a mixture of acids was obtained. These, after esterification with methanol, yielded as a major component the cyclohexene derivative **4**. The structure of this ester is assigned on the basis of its analysis, as well as absorption in the infrared region at 12.4 μ (trisubstituted olefin,[5] but more particularly on the basis of its nmr spectrum (see Experimental Section). A plausible mechanism interrelating these products is the attack by base on intermediate 2-dichloromethyl-2,6-dimethylcyclohexanone **5**, followed by base-catalyzed ring



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[3] M. Busch and H. Stove, *Ber.*, **49**, 1063 (1916).

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[5] R. T. Conley, "Infrared Spectroscopy," Allyn and Bacon, Boston, Mass., 1966.