AN INVESTIGATION OF THE REDUCTION PRODUCTS

OF CERTAIN COMPOUNDS CONTAINING AN

ISOLATED OXIRANE GROUP

By

JOHN PHILIP FRIEDRICH

Bachelor of Science
Missouri School of Mines and Metallurgy
Rolla, Missouri
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Master of Science
Missouri School of Mines and Metallurgy
Rolla, Missouri
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the Oklahoma State University in partial
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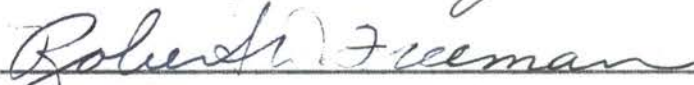DOCTOR OF PHILOSOPHY
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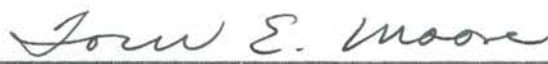Thesis Approved:

Henry A. Smith
Thesis Adviser

Robert J. Sirny

Robert H. Freeman

Tom E. Moore

Robert Morrison
Dean of the Graduate School

ii
438611

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The ultimate purpose of this experimentation was to further the basic knowledge of the chemistry of sperm oil. Since sperm oil is composed of a large variety of compounds, it was decided to work with some pure component, and furthermore since the largest single component of sperm oil is oleyl oleate, the oleic acid family of compounds was chosen for study.

It has long been a theory of organic chemistry that in reactions involving isolated double bonds, i.e., in a situation in which both carbon atoms involved in the double bond appear to be under identical electronic and steric enviroments, the probabilities of reaction taking place on either carbon atom are identical, and a statistical distribution of products, provided more than one product is formed, should result. The validity of this fact may be easily borne out by observing the manner in which the products of such reactions are recorded in the literature.

Now it should also follow that in reactions involving opening of an isolated oxirane, a statistical distribution of products should result. A survey of the literature reveals, however, that in some cases there is evidence of marked nonrandom or even exclusively unidirectional orientation, as was reported by Mack and Bickford (47, 48) for the catalytic hydrogenation of the 9,10-epoxystearic acids, which yielded the 10-isomer exclusively.

Specifically then, the purpose of this investigation was to verify

1

the above mentioned experimental evidence and to enlarge upon it by
carrying out similar experiments using oleyl alcohol and methyl oleate
as substrates.

HISTORICAL

I. THE CHEMICAL COMPOSITION OF SPERM OIL

The oils from the blubber and head cavity of the sperm whale differ markedly in chemical composition from those of other whales in that they consist largely of waxes, i.e., esters of high molecular weight fatty acids and high molecular weight alcohols with minor amounts of the more common triglycerides being present. The most abundant high molecular weight unsaturated ester is oleyl oleate.

II. THE OXYGENATED DERIVATIVES OF OLEIC ACID AND OLEYL ALCOHOL

Preparation of the 9,10-Epoxystearic Acids

An acid of this type was first reported by Saytzeff (67), who obtained a compound with the correct empirical formula by the vacuum distillation of dihydroxystearic acid. The preparation of 9,10-epoxystearic acid was later reported by LeSeuer (45), who first thought he had obtained it by fusion of the dihydroxy acid with potassium hydroxide at 270°C. This finding was denied some years later (46). Present knowledge concerning the relative stability of the oxirane group excludes application of either of these methods.

Credit for the first actual preparation of these acids has been given to Albitzky (1), who prepared them by treatment of the chloro-hydroxystearic acids with aqueous barium hydroxide. Since that time, they have been prepared by several modifications of this method (30, 39, 41, 52, 53). According to Swern (76), this method produces excellent yields in small batch operations; however, large scale experiments

3

rarely yield more than 50 per cent of theory, owing to side reactions.

A more common method of obtaining these acids has been by the treatment of the corresponding olefinic acid with peracetic (13, 20, 27, 28, 40, 56, 59, 72, 84, 93) or perbenzoic acid (7, 8, 27, 44, 63, 88). The peracid may be prepared separately and subsequently reacted with the unsaturated acid, or it is possible to start with an aldehyde, such as benzaldehyde, and produce the peracid in the reaction vessel. This is done by passing oxygen through the reactants in the presence of ultraviolet light. The yields reported by the former method are generally higher, 75 per cent or more, but the latter method does not require isolation of the peracid. Swern (73, 75) published two extensive reviews on peracids and their use as oxidizing agents.

In addition to these two principal methods of preparation, these acids have been isolated in low yield, less than 20 per cent, by air oxidation of oleic and elaidic acids (26, 42, 71, 83), usually in the presence of a cobalt catalyst.

Additional methods of preparation using benzoyl peroxide (60) ammonium persulfate (51), perlauric acid (35), and perpelargonic acid (55) have been reported.

Stereochemical relationships and mechanism of formation: Epoxy acids exhibit an interesting type of mixed stereoisomerism, i.e., stereoisomers and geometrical isomers coexist. Thus, the two 9,10-epoxystearic acids consist of a total of four isomers. These four isomers make up two racemic mixtures, one melting at 59.5°C and the other at 55.5°C. In addition, since the three-membered ring restricts rotation, these racemic mixtures are also geometric isomers. These relationships may be illustrated as follows:

Oleic acid (cis)   Elaidic acid (trans)

```
      R'      R                    R'      H
        C = C                        C = C
      H   |   H                    H   |   R
          |                            |
          ▼                            ▼
  R'  O  R   R'     R          R'  O  H   R'      H
    C - C      C - C             C - C      C - C
  H     H    H  O  H           H     R    H  O  R
```
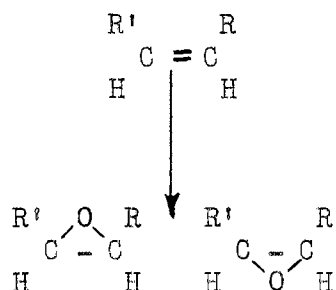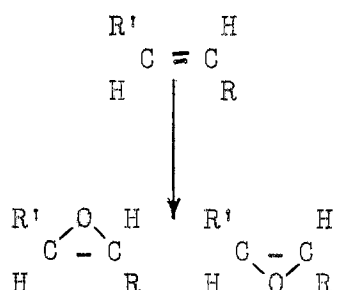
The cis-trans isomerism has been followed by way of the physical properties of monolayers (68) and also by X-ray, ultraviolet, and infrared studies (37, 54, 70, 96). The X-ray diffraction patterns have established that the high-melting racemic mixture is the cis isomer (96). It has also been shown that the cis isomer exhibits a characteristic absorption near 12 microns, caused by the ring, while the trans isomer shows an absorption near 11.2 microns. A combination of these two measurements will positively identify the two geometric isomers (70).

The stereochemical changes which take place in the various methods of preparation have been thoroughly investigated (5, 39, 40, 41, 60, 74, 91) and recently reviewed by Swern (73, 75). If oleic acid is oxidized with a peracid, 9,10-epoxystearic acid racemate (59.5°C) is obtained. If on the other hand, oleic acid is treated with hypochlorous acid, trans addition is known to take place. When HCl is split out again, another inversion takes place, and the epoxy acid produced is once more the racemic mixture melting at 59.5°C. However, if this racemic mixture is subjected to alkaline hydrolysis, the dihydroxy acids are produced with inversion. When these are treated with HCl, forming the chlorohydrins, a second inversion takes place. If HCl is split out, a third inversion takes place. The epoxy acid racemic mixture produced is the geometrical isomer of the other and melts at 55.5°C.

This sequence of reactions further establishes the fact that the reaction of a peracid with an olefinic linkage involves a cis addition.

This apparent stereospecificity would preclude the possibility of the free carbonium-ion intermediate commonly accepted for acid-catalyzed reactions. A more reasonable mechanism is presented by Swern (75):

$$
\begin{array}{l}
\text{R} \quad\quad \text{O} \\
\text{HC} \quad\quad \parallel \\
\parallel + \text{HOOC--CH}_3 \longrightarrow \\
\text{HC} \\
\text{R'}
\end{array}
\quad
\begin{array}{l}
\text{R H} \quad \text{O} \\
\text{HC}_{\cdot\cdot} \quad \parallel \\
\mid \, \text{O--O--CCH}_3 \longrightarrow \\
\text{HC} \\
\text{R'}
\end{array}
\quad
\begin{array}{l}
\text{R} \\
\text{HC} \\
\mid \rangle \text{OH}^+ + \\
\text{HC} \\
\text{R'}
\end{array}
\quad
\begin{array}{l}
\quad \text{O} \\
\quad \parallel \\
^-\text{OCCH}_3 \longrightarrow \\
\end{array}
\quad
\begin{array}{l}
\text{R} \\
\text{HC} \\
\mid \rangle \text{O} + \text{HAc} \\
\text{HC} \\
\text{R'}
\end{array}
$$
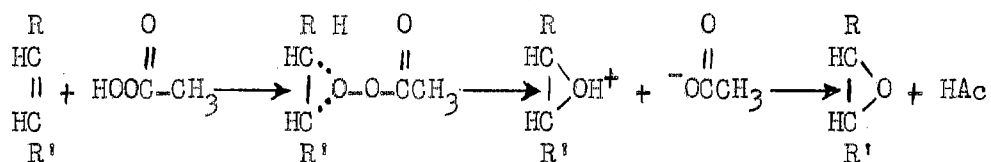
In addition to methods previously mentioned, methods for establishing purity of these acids include carbon-hydrogen analysis, neutralization equivalent, estimation of oxirane oxygen, and dissociation temperature of the urea complex. An accurate potentiometric method for determination of the neutralization equivalent was developed by Radell and Donahue (62). Estimation of oxirane oxygen was effected by titration with 0.2N HCl or HBr in dry ether (51, 87) as well as by polarographic reduction in a nonaqueous solvent (95). The dissociation temperature of the urea complex is a good micro-qualitative test for these acids (43).

Chemical properties: In general, these acids show the typical reactions of ethylene oxide, that is, they react with compounds containing active hydrogen atoms such as alcohols, amines, and acids. In the reaction of these acids with alcohols, in the presence of a mineral acid, esterification as well as ring fission occurs, and the resultant product is a hydroxyether-ester (32, 82). Reactions with carboxylic acids yield hydroxyesters or diesters. These can subsequently be dehydrated and deacylated to form conjugated dienes (23). With ammonia or amines, the hydroxy-amino acids are formed (56, 57

58, 85, 86). As was mentioned previously, alkaline hydrolysis pro-
duces the dihydroxystearic acids with inversion (8, 12, 39, 56, 74,
75).

Another important reaction involves thermal polymerization.
Since the epoxy acids are bifunctional, they polymerize quite readily
when heated, forming high molecular weight polyesters (49, 81).

The catalytic hydrogenation of these epoxy acids and their esters
(21, 47, 48, 54, 61, 66) is of considerable interest. Since the ox-
irane group is located nine carbon atoms from the carboxyl group, it
would be expected, a priori, to behave as an isolated group; however
Ross, et al. (66) reported that in the hydrogenation of methyl cis-9,
10-epoxystearate in ethyl alcohol, using Raney nickel catalyst, the
10-hydroxy ester was formed almost exclusively. They based this find-
ing on the following method of proof. The crude product obtained by
hydrogenation of 10 g. of the epoxy ester, was oxidized with a solution
of CrO_3 in acetic acid solution and hydrolyzed. The free keto acids
which were recrystallized from acetone and petroleum ether yielded
0.21 g. of 9-keto acid (m.p. 81.5°, m.p. semicarbazone 118-120°) and
8.5 g. of 10-keto acid (m.p. 71° m.p. semicarbazone 101-103°). The
oxime of the 10-keto acid was prepared and subjected to the Beckmann
rearrangement and hydrolysis. Sebacic acid was detected in the hydro-
lysis products, thus proving the presence of the 10-keto acid; however,
it should be noted at this point that the authors do not report finding
the quantitative amount of sebacic acid present to establish the purity
of the 10-isomer.

