washed until neutral with dilute base and water, dried, and freed of ether. Distillation of the residual oil gave a series of fractions (8.1 g., b.p. 85–110° at 0.4 mm.), all of which showed both C=C and C=O bands in the infrared. Other hydrolyses involved reaction times as long as 12 hr. with Girard-T reagent work-up. While such measures decreased the enol ether content of VII, analytically pure samples of the aldehydes were not obtained. *1-Phenylcyclohexylacetaldehyde* (VII, m = 5) has been obtained pure, however, *via* another route[16] and its infrared spectrum was comparable to that of the aldehyde prepared in this work, with slight contamination by the enol ether evident.

CHICAGO 26, ILL.

[CONTRIBUTION FROM THE SOUTHERN REGIONAL RESEARCH LABORATORY[1]]

Catalytic Hydrogenation of 9,10-Epoxyoctadecanol and 9,10-Epoxyoctadecyl Acetate

SARA P. FORE AND W. G. BICKFORD

Received October 13, 1958

cis-9,10-Epoxyoctadecanol and *cis*-9,10-epoxyoctadecyl acetate have been hydrogenated in ethanolic solution employing palladium-carbon catalyst. Examination of the reaction products established the fact that nearly equal proportions of the 9- and 10-hydroxy isomers were formed in both cases. These results are in marked contrast to the preferential formation of methyl 10-hydroxyoctadecanoate encountered previously during the catalytic reduction of methyl 9,10-epoxyoctadecanoate. The difference in results obtained with the two esters is attributed to the relative position of the oxirane center with respect to the acyl and alkoxyl oxygen atoms of the ester.

Investigations conducted in this laboratory[2] and elsewhere[3,4] into the catalytic hydrogenation of the 9,10-epoxyoctadecaonates have shown that the reaction products consist principally of one positional isomer. Reduction of methyl *cis*-9,10-epoxyoctadecanoate, for instance, results in the formation of methyl 10-hydroxyoctadecanoate with little or no attendant formation of the 9-isomer.

The results obtained in our previous investigation suggested that the reaction proceeded by an ionic mechanism involving the preferential attack of a hydride ion on the ninth carbon-oxygen bond of an oxonium ion intermediate.[5] The specificity of the reaction was attributed to the influence exerted at both the oxirane center and the catalyst surface by the electrophilic —COO— group.

To obtain further information regarding the nature of this reaction we have now investigated the catalytic reduction of both *cis*-9,10-epoxyoctadecanol and *cis*-9,10-epoxyoctadecyl acetate. These epoxides were hydrogenated in ethanolic solution employing a palladium-carbon catalyst. The exact positions of the secondary alcohol groups thus formed were established by the following series of reactions: the diols obtained upon hydrolysis of the acetate, as well as those derived from the free alcohol, were oxidized to the corresponding keto acids; the oximes prepared from the keto acids were transformed by means of the Beckmann rearrangement; hydrolysis of the resultant amides and separation of the hydrolysis products were effected by the procedure of Bharucha and Gunstone[6]; the mixed dicarboxylic acid fraction was separated into its components by application of elution chromatography employing a modification[7] of the method of Higuchi *et al.*[8]

Application of the above described series of reactions to either *cis*-9,10-epoxyoctadecanol or *cis*-9,10-epoxyoctadecyl acetate resulted in the formation of azelaic and sebacic acids only, which were found to be present in nearly equimolar proportions. It may be concluded, therefore, that catalytic hydrogenation of either epoxide leads to the formation of equivalent amounts of the 9- and 10-hydroxy isomers. Apparently the acyl oxygen of the acetate exerted no greater directive influence on the course of the reaction than did the hydroxyl oxygen of the alcohol. These results are in marked contrast to those obtained by the catalytic hydrogenation of methyl *cis*-9,10-epoxyoctadecanoate and *cis*-9,10-epoxyoctadecanoic acid in which cases the 10-isomer was produced prefer-

(1) One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

(2) C. H. Mack and W. G. Bickford, *J. Org. Chem.*, **18**, 686 (1953).

(3) I. G. V. Pigulevskiĭ and Z. Ya. Rubashko, *J. Gen. Chem. (U.S.S.R.)*, **9**, 829 (1939), *Chem. Abstr.*, **34**, 378 (1940).

(4) J. Ross, A. I. Gebhart, and J. F. Gerecht, *J. Am. Chem. Soc.*, **71**, 282 (1949).

(5) It was concluded that the ninth carbon atom of the epoxide was slightly positive with respect to the tenth carbon atom. Further support for this viewpoint is to be found in the observation of E. Jungermann and P. E. Spoerri, *J. Am. Chem. Soc.*, **75**, 4704 (1953), that hydrochlorination of methyl 9,10-epoxyoctadecanoate leads predominantly to the formation of methyl 9-chloro-10-hydroxyoctadecanoate.