The work of Ross, et al. is in close agreement with the work of
Pigulevskii and Rubashko (61) who, in 1939, reported obtaining ethyl
10-hydroxystearate by hydrogenation of the epoxy ester in absolute

alcohol using a palladium-black catalyst. Upon hydrolysis, the 10-hydroxy acid was formed and its reported melting point was 82.5°.

Mack and Bickford (47, 48), in 1953, carried out a rather extensive investigation into the hydrogenation of the 9,10-epoxystearic acids and their methyl esters. They found that hydrogenation was best accomplished using glacial acetic acid as a solvent and a 10 per cent carbon-palladium catalyst. Using this combination of solvent and catalyst, hydrogenation could be realized under very mild conditions, i.e., room temperature and about two atmospheres pressure. The results of their investigation are summarized in the following table:

TABLE I

MELTING POINTS OF THE HYDROGENATION PRODUCTS OF THE
9,10-EPOXYSTEARIC ACIDS AND RELATED COMPOUNDS

Compound Hydrogenated	m.p. Hydroxy Acid	m.p. Keto Acid	m.p. Semicarbazone
cis-9,10-epoxystearic acid	80° hydrazide 112°	71° yield 80%	100-101°
trans-9,10-epoxystearic acid	80°	—	—
*methyl cis-9,10-epoxystearate	80°	72° 70° 67° ↓ ↓ ↓ 3.5 g. 12 g. 2 g.	100°
methyl trans-9,10-epoxystearate	80°	71° Yield < 50%	100° "

* In this case, 33 g. of hydrogenated product yielded 21.5 g. of crude keto acid, 20 g. of which yielded the three products shown in the table.

It should be noted here that the oxidation of hydroxy compounds to the corresponding keto compounds resulted in rather poor yields. In referring to the melting points of the keto acids, Mack and Bickford

cite the work of Ross, et al. (66), who in turn cite the work of Behrend (9) and Baruch (6).

Jungermann and Spoerri (38), in 1953, reported that upon treatment of methyl cis-9,10-epoxystearate with HCl a mixture of chlorohydrins was obtained, which upon fractional crystallization yielded 10.1 g. of the 9-chloro-10-hydroxy derivative and 3.3 g. of the 10-chloro-9-hydroxy derivative. This was proved by removal of the halide with zinc and acetic acid and oxidation of the hydroxy acids to the keto acids. The oxidation gave 70-75% yields of the following keto acids:

10-ketostearic acid m.p. 72° semicarbazone 100.5-102°

9-ketostearic acid m.p. 80° semicarbazone 117-119°

The reported melting point for the 10-keto acid according to the above article is 72°, but of the three references cited, one gives 83° as the correct melting point, and another 76°.

Preparation of the 9 and the 10-Ketostearic Acids

In 1894, Goldsobel (33) reported that upon treatment of ricinoleic acid with concentrated sulfuric acid followed by addition of water, 12-hydroxy-9-ketostearic acid was formed. This was proved by formation of the oxime, Beckmann rearrangement, and analysis of the hydrolysis products; however, here again no indication is given that the analysis was quantitative.

In 1896, Behrend (9) first prepared what he reported to be pure 9-ketostearic acid. He passed hydrogen chloride gas into an acetic acid solution of 12-hydroxy-9-ketostearic acid, which yielded 12-chloro-9-ketostearic acid. The halide was removed with zinc and hydrochloric acid yielding the 9-ketostearic acid (m.p. 83°). Here again the proof

of structure was by oxime formation, rearrangement etc.; however, in this case, mention was made that the yield of hydrolysis products left something to be desired, as a considerable quantity of resinous material was obtained.

The preparation of pure 10-ketostearic acid was first reported by Baruch (6), in 1894, who obtained it by treatment of stearolic acid with sulfuric acid and addition of water. He reported its melting point to be 76° and that of its ethyl ester 41°. The proof of structure was again identical to the previous cases; however, in this case, the quantitative information is given. From 20 g. of oxime, the following products were ultimately isolated: 4 g. of nonanoic acid, 3 g. of n-octyl amine, 5 g. of sebacic acid, and 4 g. of 9-aminononanoic acid.

It has been reported (22) that in the methoxymercuration of oleic acid, the keto acid(s) derived therefrom had a melting point of 71-72° while the melting point of the corresponding semicarbazone was 99-104°. These investigators assumed this to be a mixture of the two keto acids.

Another investigator (50) reported that in the acetoxymercuration of stearolic acid followed by treatment with HCl what he assumed to be 10-ketostearic acid (m.p. 76°) was formed.

In another paper (92), it was reported that the keto acid(s) derived from the reaction of methyl oleate with tertiary butyl hypochlorite followed by pyrolysis, had a melting point of 71.5-72°. Again, this was assumed to be a mixture of the two isomers.

King (78) reported that a mixture of 9 and 10-ketostearic acids (m.p. 73.5°) was obtained as a by-product in heating 9,10-dihydroxystearic acid with HCl at 160° for several hours.

Thusfar, in the discussion, in every case involving the formation of a keto acid, with the exception of Behrend's work, there has been

an equal possibility of either or both isomers being formed; however, the 9 and 10-ketostearic acids have also been prepared by various methods which could leave no doubt as to their identity or singularity (2, 3, 10, 14, 29, 36, 64, 65).

Robinson and Robinson synthesized 10-ketostearic acid (64) by condensing ethyl sodio-2-acetyl-n-nonanoate with ethyl 9-(chloroformyl)-nonanoate formerly called, 9-carbethoxynonoyl chloride, followed by acid and alkali cleavage. The free acid was reported to melt at 83°. The same investigators prepared the 9-ketostearic acid (65) by condensing ethyl sodio-2-acetyl-n-decanoate with ethyl 8-(chloroformyl)-octanoate, formerly called 8-carbethoxy-n-octoyl chloride. The reported melting point for this acid was also 83°. They reported further that hydration of stearolic acid, the method by which Baruch (6) claimed to have prepared pure 10-ketostearic acid, gave a mixture of keto acids having a freezing point of 70.86°, which corresponded to a mixture containing 42.25% 9-keto acid and 57.75% 10-keto acid synthesized by them.

Fordyce and Johnson (29) prepared 10-ketostearic acid by reaction of n-octylmagnesium bromide with sebacyl chloride. The melting point of the pure acid was reported to be 82-82.8° and that of its semicarbazone to be 121-122°.

Perhaps the most versatile synthesis to date is the one devised by Bowman. In 1925-6 when Robinson and Robinson were trying to synthesize these two keto acids, they first tried a malonic ester synthesis but found that the conditions required for ester cleavage of the intermediate, resulted in ketone cleavage thus destroying the yield of keto acid. The acetoacetic ester synthesis, which they finally used, resulted in rather poor, yet significant, yields for the same reason.

In 1948, Bowman (15) reported a new ketone synthesis by way of malonic ester. The ethyl sodio-malonic ester was transesterified with benzyl alcohol, and the ethyl alcohol was removed azeotropically. After the condensation, the benzyl alcohol was removed as toluene by hydrogenolysis. This can be done at low pressures in the presence of a carbon-palladium catalyst. Several papers which followed (2, 3, 4, 14, 16, 17, 18) explored the applications of this synthesis to high molecular weight fatty acids and their derivatives.

In one of these papers (4), it was reported that 10-ketostearic acid was prepared by condensing ethyl 9-(chloroformyl)-nonanoate with dibenzyl n-heptylsodiomalonate. The free acid was reported to melt at 83°. In another paper (3), it was reported that 10-hydroxystearic acid was produced by the action of sodium and alcohol on methyl 9-keto-10-methoxystearate which had been previously prepared by way of the benzyl malonic ester route. The 9-hydroxystearic acid was produced by the action of zinc and hydrochloric acid on the same compound. The reported melting points of these hydroxy acids were 75.5° and 81-82° respectively. Upon oxidation with chromic acid, both keto acids melted at 82°. In still another paper (2), it was reported that reduction of the above mentioned 9-keto-10-methoxy compound with hydrogen bromide in acetic acid yielded a mixture of 9 and 10-ketostearic acids (m.p. 73°).

Bergstrom, et al. (10), in 1952, prepared the entire series of mono-ketostearic acids by condensing the proper chloroformyl carboxylate with the proper alkyl cadmium compound. They reported the melting points of the 9 and the 10-ketostearic acids to be 81.7-81.9° and 82.4-82.6° respectively.

Grey, et al. (36) reported the synthesis of 10-ketostearic acid by a desulphurization technique in which ω-(2-butyl-5-thenoyl) nonanoic

acid was treated with Raney nickel and alkali, yielding the keto acid directly. Its reported melting point was 82.5°C and that of its semi-carbazone 118-119°.

A summary of the findings of all the investigations discussed which involve the preparation of 9 and (or) 10-ketostearic(s) acid may be found in tables II and III.

Preparation of the 9,10-Epoxyoctadecyl Alcohols

Cis-9,10-epoxyoctadecyl alcohol was first prepared in 1944 by Swern, et al. (88), who obtained it in 74% yield by the action of per-benzoic acid on oleyl alcohol. The in situ process (27, 84) made it possible to produce the peracid in the reaction flask by air-blowing the corresponding aldehyde in the presence of ultraviolet light. This process, however, did not lead to appreciable yields of the epoxy compound owing to side reactions.

Peracetic acid has also been used to produce the 9,10-epoxy-oct-adecyl alcohols in yields up to 88% (28, 34, 77). The principal side products in this reaction were the 9,(10)-hydroxy-10,(9)-acetoxyoct-adecyl alcohols formed upon opening of the epoxide ring in the presence of acetic acid.

The trans isomer was also prepared by the action of peracetic acid on elaidyl alcohol (70, 87, 96). The cis isomer melted at 52.6-53.5° while the trans isomer melted at 48.0-48.8° (96). These two geometric isomers were distinguished by their infrared patterns (70), and an accurate determination of the composition of a mixture of these isomers was carried out by way of their melting point-composition curve (96). The per cent oxirane oxygen was determined for both isomers by way of HCl titration (25, 87).

TABLE II

MELTING POINTS OF THE 9 AND 10-KETOSTEARIC ACIDS AND RELATED COMPOUNDS
DERIVED FROM PARENT COMPOUNDS THEORETICALLY CAPABLE OF
YIELDING MORE THAN ONE ISOMER

	(6)*	(66)	(47)	(38)	(50)	(92)	(22)
9-Ketostearic Acid	–	81.5°	–	80°	–	–	–
Methyl Ester	–	–	–	–	–	–	–
Semicarbazone	–	118-120°	–	117-119°	–	–	–
Amide	–	–	–	–	–	**	**
10-Ketostearic Acid	75°	72-73°	71°	72°	75-75°	71.5-72°	71-72°
Methyl Ester	–	–	–	–	–	–	–
Semicarbazone	–	101-103°	100-101°	100-102°	–	–	99-104°
Amide	–	–	–	–	–	–	–
9-Hydroxystearic Acid	–	–	–	–	–	–	–
Methyl Ester	–	–	–	–	–	–	–
10-Hydroxystearic Acid	–	–	81°	–	–	–	–
Methyl Ester	–	–	–	–	–	–	–
Hydrazide	–	–	112°	–	–	–	–

* Bibliographic reference.

** These investigators believe the keto acid(s) with this melting point to be a mixture of the two isomers.

TABLE III

MELTING POINTS OF THE 9 AND 10-KETOSTEARIC ACIDS AND RELATED COMPOUNDS
SYNTHESIZED IN SUCH A MANNER AS TO YIELD ONE SPECIFIC ISOMER

	(9)	(64, 65)	(10)	(3, 4)	(36)	(29)
9-Ketostearic Acid	83°	83°	81.7-81.9°	82°	-	-
Methyl Ester	-	-	47.4-48°	-	-	-
Semicarbazone	-	-	-	-	-	-
Amide	-	79°	-	-	-	-
10-Ketostearic Acid	-	83°	82.4-82.6°	82-83°	82.5°	82-82.8°
Methyl Ester	-	-	45.8-46.1°	-	-	-
Semicarbazone	-	-	-	-	118-119°	121-122°
Amide	-	80°	-	80°	-	-
9-Hydroxystearic Acid	-	-	75.4-75.9°	75.5°	-	-
Methyl Ester	-	-	50.3-50.6°	49-50°	-	-
10-Hydroxystearic Acid	-	84.5°	79.2-79.5°	81-82°	-	-
Methyl Ester	-	-	51.5-52°	-	-	-
Hydrazide	-	-	-	-	-	-

Chemical properties: The 9,(10)-chloro-10,(9)-hydroxy and the 9,
(10)-amino-10,(9)-hydroxy derivatives of the 9,10-epoxyoctadecyl alco-
hols have also been prepared and characterized (86, 88); however, no
attempt was made to determine the isomer ratios. Hydroxy-alkoxy com-
pounds have also been produced by the action of various alcohols on the
oxirane in the presence of an acid catalyst (78, 82). Thermal polymer-
ization reportedly lead to viscous oils (79, 80).