(6) K. E. Bharucha and F. D. Gunstone, *J. Chem. Soc.*, 610 (1957).

(7) M. H. Chahine, E. R. Cousins, and R. O. Feuge, *J. Am. Oil Chemists' Soc.*, **35**, 396 (1958).

(8) T. Higuchi, N. C. Hill, and G. B. Corcoran, *Anal. Chem.*, **24**, 491 (1952).

entially. It is of interest to note in this connection that the —COOH group is much more electrophilic in nature than is either —OCOMe or —OH.[9] The essential structural difference between methyl 9,10-epxoyoctadecanoate and 9,10-epoxyoctadecyl acetate is the location of the oxirane group which is in the acid moiety of the former but in the alcohol moiety of the latter. It appears that the acyl oxygen does not exercise a directional influence on the hydrogenation when it is separated from the oxirane center by an alkoxyl oxygen. The origin of this effect can be traced to the low polarizability of the carbon-oxygen covalent bond as compared to that of the carbon-carbon covalent bond. That is, the alkoxyl oxygen of the ester interferes with the operation of the general inductive (field) effect in the case of the acetate. On the basis of the above observations, it may be concluded that the relative position of the oxirane center with respect to the acyl and alkoxyl oxygen atoms is an important factor in determining the course of the reaction.

EXPERIMENTAL

Since *cis*-9-octadecenol and *cis*-9-octadecenyl acetate were subjected to the same essential reactions, experimental details will be reported for the latter compound only.

Methyl oleate. Pecan oil was subjected to methanolysis employing sodium methylate as catalyst. The resultant mixed methyl esters were dissolved in acetone (1 g./10 ml.) and the saturated esters were removed by crystallization at −37°. Methyl oleate was isolated from the unsaturated fraction by means of two successive crystallizations from acetone (1 g./15 ml.) at −60°.

Anal. Calcd. for $C_{19}H_{36}O_2$: I.V., 85.6; diene, 0. Found: I.V., 85.5; diene, 1.5; n_D^{20}, 1.4531.

cis-9-Octadecenol. This material was prepared by the sodium reduction of methyl oleate employing 1-butanol as the reducing alcohol.[10]

Anal. Calcd. for $C_{18}H_{36}O$: C, 80.52; H, 13.52; OH, 6.4; I.V., 94.5. Found: C, 80.62; H, 13.54; OH, 6.4; I.V., 94.0; n_D^{20}, 1.4620.

cis-9-Octadecenyl acetate. cis-9-Octadecenol was dissolved in a 200% excess of an acetic anhydride-pyridine reagent and stirred at 100° for 1 hr. The reaction mixture was drowned with water and extracted with ether. The ethereal solution was washed first with dilute hydrochloric acid, then with 5% sodium bicarbonate solution and finally with water. After the solution had been dried with sodium sulfate, the *cis*-9-octadecenyl acetate was recovered by evaporation of the ether.

Anal. Calcd. for $C_{20}H_{38}O_2$: I.V., 81.5; sap. equiv., 310.5. Found: I.V., 81.9; sap. equiv., 310.4; n_D^{20}, 1.4527.

cis-9,10-Epoxyoctadecyl acetate. cis-9-Octadecenyl acetate, 40.4 g. (0.13 mole), was dissolved in 100 ml. of chloroform and maintained at 15–20° during the dropwise addition of 249 ml. of a chloroform solution containing 0.143 mole of perbenzoic acid. Titration of aliquots showed that the theoretical quantity of oxygen had been absorbed after a reaction period of 2 hr. The reaction mixture was diluted with two volumes of ethyl ether, washed successively with 5% aqueous potassium hydroxide and distilled water and then dried over anhydrous sodium sulfate. After removal of the solvent, there was obtained 40.7 g. of *cis*-9,10-epoxyoctadecyl acetate.

Anal. Calcd. for $C_{20}H_{38}O_3$: C, 73.57; H, 11.73; oxirane O, 4.9. Found: C, 73.41; H, 11.63; oxirane O, 4.6.

1,9(10)-Octadecanediol. Epoxyoctadecyl acetate, 36.0 g., containing palladium-carbon catalyst, 7.2 g., was dissolved in 150 ml. of absolute ethanol. Hydrogenation at room temperature and an initial pressure of 27.5 p.s.i. was complete in 2.5 hr. After removal of the catalyst and addition of 14.5 g. of potassium hydroxide in 15 ml. of distilled water, the alcoholic solution was refluxed for 1 hr. to effect saponification of the ester. Recovery of the reaction product by the usual means yielded 30.1 g. of crude 1,9(10)-octadecanediol, m.p. 62–65°.

Anal. Calcd. for $C_{18}H_{38}O_2$: OH, 11.9. Found: OH, 10.6.