The following diagram illustrates, in part, the controversial
points discussed in this chapter:

FIGURE 1

ISOMER DISTRIBUTION AMONG THE CATALYTIC HYDROGENATION PRODUCTS
OF METHYL 9,10-EPOXYSTEARATE AND THE 9,10-EPOXYSTEARIC ACIDS
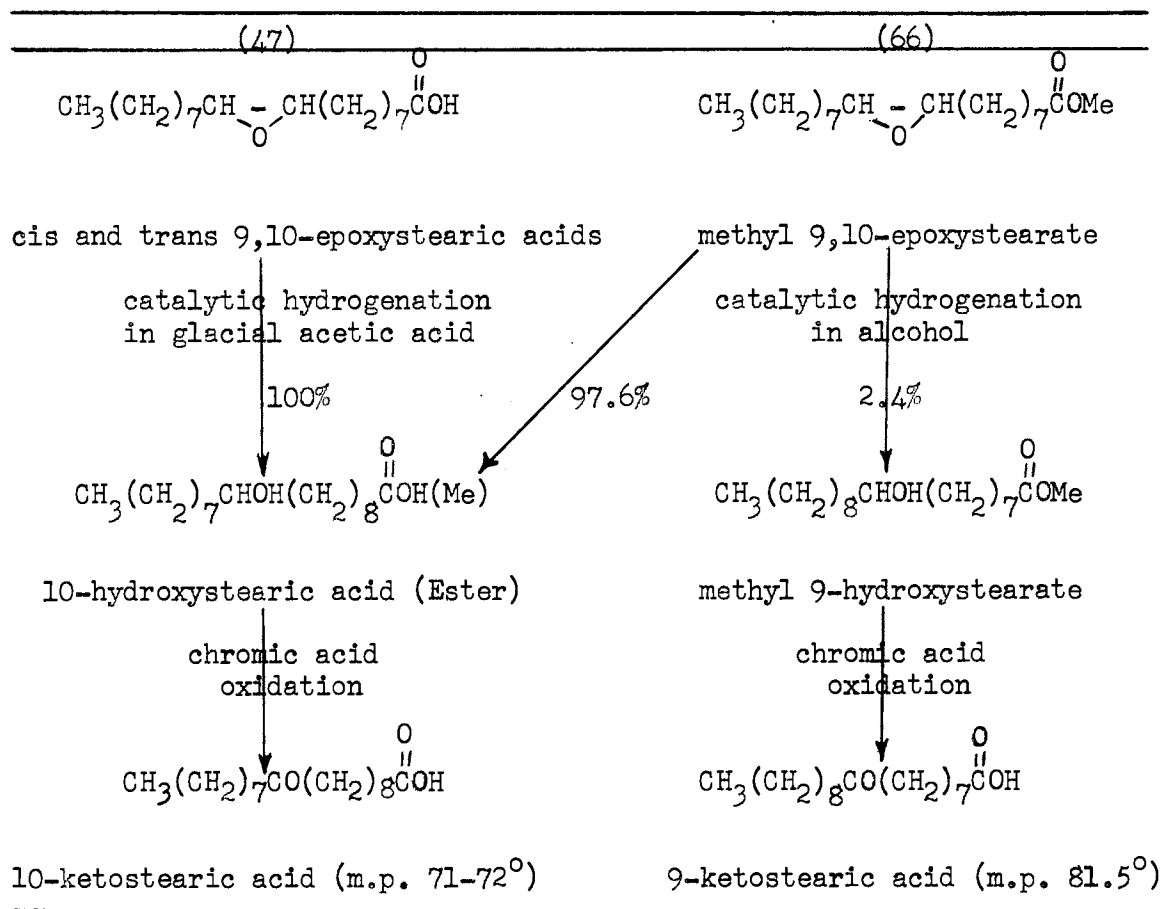
The findings illustrated in figure 1, as well as those of other investigators (6, 38), appear to be contrary to what one would predict from theoretical considerations. There is, moreover, a definite disagreement in the literature concerning the melting point of the 10-ketostearic acid. In the studies outlined in figure 1, the proof of structure was based on the melting point of the keto acid and its semicarbazone.

EXPERIMENTAL

Purification of Oleyl Alcohol (89, 90)

Ten pounds of a technical grade of oleyl alcohol (Adol 32) was obtained from Archer-Daniels-Midland Company. Adol 32 is described as "a straight chain unsaturated monohydric alcohol essentially consisting of oleyl alcohol."

The low temperature crystallization was carried out in a four liter stainless steel beaker suspended in a cooling bath. The bath consisted of a five gallon can inserted into a drum which had a diameter six inches greater than the diameter of the five gallon can. Glass wool was used for insulation. The cooling mixture consisted of acetone and dry ice.

The impure alcohol was disolved in fifteen times its volume of reagent grade acetone. The mixture was cooled slowly with rapid and constant stirring to -22° by maintaining a temperature gradient of approximately five degrees between the alcohol solution and the cooling bath. The temperature was maintained for two hours with constant stirring. At this point, a filter stick was introduced into the slurry and the liquid portion removed by vacuum into a four liter suction flask. The bulk of the acetone was stripped off at room temperature. The last traces of solvent were removed at 100° and under a pressure of about 10-15 mm. Iodine numbers were run by Wijs' method. The iodine number of the original material was ≈81 while that of the stripped liquid was ≈97.

The fractionation of the liquid portion was carried out at the Continental Oil Company Laboratories in Ponca City, Oklahoma. It was fractionated on a three foot column, 41 mm. I.D., packed with no. 2918 Heli-Pak. This column had 60 theoretical plates at atmospheric pressure and total reflux. Under the operating pressure, 15 mm., the efficiency would have been reduced to about 15 plates. After the column was brought to equilibrium, the reflux ratio was set at 10 to 1, and a distillation rate of approximately 2 ml./min. was maintained. Fractions were taken over 1° or 50-ml. intervals, whichever was the larger. The total charge was 3082 g., and a total of 19 cuts were taken. A composite of fractions 12, 13, 14 and 15, boiling range 202-205°, yielded 1216 g. of what was considered to be pure oleyl alcohol. Infrared analysis of cut 14 indicated no carbonyl and only traces of trans isomer.

Preparation of 9,10-Epoxy-1-Octadecanol

The apparatus consisted of a three-necked round-bottom flask which was fitted with a thermometer and a 250-ml. separatory funnel. The flask was further equipped with a variable speed stirrer and this system mounted above an ice bath.

Pure oleyl alcohol, cut number 14, (200 g., about 0.75 mole) was introduced into the flask and 10 g. of anhydrous sodium acetate added.[1] Approximately 50 ml. of acetic anhydride was added to maintain fluidity of the reaction mixture during the reaction. This mixture was stirred rapidly while (157 g., 0.825 moles) of Becco 40% peracetic acid was

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[1]The Becco peracetic acid is produced by a process involving the use of small amounts of sulfuric acid as catalyst. This acid remains as an impurity, and unless a buffer is added, epoxidation is followed by ring opening and formation of the diol. Because of the tendency of the undissolved sodium acetate to clog up the separatory funnel, the buffer was added to the oleyl alcohol in the reaction flask.

slowly added over a period of an hour, keeping the temperature below 25°. The temperature was held at 25° for two hours; at this point, the reaction mixture was poured into cold water, extracted with ether, and the ether solution washed several times with cold water to remove the last traces of acid. The ether solution was evaporated to dryness and the crude product recrystallized from acetone (1 g./3 ml.) at 10°. After several recrystallizations, the following products were obtained: (A) 90 g. of pure cis-9,10-epoxy-1-octadecanol (m.p. 52-53.5°), (B) 8 g. of material (m.p. 43-44°) and assumed to be a 50-50 mixture of the cis and trans isomers (98), (C) 25 g. of a mixture of (A) and (B), and (D) 70 g. of presumedly unreacted oleyl alcohol.

The per cent oxirane oxygen was determined for products (A) 5.56% and (B) 5.54% by direct titration with an acetic acid solution of anhydrous hydrogen bromide (24). These values were in good agreement with the theoretical value of 5.59%.

Hydrogenation of Cis-9,10-Epoxy-1-Octadecanol: Method One

A 10 g. sample of pure cis-9,10-epoxy-1-octadecanol was dissolved in 30 ml. of cold glacial acetic acid and one gram of 10% palladium on carbon catalyst added. This mixture was immediately placed in a Parr model CA-560 analytical hydrogenator and shaken for three quarters of an hour under an initial pressure of 60 p.s.i. Absorption appeared to be complete after 15 minutes. It was found that hydrogenation would proceed under much lower pressures; however, in order to avoid ring opening in the presence of the acetic acid, with formation of the 9,(10)-hydroxy-10,(9)-acetoxy derivative, rapid hydrogenation was desirable. The rate of ring opening at room temperature has been reported to be approximately 1% per hour (28). The reaction mixture was filtered to

remove the catalyst and poured slowly into 800 ml. of cold water, which
was being stirred rapidly by means of a magnetic stirrer. The white
solid was filtered off, washed free of acid, and extracted with ether.
The ether solution was dried and evaporated on a steam bath. The re-
sulting product was recrystallized from petroleum ether. The solvent
to product ratio was not critical as the product was quite soluble in
hot and quite insoluble in cold petroleum ether. After several recrys-
tallizations at room temperature, there was obtained (E) 7.8 g. of
shiny flakes (m.p. 66.5-67.5°). By cooling the mother liquor down to
0° another 1.32 g. of material (m.p. 52.5-54°) was obtained as dull
white prisms. Repeated recrystallizations of this latter product
yielded small amounts of the higher melting product and (F) 0.8 g. of
shiny flakes (m.p. 53.5-55°). The infrared patterns of (E) and (F)
were very similar, and (F) may in fact be composed principally of (E)
with some impurity present.

Reduction of Cis-9,10-Epoxy-1-Octadecanol: Method Two

The apparatus consisted of a 500-ml. Erlenmeyer flask fitted with
a ground glass reflux condenser and drying tube. A magnetic stirrer
was used to agitate the reaction mixture.

Dry ether (200 ml.) was introduced into the flask and 4 g. of
lithium aluminum hydride added. The small chunks of hydride were
broken up under the ether by means of a glass stirring rod. This mix-
ture was stirred rapidly under reflux for 24 hours. A considerable
portion of the hydride remained undissolved;[1] however, this apparently

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[1]Contrary to manufacturers claims, it has been the author's experi-
ence (31) that the grey variety of lithium aluminum hydride is only par-
tially soluble in ether even in very dilute solution; however, the white
variety is almost completely soluble even at relatively high concentra-
tions.

did not interfere with the ensuing reduction. A solution of 10 g. of cis-9,10-epoxy-1-oxtadecanol in 200 ml. of dry ether was then introduced slowly through the reflux condenser. Reaction was rapid and the mixture became thick. The reaction was allowed to continue under reflux with constant stirring for 12 hours. At this point, the mixture was cooled and the condenser removed. Ethyl alcohol was added drop by drop with constant stirring until all violent reaction ceased. A 10-20 ml. excess of alcohol was then added and stirring continued for one hour. A 50% mixture of alcohol and water was then added slowly until apparent reaction ceased. An excess of water was then added and the mixture turned from grey to white indicating removal of the last traces of hydride. An excess of 10% sulfuric acid was added slowly with rapid stirring until both the water and ether layers became clear. The two layers were then separated. The ether layer was washed twice with cold water, dried over anhydrous sodium sulfate, and evaporated to dryness. The solid material remaining was recrystallized three times from petroleum ether, yielding 9.7 g. of material (m.p. 66.5-67.5°). A mixed melting point of this material with material (E) obtained in the hydrogenation of the epoxide showed no depression.

Oxidation of the 1,9 and (or) 1,10-Octadecanediol(s)

The chromic acid oxidation of 1,9 and (or) 1,10-octadecanediol(s) was carried out under a variety of conditions. Using only a slight excess of oxidizing agent and temperatures below 30°, yields up to 92% of theoretical were obtained; however, the resulting product melted over a wide range (67-71°), and attempts to purify this material by recrystallization were unsuccessful.

The method which was finally adopted may be illustrated by the

following example. A 7.5 g. sample of diol was dissolved in about 20 ml. of glacial acetic acid in a 180-ml. titration beaker. This beaker was placed in a cooling bath which consisted of a 400-ml. beaker containing approximately 100 ml. of water. The mixture was stirred by means of a magnetic stirrer, and a solution of 16 g. of chromic oxide (3-fold excess), 120 ml. of glacial acetic acid and 15 ml. of water was added slowly, keeping the temperature below 25° during the addition. The temperature was then increased to 30° and maintained for two hours. The reaction mixture was poured slowly into 600-800 ml. of cold water which was being agitated vigorously. The greenish-white solid, containing reduced chromium ion and acetic acid, was filtered off and washed several times by redispersing in cold water and filtering. The resulting wet material was extracted with ether and the water layer removed. The ether layer was washed with water, treated with decolorizing charcoal, and filtered through a jacketed sintered glass filter containing an asbestos pad. This removed the green color. The resulting clear ether solution was dried over anhydrous sodium sulfate and the solvent evaporated. Recrystallization of the crude product from a mixture of one part acetone to two parts petroleum ether gave 5.5 g. or about a 70% yield of product (m.p. 69-71°).

Epoxidation of Oleic Acid

An 80 g. sample of U.S.P. oleic acid, obtained from Mallinckrodt, was treated with 100 ml. of buffered 25% peracetic acid in the same manner as the oleyl alcohol. The crude product was recrystallized from acetone (1 g./3 ml.), but no sharp melting material could be obtained.

A 40 g. sample of the recrystallized material was dissolved in 80 ml. of glacial acetic acid, 4 g. of C-Pd catalyst added, and the

mixture hydrogenated as before under an initial pressure of 70 p.s.i. The pressure drop was slow, but absorption appeared to be complete within three hours. The product was isolated in the usual way; however, in filtering off the catalyst, it was noted that a considerable quantity of solid material remained in the filter. This was dissolved in warm acetic acid and the catalyst again filtered off. By wasteful recrystallization of the crude product first from ethanol and then from petroleum ether, there was obtained 12 g. of material (m.p. 80.5-81.5°), assumed to be the hydroxy acid(s). The hydrazide was prepared by the standard method (m.p. 110-112°).

Reduction of 9 and (or) 10-Hydroxystearic Acid(s)

A 1.8 g. sample of the hydroxy acid(s) was reduced with 2 g. of lithium aluminum hydride in ether, by the procedure previously outlined. Reaction in this case was slow, and the reduction was allowed to continue under reflux and stirring for four days. The crude product weighed 1.6 g. After a second recrystallization from petrolium ether, 1.4 g. of material (m.p. 66.5-67.5°) was obtained. A mixed melting point of this material with that obtained by hydrogenation of the cis-9, 10-epoxy-1-octadecanol showed no depression.

Oxidation of 9 and (or) 10-Hydroxystearic Acid(s)

A 4 g. sample of the hydroxy acid(s) was oxidized with a chromic acid solution as previously outlined. The crude product was recrystallized from petroleum ether first at 35° giving (G) 1.8 g. of material (m.p. 69.5-72°) and then at 0° giving (H) 1 g. of material (m.p. 70-70.5°). Repeated recrystallization of (G) gave (I) 1.5 g. of material (m.p. 70.5-71.5°) and 0.2 g. (m.p. 72-75°).

All the products previously obtained by oxidation of the diols

were combined and dissolved in hot petroleum ether. The solution was treated with decolorizing charcoal, filtered, and fractionated at 35° and 0°. The melting point of the first and largest fraction (J) was $69.5-70.5^{\circ}$ while the melting point of the second fraction was $66-68^{\circ}$.

The mixed melting point of fractions (H) and (J) was $69.5-70.5^{\circ}$.

Formation of the Semicarbazones of the Keto Acids

Special attention was given to the formation of the semicarbazones of the 9 and the 10-ketostearic acids since it was impossible to obtain them by the standard methods without considerable modification. After many unsuccessful attempts, the following procedure was found to be satisfactory.

A 0.5 g. sample of keto-acid was dissolved in about 30 ml. of 95% ethanol in a large test tube. Water was then added drop by drop until the solution became turbid. This turbidity was cleared up with additional alcohol. To this solution, a mixture 0.5 g. of semicarbazide hydrochloride and 0.75 g. of anhydrous potassium acetate was added and the contents of the tube shaken vigorously. The tube was then placed in a beaker of boiling water and allowed to cool again to room temperature.[1]

The solid material was filtered off, and the clear liquor was cooled in an ice bath. The resulting solid crystalline material was filtered on a coarse sintered glass filter, washed with water, and dried. The dried product was dissolved in a minumum of hot 95% alcohol and allowed to crystallize at room temperature. This material was filtered off and melting points taken. In some cases more than one re-

[1]The mixture of semicarbazide hydrochloride and potassium acetate was never completely in solution, but by using such a large amount of alcohol and thereby increasing the tolerance for water, apparently enough of the salt mixture was soluble to permit reaction.

crystallization from alcohol was required.

The semicarbazone of (H) had a melting point of 97-100° while the semicarbazone of (J) had a melting point of 97-99°. A mixed melting point of the two semicarbazones gave no depression.

Synthesis of the Pure 9 and 10-Ketostearic Acids (4)(14)

General Scheme: The equations representing the most significant steps in the preparation of the 9 and the 10-ketostearic acids are outlined in figure 2. The preparation of the 9-isomer was chosen arbitrarily for illustration since both isomers were prepared by the same general method.

Reagents: The following Eastman white label chemicals were used in this synthesis:

n-Bromoheptane	100 g.	
n-Bromooctane	100 g.	
Sebacic Acid	200 g.	
Diethyl Sebacate	100 g.	
Azelaic Acid	500 g.	
Thionyl Chloride	200 g.	
Diethyl Malonate	300 g.	
Benzyl Alcohol	500 g.	Matheson
Dibutyl Ether	250 ml.	

The diethyl malonate was redistilled at reduced pressure through a Todd column and the center cut taken for this synthesis. The refractive index of this cut was in good agreement with the accepted value.

The dibutyl ether was dried over sodium, redistilled through a Todd column, and the center cut was again taken. The boiling point and refractive index were in good agreement with accepted values.

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[1]The physical constants of these compounds were checked i.e. boiling point, melting point, and refractive index, and were found to be in good agreement with the accepted values; so these materials were used without further purification.

FIGURE 2

EQUATIONS ILLUSTRATING THE SIGNIFICANT STEPS IN THE
PREPARATION OF 9-KETOSTEARIC ACID
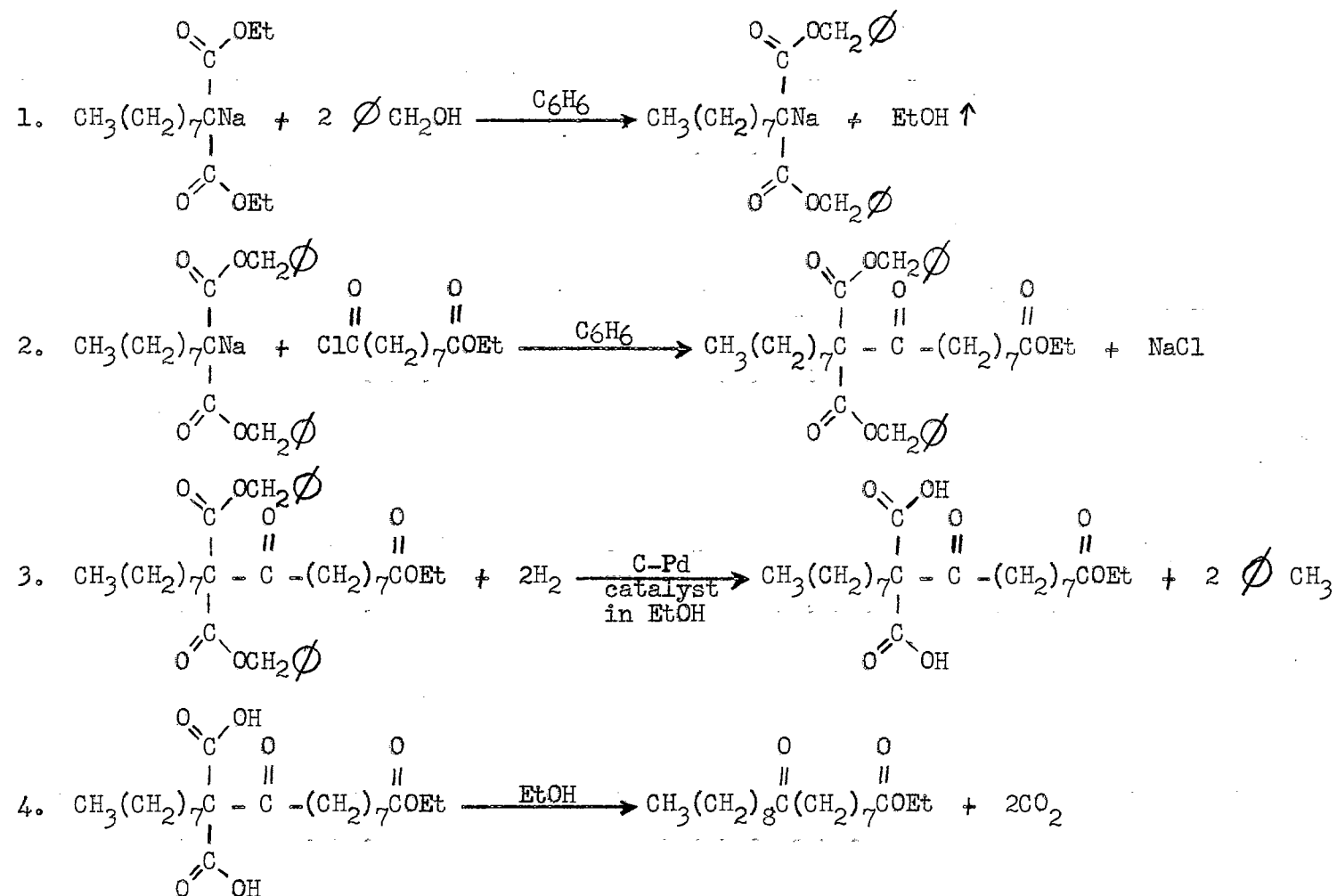
The benzyl alcohol was purified according to the procedure used by Bowman (14). In this procedure, the benzyl alcohol was heated on a steam bath with one-twentieth its weight of Raney nickel for three hours with occasional stirring. The bulk of the alcohol was then decanted off and distilled at reduced pressure and under an atmosphere of nitrogen. In the present synthesis, the benzyl alcohol was purified just prior to its use and kept under an atmosphere of nitrogen at all times.