9(10)-Oxo-octadecanoic acid. Crude 1,9(10)-octadecanediol, 27.9 g. (0.097 mole), dissolved in 185 ml. of glacial acetic acid, was stirred and maintained at 30–35° during the dropwise addition of chromium trioxide, 26.3 g. (0.263 mole), dissolved in 18.5 ml. of distilled water and 273 ml. of glacial acetic acid. After addition of the reagent, which required 1 hr., the reaction mixture was maintained at the same temperature for another hour and then at 38–40° for 2 hr. The crystals which separated on dilution of the reaction mixture with water were boiled first with dilute hydrochloric acid and then with water. The resultant keto acids were dissolved in 826 ml. of 33% ethanol containing 12.0 g. of potassium hydroxide and extracted with ether for the removal of neutral materials. The keto acids, 20.6 g., were liberated from their potassium salts with dilute acid and recovered in the usual manner.

Anal. Calcd. for $C_{18}H_{34}O_3$: carbonyl O, 5.36; neut. equiv.. 298.5. Found: carbonyl O, 4.51; neut. equiv., 298.0,

Oximes of oxo-octadecanoic acids. A solution of 12.4 g. (0.21 mole) of potassium hydroxide in 46 ml. of water was added to a mixture of 18.6 g. (0.062 mole) of the keto acid, 5.51 g. (0.077 mole) of hydroxylamine hydrochloride and 240 ml. of ethanol. The mixture was stirred and refluxed for a period of 6 hr. After removing most of the ethanol by vacuum distillation at room temperature employing nitrogen as a sweep gas, the product was treated with 100 ml. of 1.5*N* hydrochloric acid. Separation of the organic material by ether extraction yielded 17.9 g. of crude oximes.

Anal. Calcd. for $C_{18}H_{35}NO_2$: N, 4.5. Found: N, 3.9.

The Beckmann rearrangement. A 9.4 g. quantity of the oxime of 9(10)-oxo-octadecanoic acid was dissolved in 60 ml. of concentrated sulfuric acid and stirred at 100° for 1 hr. After addition of 74 ml. of distilled water, the sample was refluxed for 4 hr. in order to hydrolyze the amide.

Dicarboxylic acids. The hydrolysis mixture was diluted with 400 ml. of distilled water and subjected to steam distillation for the removal of monocarboxylic acids. Ether extraction of the distillation residue yielded 5.91 g. of a brown, waxy material containing the dicarboxylic acids. This fraction was extracted 10 times with 15-ml. portions of boiling water. The extract was concentrated to a volume of 40 ml. and upon standing at 5° deposited 0.835 g. of mixed dicarboxylic acids.

Anal. Calcd. for $C_9H_{16}O_4$: neut. equiv., 94.1. Calcd. for $C_{10}H_{18}O_4$: neut. equiv., 101.1. Found: neut. equiv., 97.1.

Chromatographic separation of the dicarboxylic acids. Duplicate samples of the mixed dicarboxylic acids, *ca.* 0.2 g., accurately weighed, were dissolved in 0.5 ml. of *t*-amyl alcohol and diluted to 10.0 ml. with chloroform. One-ml. aliquots of these solutions were added to a column prepared according to the procedure described by Higuchi *et al.*,[8] using 25.0 g. of dry silicic acid, 10.0 ml. of citrate buffer, *p*H 5.4, and 100 ml. of chloroform. The acids were eluted with successive 100 ml. portions of chloroform containing O, 1.5, 3, 5, and 10% of 1-butanol, and 10.0 ml. portions of the eluate were titrated with 0.0255*N* sodium hydroxide solution. Only two fractions were encountered and these were

(9) H. J. Lucas, *J. Am. Chem. Soc.*, **48**, 1827 (1926).

(10) E. E. Reid, F. O. Cockerille, J. D. Meyer, W. M. Cox, Jr., and J. R. Ruhoff, *Org. Syntheses*, **Coll. Vol. II**, 468 (1943).

identified as azelaic and sebacic acids by chromatographing a sample of the mixed dicarboxylic acids to which known quantities of azelaic and sebacic acids had been added. The dicarboxylic acids obtained from *cis*-9,10-epoxyoctadecyl acetate consisted of 54.4 mole percent azelaic and 45.6 mole percent sebacic acids.

Application of the above described procedures to the dicarboxylic acids obtained from *cis*-9,10-epoxyoctadecanol showed the mixture to be 54.8 mole percent azelaic and 45.2 mole percent sebacic acids.

Acknowledgment. The authors express their appreciation of L. E. Brown for elemental analyses and to J. A. Harris for other analyses.

NEW ORLEANS, LA.