Preparation of diethyl n-heptylmalonate: A 500-ml. round-bottom flask fitted with a reflux condenser, separatory funnel, and magnetic stirrer was clamped on a steam bath. Absolute alcohol (250 ml.) which had been previously dried over anhydrous cupric sulfate, was distilled, over one-twentieth its weight of sodium, directly into the flask. Clean sodium (11.5 g., 0.5 mole) weighed by difference from a weighing bottle containing dry toluene, was dropped piece by piece through the condenser into the alcohol. The temperature of the alcoholic solution was maintained below 50° until the reaction was complete. At this point, diethyl malonate (82.5 g., 0.515 mole) was added slowly through the separatory funnel. No heat effect was observed. 1-bromoheptane (89.5 g., 0.5 mole) was added slowly to this solution. Here again no heat effect was observed; however, a white precipitate, sodium bromide, began to form quickly and soon became quite heavy. The reaction mixture was refluxed until neutral to indicator paper, about six hours being required. The reflux condenser was then removed and the excess alcohol distilled off. Water was used to wash the sodium bromide and remaining alcohol from the organic layer. After drying, the residual material was distilled through a Todd column $142^{\circ}/5$ mm. yielding 94.5 g. of almost odorless, water white, diethyl n-heptylmalonate.

Preparation of diethyl n-octylmalonate: This compound was prepared in the same manner as its homologue. In this case there was obtained 104 g. of diethyl n-octylmalonate, distilling at $153^{\circ}/5$ mm.

Preparation of diethyl azelate: A mixture of azelaic acid (61 g., 0.324 mole), absolute alcohol (58 ml., 1 mole), about 65 ml. of toulene, and 0.6 g. of concentrated sulfuric acid was prepared. This mixture was introduced into a distilling flask fitted with a thirty cm. column and the fractionating head from the Todd column. Distillation was begun under a one to ten reflux ratio. The azeotrope began to distill at 74°, and distillation was continued until a temperature of 78° was reached. The distillate was collected over an excess of anhydrous potassium carbonate. The distillate and carbonate were shaken, the excess carbonate filtered off, and the distillate returned to the distilling flask. The distillation was carried out as before. When the overhead temperature reached 78°, the remaining solvent was flashed off. The last traces were removed at 100° under the vacuum produced by a water aspirator. The residual material was finally distilled through a Todd column $130-132^{\circ}/2$ mm. The yield was 65 g.

Preparation of ethyl hydrogenation sebacate (11): A mixture of sebacic acid (101.1 g., 0.5 mole), diethyl sebacate (67 g., 0.26 mole), about 25 ml. of n-dibutyl ether, and 15 g. of concentrated hydrochloric acid was prepared. This mixture was introduced into a 500-ml. round-bottom flask equipped with a reflux condenser. The flask was heated in an oil bath to $150-160^{\circ}$ and held until the mixture appeared homogeneous. This material was cooled to about 130°. Absolute alcohol (30 ml.) was then added through the condenser. The resulting mixture was refluxed for two hours, at which time an additional 10 ml. of alcohol was added and the mixture allowed to reflux for another two hours. The flask and

contents were then cooled to 70° and subjected to distillation under the vacuum of a water aspirator. The temperature was gradually increased to 140°. The products were cooled and transferred to a modified Claisen flask of 500 ml. capacity.

This flask was made by attaching a length of 10 mm. pyrex glass tubing to a 500-ml. round-bottom flask containing a thermometer well. A side arm was attached to the tube approximately 40 cm. above the top of the flask. A standard taper joint was attached to the upper end of the 10 mm. column to accomodiate a ground glass thermometer, and the entire length of the column was tightly wrapped with one half inch asbestos rope. This modified flask was designed to eliminate leakage at high temperatures and low pressures. All attempts to use the Todd column met with failure as none of the commercial vacuum greases available would maintain a continuous film under the conditions of temperature and pressure required.

The material which was transferred to this modified Claisen flask was distilled. Diethyl sebacate (133-135°/1 mm.) was the first fraction to come over followed by ethyl hydrogen sebacate (163-166°/1 mm.). Approximately 60 g. of this half ester was collected.

Preparation of ethyl hydrogen azelate: This compound was prepared in the same way as its homologue. The yield was again approximately 60 g., distilling at (159-161°/2-3 mm.).

Preparation of ethyl 9-(chloroformyl)-nonanoate: A mixture of ethyl hydrogen sebacate (53 g., 0.23 mole) and thionyl chloride (35 ml., 0.53 mole) was introduced into a 250-ml. round-bottom flask equipped with a reflux condenser. This mixture was heated in an oil bath at 95° for five hours. The excess thionyl chloride was distilled off under the vacuum of a water aspirator. The temperature of the oil bath was

gradually raised to 140°. After cooling, the contents of the flask were transferred to the modified Claisen flask previously mentioned and distilled at 137-139°/2-3 mm. yielding 50 g. of the acid chloride.

Preparation of ethyl 8-(chloroformyl)-octanoate: This compound was prepared in the same manner as its homologue. The yield was 49 g., distilling at 128-130°/2-3 mm.

Preparation of 10-ketostearic acid: Approximately 100 ml. of absolute alcohol was distilled over one-twentieth its weight of sodium, directly into a 500-ml. three necked round-bottom flask fitted with a reflux condenser and drying tube. Clean sodium (4.6 g., 0.2 mole), weighed by difference from a weighing bottle containing dry toluene, was dropped into the alcohol piece by piece. The temperature was kept below 50° until reaction ceased. The bulk of the excess alcohol was then distilled off at atmospheric pressure. When a crust began to form, the water aspirator was connected to the system the remaining alcohol flashed off. The residual sodium ethoxide formed a solid white foam almost filling the flask. The contents of the flask were allowed to cool under a vacuum,[1] and a solution of diethyl n-heptylmalonate (54.5 g., 0.2 mole) in about 200 ml. of dry benzene was introduced through the separatory funnel. Solution of the sodium ethoxide was immediate. The vacuum was released and pure benzyl alcohol (43.3 g., 0.4 mole) added to the contents of the flask. This mixture was set up for distillation on the Todd column. The reflux ratio was set just high enough to maintain the azeotropic boiling point for benzene and ethanol (68-69°). The ratio had to be increased as the distillation progressed, finally it was set at 20 to 1. About 12 to 14 hours in all were re-

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[1]It was noted that when the vacuum was released prior to addition of the malonic ester, the foam turned dark red.

quired for the boiling point to reach and maintain the boiling point of pure benzene under full reflux. At this point, the exchange was considered complete, and the mixture was cooled.

A solution of ethyl 9-(chloroformyl)-nonanoate, the acid chloride of ethyl hydrogen sebacate, (47 g., 0.2 mole) in about 100 ml. of dry benzene was added slowly through a separatory funnel while stirring constantly (magnetic stirrer). There was a pronounced heat effect, and after about 9/10 of the acid chloride had been added the mixture began to jell. It was necessary to heat the mixture and stir it with a mechanical stirrer during the addition of the remainder of the acid chloride. The reaction mixture was refluxed for one half hour, then cooled and poured into ice water containing a trace of sulfuric acid. The two layers were separated. The water layer was extracted with benzene, and the organic layer along with the combined benzene extracts were washed with water. The benzene layer was dried overnight with anhydrous sodium sulfate. The benzene was stripped off, first at atmospheric pressure, and finally at $100^\circ/0.5$ mm.

A 20 g. sample of the residual material, which represented about 1/4 of the total yield, was dissolved in about 80 ml. of absolute alcohol and 2 g. of carbon-palladium catalyst added. This mixture was placed in the analytical hydrogenator, previously mentioned. Hydrogenolysis was rapid and essentially quantitative under an initial pressure of 45 p.s.i. The catalyst was filtered off and the solution refluxed to promote decarboxylation.

The alcohol was distilled from the product, first at atmospheric pressure, and finally at $100^\circ/0.5$ mm. The rather dark residue was then boiled with a mixture of 25 ml. of glacial acetic acid containing about 0.8 ml. of 20 normal sulfuric acid, to bring about ketone cleavage of

any remaining β-keto ester. This mixture was then poured into ice water, washed free of acid, and dried. From this point, two separate procedures were followed.

(1) One half of the crude product was azeotropically esterified by the procedure outlined previously.[1] The mixed esters were distilled from a 50-ml. Claisen flask modified as previously described. The flask was heated to 190° under a pressure of 0.5 mm. The residual material in the flask was saponified with alcoholic potassium hydroxide and the free acid isolated in the usual manner. This crude product, after several recrystallizations from absolute alcohol and finally from petroleum ether, yielded approximately 3 g. of 10-ketostearic acid (m.p. 82-82.5°).

(2) The second half of the crude product was recrystallized directly from alcohol without going through the esterification, distillation, and saponification. After three recrystallizations from alcohol, approximately 4 g. of 10-ketostearic acid (m.p. 82-82.5°) was obtained. Recrystallization of this material from petroleum ether did not affect the melting point. A mixed melting point of this material with that obtained by the first method showed no depression.

The semicarbazone of 10-ketostearic acid was prepared by the method previously outlined and found to have a melting point of 117-119°.

Preparation of 9-ketostearic acid: This compound was prepared in the same manner as its homologue, using the second procedure outlined above in the final stages. In this case, 6.8 g. of 9-ketostearic acid (m.p. 81.2-81.7°) was obtained.

The semicarbazone of this keto acid had a melting point of 118-120°, and a 50% mixture of the semicarbazones of the 9 and the 10-keto-

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[1]See page 29

stearic acids had a melting point of 102-104°.

The melting point-composition curve for the 9 and the 10-keto-stearic acids may be found in figure 3.

Preparation of the 1,10-Octadecanediol

A 2 g. sample of 10-ketostearic acid was reduced with 2 g. of lithium aluminum hydride by the procedure previously outlined. The crude product was recrystallized three times from petroleum ether yielding 1.82 g. of diol (m.p. 73.5-74°). This represented about a 95% yield.

Preparation of the 1,9-Octadecanediol

This compound was prepared in the same manner as its homologue. In this case, 2 g. of keto acid yielded 1.79 g. of 1,9-octadecanediol (m.p. 73.8-74.3°). This represented a yield of about 93%.

A melting point composition curve for the 1,9 and the 1,10-oct-adecanediols may be found in figure 3.

Infrared Spectra of the Keto Acids and Diols

The spectra of the 9 and the 10-ketostearic acids and the 1,9 and the 1,10-octadecanediols have been investigated through the courtesy of Dr. J. C. Cowan of the U.S.D.A. Research Laboratories in Peoria, Illinois.

The analysis was carried out on a Beckmann model IR-3 infrared-spectrophotometer. One millimeter sodium chloride cells were used. Chloroform was used as the solvent and as the reference material in this double-beam instrument.

The spectra of each pair of compounds is quite similar as would be expected; however, the 1,9-diol does show one maximum at about 10 μ not exhibited by the 1,10-diol. This difference may be seen by refer-ence to figure 4.

FIGURE 3

Melting Point vs. Composition Curves for the
1,9 & 1,10 - Octadecanediols and the 9 & 10 - Ketostearic Acids
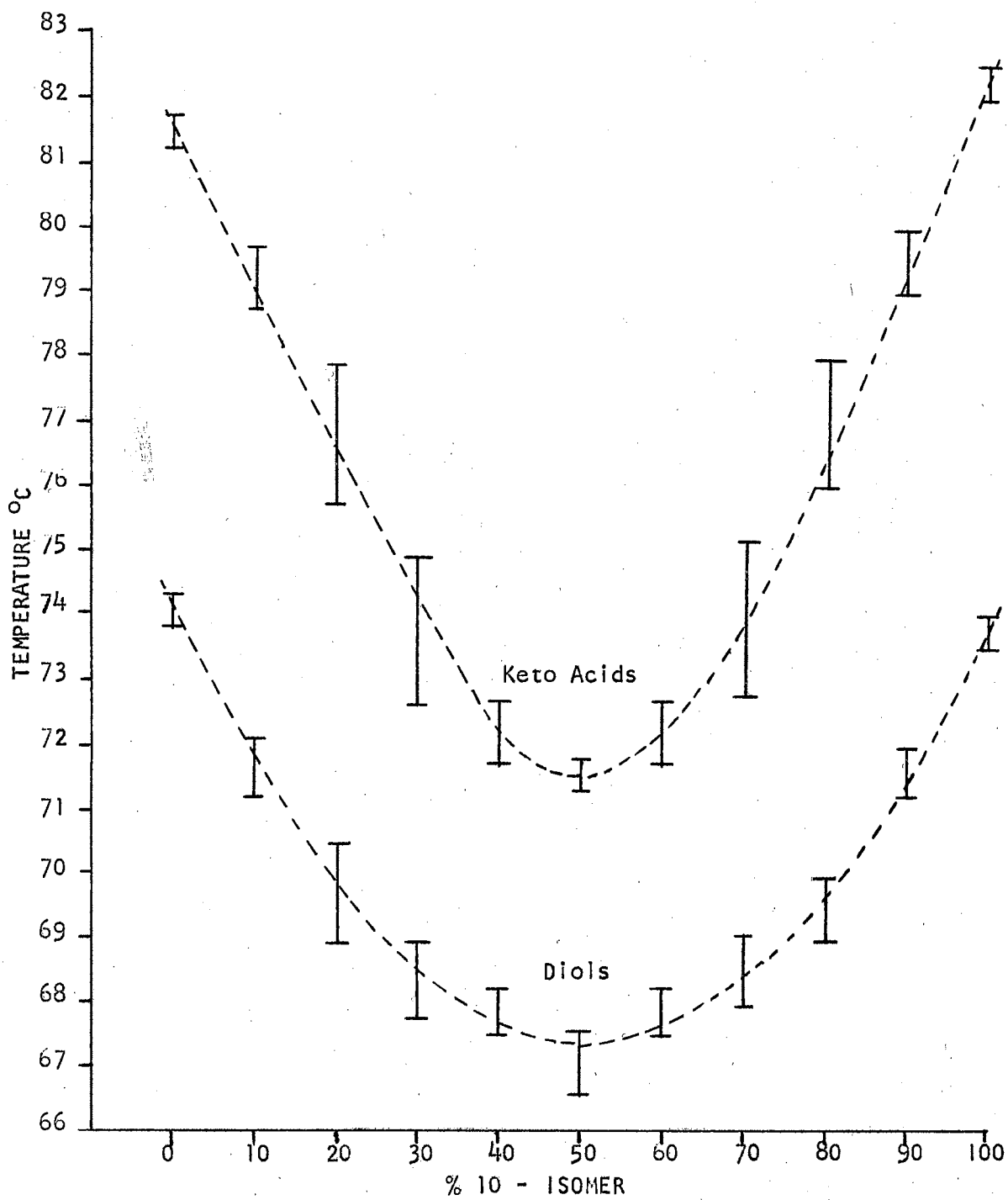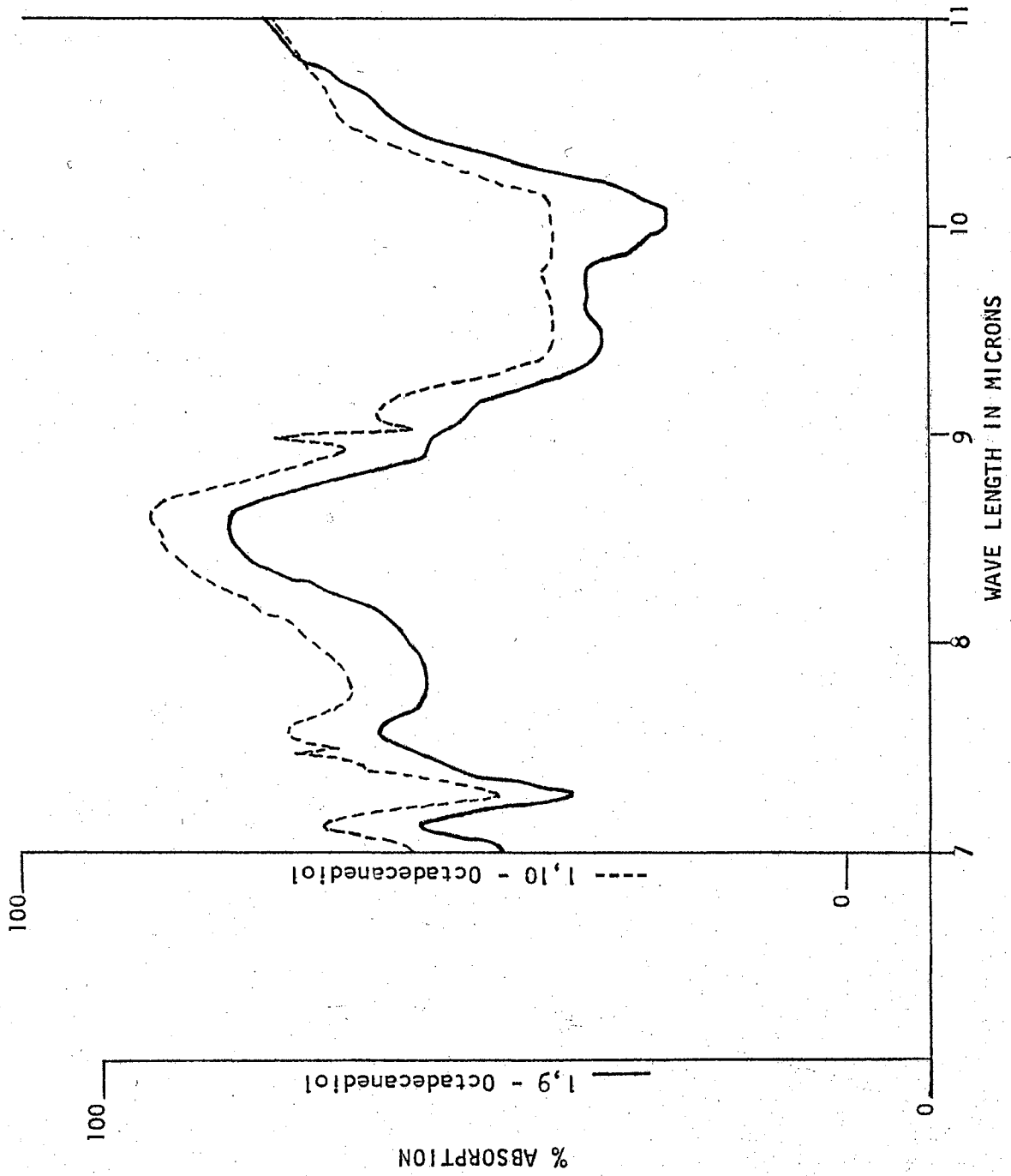
FIGURE 4. Absorption Curves of the 1,9 & 1,10 - Octadecanediols

DISCUSSION

It was mentioned previously that the work of certain investigators (47, 48, 61, 66) indicated that the catalytic hydrogenation of methyl 9,10-epoxystearate and the 9,10-epoxystearic acids resulted in a nonrandom distribution of the expected products. It has, in fact, been claimed that the catalytic hydrogenation of the 9,10-epoxystearic acids, in glacial acetic acid using a C-Pd catalyst, was unidirectional, yielding 10-hydroxystearic acid to the complete exclusion of the other isomer. It should be recalled that proof of the identity of 10-hydroxystearic acid was based primarily on the melting point of its oxidation product, 10-ketostearic acid (m.p. 71-72°), and the semicarbazone of 10-ketostearic acid (m.p. 100-103°).

The following arguments were presented to explain this unexpected orientation. "The fact that 10-hydroxystearic acid is produced to the exclusion of the 9-isomer indicates that there is a strong directional force within the molecule which favors the rupture of the ninth carbon-oxygen bond. Consideration of the geometrical configuration of the molecule as well as its infrared spectra (54) suggests a folding back (field effect) of the carboxyl group which would cause the ninth carbon atom to be slightly positive with respect to the tenth carbon atom. Yet the relative non-selectivity of other addition reactions of epoxystearic acid indicates that the field effect in itself is not sufficient to account for the high selectivity encountered in the hydrogenation reaction. Therefore the electrophilic nature of the -COO- group must

also exert its influence on the activated hydrogen on the catalyst sur-
face, so orienting the respective ions that a hydride ion is exclusively
directed toward the more positive ninth carbon atom resulting in the
selective rupture of the ninth carbon oxygen bond" (47). The infrared
spectra referred to above (54) was that of the 10-hydroxystearic acid
prepared by the method just outlined. In the analysis of this spectra,
it was found that the normal prominent band due to the O-H bond stretch-
ing, which occurs in the region of 2.7 to 3.0μ, was not in evidence.
This was interpreted as being caused by hydrogen bonding, O-H----O which
would shift the band above 3μ, where it would be impossible to resolve
it from the C-H band occuring at 3.3μ. It was further argued that
since repeated dilutions did not reveal the presence of the O-H bond, the
hydrogen bonding might be intramolecular rather than intermolecular.

The proposed model is shown in the following figure.

$$CH_3(CH_2)_7CH \underset{\displaystyle O \underset{\diagdown H \text{---} O}{\overset{\diagup H \text{---} O \diagdown}{}} C}{\overset{\displaystyle |}{}} (CH_2)_8$$

This is the proposed folding back (field effect) mentioned previously.
It was found that in the case of methyl 10-hydroxystearate, the O-H
band could be resolved (2.86μ), and it was argued that the reason for
this was, that in this case, only a single hydrogen bridge could be
formed as shown below. Therefore the field effect would not be as

$$CH_3(CH_2)_7CH \underset{\displaystyle O \underset{\diagup R \text{---} O}{\overset{\diagup H \text{---} O \diagdown}{}} C}{\overset{\displaystyle |}{}} (CH_2)_8$$

great, and the O-H band could be resolved.

The mechanism proposed by Mack and Bickford for the catalytic hydrogenation of the 9,10-epoxystearic acids in glacial acetic acid is as follows:

$$1. \quad RC\overset{H}{\underset{O}{\diagdown}}CR' + H^+ + CH_3COO^- \rightleftharpoons RC\overset{H}{\underset{O^+}{\diagdown}}CR' + CH_3COO^-$$

$$2. \quad Pd_x + H_2 \rightleftharpoons H^+ Pd_x H^-$$

$$3. \quad RC\overset{H}{\underset{\underset{H}{O^+}}{\diagdown}}CR' + H^+ Pd_x H^- \rightleftharpoons \begin{bmatrix} H & H \\ RC & - & CR' \\ OH & HPd_x H^+ \end{bmatrix}^+$$

$$4. \quad \begin{bmatrix} H & H \\ RC & - & CR' \\ HO & HPd_x H^+ \end{bmatrix}^+ \rightleftharpoons \begin{matrix} H & H \\ RC & - & CR' \\ HO & H \end{matrix} + Pd_x + H^+$$

$$5. \quad H^+ + CH_3COO^- \longrightarrow CH_3COOH$$
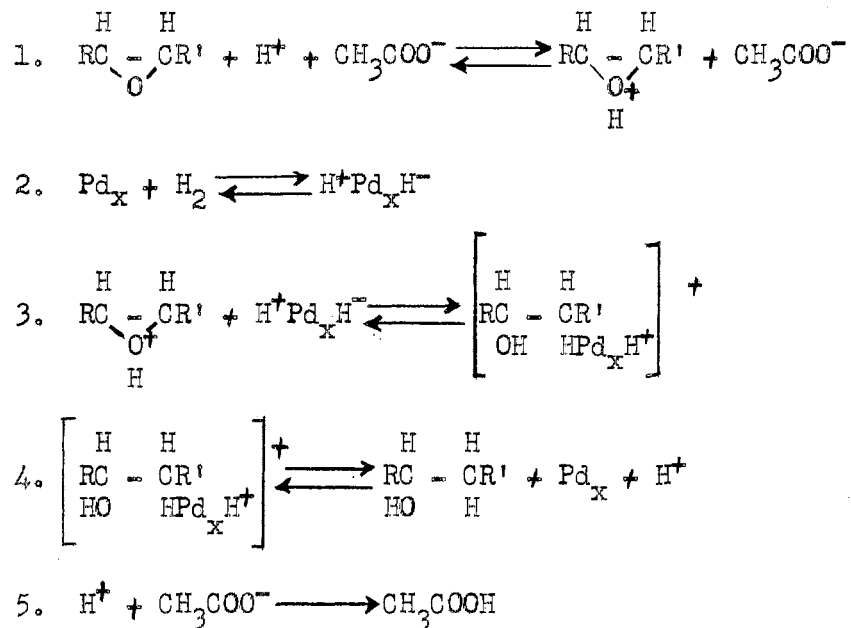
A diagramatical outline of the results of the present experimentation may be found in figure 5. Hereafter, in this discussion, the symbol (d) will be used when referring to this diagram.