[CONTRIBUTION FROM THE DEPARTMENTS OF CHEMISTRY OF MARQUETTE UNIVERSITY AND IOWA STATE COLLEGE]

Studies in the Synthesis of Long-Chained Hydroxy Acids

KENNETH E. MILLER, CLIFFORD HAYMAKER, AND HENRY GILMAN

Received October 9, 1958

Four long-chained hydroxy acids have been prepared. Included in the group are 6-hydroxyhexacosanoic acid, 4-hydroxytetracosanoic acid, 10-hydroxydotriacontanoic acid, and 10-hydroxyhexacosanoic acid. In each preparation, thiophene was used as a chain extender, the thiophene sulfur ultimately being removed by desulfurization.

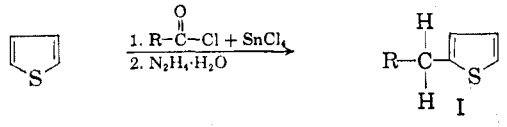
The preparation of hydroxy acids has generally been based upon hydrolysis of the halogenated acid or reduction of the keto acid. Because of the relative unavailability of the starting materials such syntheses have, of necessity, been limited. The present work was thus undertaken to investigate the synthesis of hydroxy acids by Raney nickel catalyzed reduction and desulfurization of selected acidic derivatives of thiophene.

While it has been known for about twenty years that Raney nickel easily and readily desulfurized sulfur-containing organic compounds,[1] it is only during the most recent years that the desulfurization reaction has been used in various synthetic applications. The preparation of an aldehyde from a thiolester[2] is an example.

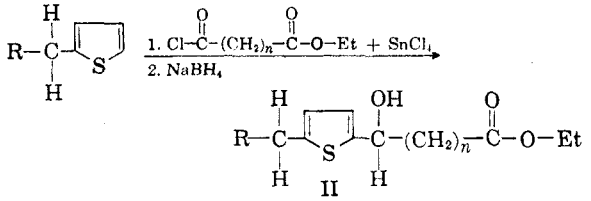
Of greater importance to the present study is the work which has been carried out on the desulfurization of thiophene derivatives.[3-5] During the past four years a number of investigators[6-10] have reported the synthesis of fatty acids by the desulfurization of substituted thiophenes.

Even more recently the work has been extended by the splendid studies of Wynberg and co-workers[11] to the preparation of long-chain mono- and dicarboxylic acids, ketones, alcohols and hydrocarbons.

The acylation of thiophene by an acyl chloride[9] using anhydrous stannic chloride as catalyst was followed by reduction of the resulting acylthiophene with hydrazine hydrate.[12] The resultant



n-alkylthiophene was then acylated with a selected ester-acid chloride, this acylation being followed by reduction of the keto compound to the corresponding hydroxy compound, employing sodium borohydride as the reducing agent.[13-15] Reduction



and desulfurization[9,10] of the acidic thiophenes obtained by hydrolysis of the corresponding thienyl esters yielded the desired hydroxy acids.

---

(1) J. Bougault, B. Cattelain, and P. Chabrier, *Bull. soc. chim. France*, **5**, 1699 (1938); **7**, 781 (1940).
(2) E. Mossetig, *Org. Reactions*, VIII, 232 (1954).
(3) D. Papa, E. Schwenk, and H. Ginsberg, *J. Org. Chem.*, **14**, 723 (1949).
(4) E. Modest and Symuszkovicz, *J. Am. Chem. Soc.*, **72**, 577 (1950).
(5) F. Blicke and D. Sheets, *J. Am. Chem. Soc.*, **70**, 3768 (1948).
(6) M. M. Michel-Sy, N. P. Buu-Hoï, and N. Dat. Xuong, *Compt. rend.*, **239**, 1224 (1954).
(7) G. M. Badger, H. J. Rodda, and W. H. F. Sasse, *Chem. & Ind.*, (*London*), 308 (1954).
(8) J. F. McGhie, H. K. Pradhan, and W. A. Ross, *Chem. & Ind.*, (*London*), 578 (1954).
(9) G. M. Badger, H. J. Rodda, and W. H. F. Sasse, *J. Chem. Soc.*, 4162-68 (1954).
(10) N. P. Buu-Hoï and M. M. Michel-Sy, *J. Org. Chem.*, **23**, 97 (1958).
(11) H. Wynberg and A. Logothetis, *J. Am. Chem. Soc.*, **78**, 1958 (1956).
(12) Huang-Minlon, *J. Am. Chem. Soc.*, **68**, 2487 (1946).
(13) W. B. Reid and B. Siegel, *J. Chem. Soc.*, 520 (1949).
(14) S. W. Chaikin and W. G. Brown, *J. Am. Chem. Soc.*, **71**, 122 (1949).
(15) M. Abdel-Akher, J. K. Hamilton, and F. Smith, *J. Am. Chem. Soc.*, **73**, 4691 (1951).