The epoxidation and hydrogenation of a sample of commercial oleic acid resulted in the isolation of a hydroxy acid(s) from which the hydrazide derivative was prepared (d). This hydroxy acid(s) was oxidized to the keto acid(s) from which the semicarbazone was prepared (d). The melting points of these four compounds were in good agreement with those reported by Mack and Bickford (47).

Oxidation of the hydroxy acid to the keto acid resulted in an undesirably poor yield, and it was found throughout this investigation that oxidations, in general, were accompanied by rather poor yields. To complicate the situation even further, the yields were not reproducible with any degree of precision, even under identical conditions. If the

FIGURE 5

THERMAL INTERRELATIONSHIPS OF THE OXYGENATED DERIVATIVES
OF OLEIC ACID AND OLEYL ALCOHOL

Semicarbazone m.p. 97-99°

9 and (or) 10-Ketostearic Acid
m.p. 69.5-71°

CrO₃ oxidation

1,9 and (or) 1,10-Octadecanediol
m.p. 66.5-67.5°

m.p. 53-55°

LiAlH₄
97% yield   87%   9%
cat-hydrogenation

9,10-Epoxy-1-Octadecanol   9,10-Epoxy-1-Octadecanol

50-50 Mixture

1,10-Octadecanediol   1,9-Octadecanediol
m.p. 73.5-74°   m.p. 73.8-74.3°

LiAlH₄ 95% yield   LiAlH₄ 95% yield

10-Ketostearic Acid (Pure)   9-Ketostearic Acid (Pure)
m.p. 82-82.5°   m.p. 81.2-81.7°

50-50 Mixture

m.p. 71.3-71.8°

Semicarbazone   Semicarbazone
m.p. 117-119°   m.p. 118-120°

50-50 Mixture

m.p. 102-104°

Oxidation
m.p. 70.5-71.5°
semicarbazone
97-100°

1,9 and (or) 1,10-Octadecanediol   LiAlH₄
m.p. 66.5-67°   82% yield

Commercial   Peracetic Acid   epoxide not   cat   hydroxy acid
Oleic Acid   90% Pure   isolated   Hydrogenation   m.p. 80.5-81.5°
                                                                    hydrazide
                                                                    m.p. 110-112°
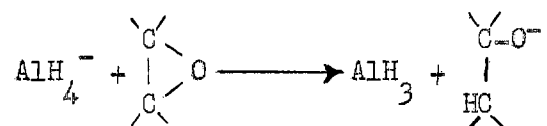
conditions are too severe, oxidative cleavage may result in loss of product, while if conditions are not severe enough, oxidation may not be complete. In either case, isolation of the final product in the pure form is difficult, and the yields consequently poor. On the other hand, reductions are less subject to side reactions and in many cases, result in cleaner products and better yields. Reduction of the hydroxy acid was carried out in ether solution using lithium aluminum hydride and resulted in a reasonably good yield (82%) of the corresponding diol(s) (m.p. 66.5-67.5°).

Since cis-9,10-epoxy-1-octadecanol could exhibit only one hydrogen bridge in the proposed folding back effect, one might expect, on the basis of arguments presented previously, that in the hydrogenation of this epoxy alcohol, a less marked directional orientation might result. Hydrogenation of this compound gave an 87% yield (based on the total crude product recovered) of a diol(s) (m.p. 66.5-67.5°) apparently identical (mixed melting point) with the diol(s) obtained by reduction of the hydroxy acid. A small amount (9%) of a lower melting unidentified material was also obtained.[1] Chromic acid oxidation of the diol(s) (m.p. 66.5-67.5°) gave a keto acid(s) (m.p. 69.5-70.5°) which was apparently identical (mixed melting point) with that obtained in the chromic acid oxidation of the hydroxy acid(s).

If one could eliminate the solvent effect caused by the strongly polar glacial acetic acid, by use of an inert nonpolar solvent, and if one could, in addition, eliminate the surface effect caused by the catalyst, a more accurate estimate of the importance of the field effect could be made. This was accomplished by reducing cis-9,10-epoxy-1-

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[1]See page 21.

octadecanol with lithium aluminum hydride in ether solution. Almost all reductions involve "the displacement of a strongly electronegative atom (O, N, halogen, etc.) and the accession of a hydrogen atom to the electron deficient center, usually a carbon atom" (19). If the reactive species is the aluminohydride ion, the most reasonable mechanism could be illustrated as follows:

$$AlH_4^- + \begin{matrix} \diagdown C \diagup \\ | \quad \diagdown \\ | \quad \diagup O \\ \diagup C \diagdown \end{matrix} \longrightarrow AlH_3 + \begin{matrix} \diagdown \diagup \\ C-O^- \\ | \\ HC \\ \diagup \diagdown \end{matrix}$$

The alkoxide ion may then coordinate with the AlH_3 and the reaction continue until $Al(OR)_4^-$ is formed. In any case, if there is an appreciable field effect in the molecule of cis-9,10-epoxy-1-octadecanol which would cause the number 9 carbon to be slightly positive with respect to the number 10 carbon, the number 9 carbon would be the favored reactive site, and one would expect a nonrandom distribution of reduction products resulting in the predominance of the 1,10-octadecanediol. The results of this reduction were indeed very similar to the results of the catalytic hydrogenation of the same compound. In this case, a 97% yield of the diol(s) (m.p. 66.5-67.5°) was obtained.

Provided one accepts the method of proof used by previous investigators (47, 66), the results of this experimentation as conducted to this point would appear to indicate that nonrandom unidirectional orientation is achieved in (I) the catalytic hydrogenation and (II) the chemical reduction of cis-9,10-epoxy-1-octadecanol as well as in (III), the catalytic hydrogenation of the cis-9,10-epoxystearic acid. This, however, would seem highly unlikely when one considers that in (I) the experimental conditions were identical to (III), but the functional group was changed from -COOH to -OH, and that (II) involved a drastic

change in experimental conditions as well as a change of functional

groups.

The apparent resolution of this problem may be found in the above

mentioned method of proof. As was indicated in the historical section,

there is some obvious disagreement in the literature as to the correct

melting point of 10-ketostearic acid and its semicarbazone. Reference

to tables II and III would indicate the melting point of 10-ketostearic

acid obtained by purely synthetic means is 82-83°, while that of its

semicarbazone is 118-122°. On the other hand, the melting point of

this acid as given by other investigators who have obtained it by some

modification of oleic or stearolic acid is set in most cases at 71-73°

while that of its semicarbazone is reported to be 100-103°.

Both the 9 and the 10-ketostearic acids have been prepared for

this investigation (d) by a malonic ester synthesis, which can leave no

doubt as to their identity. Both of these compounds melt at a temper-

ature in excess of 80°, the 10-isomer melting at 82-82.5° as opposed to

71-73°. The semicarbazones of both of these keto acids were also pre-

pared (d), each melting at a temperature in excess of 117°, the 10-

isomer melting at 117-118° as opposed to 100-103°. The melting point

composition curve for the 9 and the 10-ketostearic acids shows that a

50% mixture of these two acids has a melting point of 71.3-71.8°. In

addition, a 50% mixture of the semicarbazones (d) melts at 102-104°.

This data in itself would point strongly to the fact that the so-called

10-ketostearic acid (m.p. 71-72°) is in fact composed of equivalent

amounts of the 9 and the 10-isomers; however, in order to strengthen

this conclusion, the 9 and the 10-ketostearic acids were reduced with

lithium aluminum hydride in ether solution to the corresponding diols.

No reference to the preparation of 1,9-octadecanediol could be

found in the literature; however, 1,10-octadecanediol is reported to have a melting point of 66° (69). It was prepared by addition of water to the double bond in oleic acid, by reduction of 1,10-dibromooctadecane, and by reduction of 10-hydroxystearic acid (m.p. 81°). In the present investigation, the diols obtained by reduction of the 9 and the 10-keto-stearic acids both had melting points in excess of 73° (d). Again, it may be shown from the melting point composition curve that a 50% mixture of these two diols has a melting point of 66.5-67.5°. On the basis of mixed melting points, this 50% mixture would appear to be identical with (E)[1] the catalytic hydrogenation product of cis-9,10-epoxy-1-octade-canol, as well as the lithium aluminum hydride reduction product of the same compound, and the lithium aluminum hydride reduction product of the hydroxy acid(s) (m.p. 80.5-81.5°).

The only anomaly encountered in this investigation which cannot be explained involves the authenticity of this hydroxy acid (m.p. 80.5-81.5°) obtained by hydrogenation of the cis-9,10-epoxystearic acid. The pure 9 and 10-hydroxystearic acids have been prepared by several reliable purely synthetic methods (3, 10, 94) and the melting point of the pure 9-isomer was reported to be 74-76° while that of the 10-isomer was reported to be 79-82°, and mixtures of these two isomers were reported to have even lower melting points. This then would lend support to the fact that the 10-isomer is the only one formed in the hydrogenation of the epoxy acid; however, all of the other data collected in this experimentation points overwhelmingly to the fact that both isomers are produced and in at least nearly equal proportion. This then must of necessity lead to the conclusion that the hydroxy acid (m.p. 80.5-

[1]See page 21.

81.5°) is not the pure 10-isomer but a mixture composed of equal amounts of both isomers.

SUMMARY AND CONCLUSIONS

The catalytic hydrogenation of cis-9,10-epoxystearic acid and cis-9,10-epoxy-l-octadecanol as well as the lithium aluminum hydride reduction of cis-9,10-epoxy-l-octadecanol have been studied.

It has been shown that in each case a random distribution of reduction products was obtained. This finding is contrary to the findings of previous investigators (47) who claim that catalytic hydrogenation of the 9,10-epoxystearic acids results in unidirectional orientation with the exclusive formation of 10-hydroxystearic acid.

The 9 and the 10-ketostearic acids have been synthesized. The melting point-composition curve for these acids has been used to estimate the per cent of each component in a mixture of the two isomers. The infrared patterns have also been obtained for these compounds.

The 1,9 and the 1,10-octadecanediols have been prepared by the lithium aluminum hydride reduction of the corresponding keto acids. The preparation of the 1,9 diol has not been recorded in the literature previously. The melting point of the 1,10 diol (73.5-74°) was found to be higher than the recorded value of 66°. The melting point-composition curve for these acids has been used to estimate the per cent of each diol present in a mixture of the two. The infrared patterns of these two isomers have also been obtained.

46

BIBLIOGRAPHY

1. A. Albitzky, J. Russ. Phys. Chem. Soc., 31, 76-100 (1899);
    via Chem. Zentr. 1, 1068-70 (1899).

2. D. E. Ames and R. E. Bowman, J. Chem. Soc., 1079-86 (1951).

3. D. E. Ames and R. E. Bowman, J. Chem. Soc., 2752-53 (1951).

4. D. E. Ames, R. E. Bowman, and R. G. Mason, J. Chem. Soc.,
    174-77 (1950).

5. D. Atherton and T. P. Hilditch, J. Chem. Soc., 204-8 (1943).

6. J. Baruch, Ber., 27, 174 (1894).

7. K. H. Bauer, Chem. Umschau Gebiete Fette, Öle, Wachse u Harze,
    33, 198 (1929); via R. Adams, "Organic Reactions," Vol.
    7, J. Wiley and Sons, Inc., New York, 1953, P. 415.

8. K. H. Bauer and O. Bähr, J. prakt. Chem., 122, 201-13 (1929);
    via C. A., 24, 60 (1930).

9. O. Behrend, Ber., 29, 806-9 (1896).

10. S. Bergstrom, G. Aulin-Erdtman, B. Rolander, E. Stenhagen,
    and S. Ostling, Acta Chem. Scand., 6, 1157-74 (1952).

11. A. H. Blatt, "Organic Synthesis," Collective Vol. 2, J. Wiley
    and Sons, Inc., New York, 1948, p. 276.

12. J. Böeseken and A. H. Belinfante, Rec. trav. chim. 45, 914-18
    (1926); via C. A., 21, 3601 (1927).

13. J. Böeseken, W. C. Smit, and A. Gaster, Proc. Acad. Sic. Am-
    sterdam, 32, 377-83 (1929); via C. A., 23, 4192 (1929).

14. R. E. Bowman, J. Chem. Soc., 325-9 (1950).

15. R. E. Bowman, Nature, 162, 111 (1948).

16. R. E. Bowman and W. D. Fordham, J. Chem. Soc., 2753-58 (1951).

17. R. E. Bowman and W. D. Fordham, J. Chem. Soc., 2758-60 (1951).

18. R. E. Bowman and R. G. Mason, J. Chem. Soc., 2748-51 (1951).

19. W. G. Brown, "Organic Reactions," Vol. 6, J. Wiley and Sons, Inc., New York, 1951, p. 472.

20. L. Canonica, M. Martinolli, and E. Alneri, Atti accad. nazl. Lincei, Rend., Classe sci. fis., mat. e nat., 14, 105-12 (1953); via C. A., 48, 2578e (1954).

22. J. E. Coleman and D. Swern, J. Am. Oil Chemists' Soc,, 32, 221-4 (1955).

22. T. Connor and G. F. Wright, J. Am. Chem. Soc., 68, 256-58 (1946).

23. J. A. Crowder and A. C. Elm, Ind. Eng. Chem., 41, 1771-73 (1949).

24. A. J. Durbetaki, Anal. Chem., 28, 2000 (1956).

25. A. J. Durbetaki, J. Am. Oil Chemists' Soc., 33, 221-23 (1956).

26. G. Ellis, Biochem. J. (London), 30, 753-61 (1936).

27. T. W. Findley and D. Swern, U. S. 2,567,930 (Sept. 18, 1951); via C. A. 46, 3560 g. (1952).

28. T. W. Findley, D. Swern, and J. T. Scanlan, J. Am. Chem. Soc., 67, 412-14 (1945).

29. C. R. Fordyce and J. R. Johnson, J. Am. Chem. Soc., 55, 3368-72 (1933).

30. W. Granke and J. Mönch, Ann., 556, 200-23 (1944); via C. A., 43, 126f (1949).

31. J. P. Friedrich, M.S. Thesis, Mo. School of Mines and Metallurgy, Rolla, Mo. (1955).

32. L. E. Gast, C. B. Croston, W. J. Schneider, and H. M. Teeter, Ind. Eng. Chem., 46, 2205-8 (1954).

33. A. G. Goldsobel, Ber., 27, 3121-29 (1894).

34. F. P. Greenspan and R. J. Gall, U. S. 2,692,271 (Oct. 19, 1954); via C. A., 49, 13288h (1955).

35. F. P. Greenspan, R. J. Gall, and D. G. MacKellar, J. Org. Chem., 20, 215-17 (1955).

36. T. F. Grey, J. F. McGhie, M. K. Pradhan, and W. A. Ross, Chemistry and Industry, 578-9 (1954).

37. R. T. Holman, W. O. Lundberg, W. M. Laver, and G. O. Burr, J. Am. Chem. Soc., 67, 1285-92 (1945).

38. E. Jungermann and P. E. Spoerri, J. Am. Chem. Soc., 75, 4704-5 (1953).

39. G. King, _J. Chem. Soc._, 387-91 (1942).

40. G. King, _J. Chem. Soc._, 37-8 (1943).

41. G. King, _J. Chem. Soc._, 1817-23 (1949).

42. H. B. Knight, E. F. Jordan, R. E. Koos, and D. Swern, _J. Am. Oil Chemists' Soc._, 31, 93-5 (1954).

43. H. B. Knight, L. P. Witnauer, J. E. Coleman, W. R. Nobel, and D. Swern, _Anal. Chem._, 24, 1331-34 (1952).

44. I. M. Kolthoff and T. S. Lee, _J. Polymer Sci._, 2, 206-19 (1947).

45. H. R. LeSueur, _J. Chem. Soc._, 79, 1313-28 (1901).

46. H. R. LeSueur and J. C. Withers, _J. Chem. Soc._, 105, 2800-19 (1914).

47. C. H. Mack and W. G. Bickford, _J. Org. Chem._, 18, 686-92 (1953).

48. C. H. Mack, W. G. Bickford, and K. S. Markley, U. S. 2,727,048 (Dec. 13, 1955); via _C. A._, 50:10764c (1956).

49. R. S. Morrell and E. O. Phillips, _J. Chem. Soc. Ind._, 59, 144-48 (1940); via _C. A._, 34, 7630 (1940).

50. W. W. Myddleton, R. G. Berchem, and A. W. Barrett, _J. Am. Chem. Soc._, 49, 2264-69 (1927).

51. M. Naudet, _Compt. rend._ 27ᵉ _congr. intern. chim. ind._, Brussels, (1954) 3; Industrie chim. belge. 20, Spec. No., 721-23 (1955); via _C. A._, 50, 16674c (1956).

52. M. Naudet and P. Desnuelle, _Bull. soc. chim. France_, 845-48 (1950); via _C. A._, 45, 9474i (1951).

53. B. H. Nicolet and T. C. Poulter, _J. Am. Chem. Soc._, 52, 1186-91 (1930).

54. R. T. O'Connor, C. H. Mack, E. F. DuPre, and W. G. Bickford, _J. Org. Chem._, 18, 693-701 (1953).

55. W. E. Parker, C. Ricciuti, C. L. Ogg, and D. Swern, _J. Am. Chem. Soc._, 77, 4037-41 (1955).

56. G. V. Pigulevskii and I. L. Kuranoua, _Doklady Akad. Nauk, U.S.S.R._, 82, 601-2 (1952); via _C. A._, 47, 2703b (1953).

57. G. V. Pigulevskii and I. L. Duranoua, _Zhur. Obshchei Khim._, 24, 1971-73 (1954); via _C. A._, 50, 10700f (1956).

58. G. V. Pigulevskii and I. L. Kuranoua, _Zhur. Obshchei Khim._, 24, 2006-10 (1954); via _C. A._, 49, 7492d (1955).

59. G. V. Pigulevskii and I. L. Kuranoua, Zhur. Priklad. Khim.,
        28, 1353-55 (1955); via C. A., 50, 10073d (1956).

60. G. V. Pigulevskii and M. A. Petrov, Zhur. Russ. Fiz. Khim.
        Obshchestva, 58, 1062-66 (1926); via C. A., 22, 943 (1928).

61. G. V. Pigulevskii and Z. Ya. Rubashko, Zhur. Obshchei Khim., 9,
        829-31 (1939); via C. A., 34, (1940).

62. J. Radell and E. T. Donahue, Anal. Chem., 26, 590-1 (1954).

63. E. Raymond, J. chim. phys., 28, 480 (1931); via C. A., 26, 900
        (1932).

64. G. M. Robinson and R. Robinson, J. Chem. Soc., 175-80 (1925).

65. G. M. Robinson and R. Robinson, J. Chem. Soc., 2204-9 (1926).

66. J. Ross, A. I. Gebhart, and J. F. Gerecht, J. Am. Chem. Soc.,
        71, 282-86 (1949).

67. A. Saytzeff, J. Prakt. Phys. Chem. Soc., [2] 33, 313 (1886);
        via J. Chem. Soc., 79, 1313-24 (1901).

68. V. L. Schneider, R. T. Holman, and G. O. Burr, J. Phys. and
        Colloid Chem., 53, 1016-29 (1949).

69. W. Seck and F. Dittmar, Chem. Umschau Gebuete Fette, Öle, Wachse
        u Harze, 39, 226-9 (1932); via C. A., 27, 703 (1933).

70. O. D. Shreve, M. R. Heether, H. B. Knight, and D. Swern, Anal.
        Chem., 23, 277-82 (1951).

71. J. H. Skellon and M. N. Thurston, J. Chem. Soc., 138-42 (1953).

72. W. C. Smit, Rec. trav. chim., 49, 686-90 (1930); via C. A., 24,
        4261 (1930).

73. D. Swern, Chem. Rev., 45, 1-68 (1949).

74. D. Swern, J. Am. Chem. Soc., 70, 1235-40 (1948).

75. D. Swern, "Organic Reactions," Vol. 7, J. Wiley and Sons, Inc.,
        New York, 1953, chapter 7.

76. D. Swern, "Progress in the Chemistry of Fats and Other Lipids,"
        Vol. 3, Pergamon Press, New York, 1955, chapter 6.

77. D. Swern, U. S. 2,411,762 (Nov. 26, 1946); via C. A., 41, 1698a
        (1947).

78. D. Swern, U. S. 2,491,533 (Dec. 20, 1949); via C. A., 44, 4025e
        (1950).

79. D. Swern and G. N. Billen, J. Am. Chem. Soc., 71, 3849-51 (1949).

80. D. Swern and G. N. Billen, U. S. 2,457,329 (Dec. 28, 1948); via C. A., 43, 3660f (1949).

81. D. Swern, G. N. Billen, and C. R. Eddy, J. Am. Chem. Soc., 70, 1228-35 (1948).

82. D. Swern, G. N. Billen, and J. T. Scanlan, J. Am. Chem. Soc., 70, 1226-28 (1948).

83. D. Swern and J. E. Coleman, J. Am. Oil Chemists' Soc., 32, 700-3 (1955).

84. D. Swern and T. W. Findley, J. Am. Chem. Soc., 72, 4315-16 (1950).

85. D. Swern and T. W. Findley, J. Am. Chem. Soc., 74, 6139-41 (1952).

86. D. Swern and T. W. Findley U. S. 2,445,892 (1948); via C. A., 43, 2224f (1949).

87. D. Swern, T. W. Findley, G. N. Billen, and J. T. Scanlan, Anal. Chem., 19, 414-15 (1947).

88. D. Swern, T. W. Findley, and J. T. Scanlan, J. Am. Chem. Soc., 66, 1925-27 (1944).

89. D. Swern, H. B. Knight, and T. W. Findley, Oil and Soap, 21, 133-9 (1944).

90. D. Swern, J. T. Scanlan, and E. T. Roe, Oil and Soap, 23, 128-31 (1946).

91. D. Swern, L. P. Witnauer, and H. B. Knight, J. Am. Chem. Soc., 74, 1655-57 (1952).

92. H. M. Teeter, D. L. Gast, and L. C. Woods, J. Am. Chem. Soc. 73, 2302 (1951).

93. D. E. Terry and D. H. Wheeler, U. S. 2,458,484 (Jan. 4, 1949); via C. A., 43, 3030d (1949).

94. C. G. Tomecko and R. Adams, J. Am. Chem. Soc., 49, 522-30 (1927).

95. C. O. Willits, C. Ricciuti, H. B. Knight, and D. Swern, Anal. Chem., 24, 785-90 (1952).

96. L. P. Witnauer and D. Swern, J. Am. Chem. Soc., 72, 3364-68 (1950).

VITA

John Philip Friedrich

Candidate for the Degree of

Doctor of Philosophy

Thesis: AN INVESTIGATION OF THE REDUCTION PRODUCTS OF CERTAIN COM-
POUNDS CONTAINING ISOLATED OXIRANE GROUPS

Major Field: Organic Chemistry

Biographical:

Personal Data: Born in Pekin, Illinois, March 28, 1932, the
son of N. J. and Lillian Elizabeth Friedrich.

Education: Attended grade school in Pekin, and Sand Prairie,
Illinois; graduated from Pekin Community High School in
1949; received the Bachelor of Science degree from the
Missouri School of Mines and Metallurgy, with a major in
Chemistry in May 1953; received the Master of Science de-
gree from the Missouri School of Mines and Metallurgy,
with a major in Chemistry, in May 1955; began work at
Oklahoma State University in 1955; completed the require-
ments for the degree of Doctor of Philosophy, with a major
in Organic Chemistry, in January, 1959.

Professional experience: Chemist for Shell Oil Co. summers of
1953-54. Teaching assistant, Missouri School of Mines
1953-54. Instructor, Missouri School of Mines, 1955. In-
structor, Oklahoma State University, 1955-56. Research
assistant, Oklahoma State University, 1956-58.

Member of Sigma Xi and Alpha Chi Sigma.