A STUDY OF BASE DISPLACEMENTS ON

3-BROMO-1,2-EPOXYBUTANE AND 1-BROMO-2,3-EPOXYBUTANE

by

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Introduction

It is of interest to compare the relative reactivities of halogen-bearing and epoxide ring carbon atoms toward nucleophilic substitution. Such a comparison can conveniently by made by consideration of the products formed from such reactions of compounds in which both functions are present in the same molecule. Some work along this line with alpha-halogenated epoxides, particularly epichlorohydrin, has been reported in the literature.

For example, Koelsch and McElvain[1] reported the formation of 1-chloro-2-pentanol and 1-chloro-3-bromo-2-propanol from the reaction of epichlorohydrin with ethyl magnesium bromide. Later, the same workers[2] reported the preparation of sixteen different chlorohydrins by the reaction of various Grignard reagents with epichlorohydrin. In all cases, reaction occurred which resulted in the formation of products homologous to the 1-chloro-2-pentanol formed with ethyl magnesium bromide, clearly indicating exclusive attack at the terminal carbon atom of the epoxide ring.

Tapia and Hernandez[3] reported the formation of 3-bromo-1-chloro-2-propanol from the reaction between epichlorohydrin and phenyl magnesium bromide, with a small amount of methyl stilbene formed as a by-product. Moreover, in reaction of epichlorohydrin with another aryl Grignard reagent, o-anisyl magnesium bromide, Normant[4] obtained a

25 to 30% yield of 1-(o-anisyl)-3-chloro-2-propanol. It
is clear that in both cases, there was exclusive attack by
the nucleophilic agent at the terminal epoxide carbon atom.

Margrane and Cottle[5] found similarly that in reactions
of epichlorohydrin with Grignard reagents, fission of the
epoxide ring occurred to the exclusion of displacement of
a chloride ion by the nucleophilic group. In order to
increase the yield of alkyl substituted material, these
workers used dialkyl magnesium compounds, particularly
diethyl magnesium, in place of the Grignard reagent, thus
eliminating attack by the halide ion which is significant
in the case of Grignard reagents. With these compounds,
they again found that substitution occurred by rupture of
the epoxide ring at the terminal carbon atom.

Nucleophilic substitutions of epichlorohydrin with
sulfides and mercaptans have been reported. Nenitescu and
Scarlatescu[6] reported reactions between mercaptans and
epichlorohydrin to give various primary thioethers. For
example, ethyl mercaptan gave 3-chloro-2-hydroxypropyl
ethyl sulfide, indicating attack at the primary carbon atom
of the epoxide ring. Propyl mercaptan and phenyl mercaptan
gave analogous products. Sjoberg[7] reported the formation
of 3-chloro-2-hydroxypropyl mercaptan from a reaction of
epichlorohydrin and hydrogen sulfide in alkaline solution.

An interesting reaction has been observed by Haynes
and co-workers[8] between epichlorohydrin and sodium acetylide
in liquid ammonia in which a 40% yield of 2-penten-4-yn-1-ol

was obtained. With epibromohydrin, a 25% yield of the same product was formed. These workers postulate direct displacement of halide ion to form an intermediate epoxypentyne. This, they suppose subsequently rearranges to form the product which was isolated. This mechanism may be represented in the following way:

$$CH \equiv C^- \ + \ Cl-CH_2-CH-CH_2 \longrightarrow CH \equiv C-CH_2-CH-CH_2 \ + \ Cl^-$$

$$CH \equiv C-CH_2-CH-CH_2 \longrightarrow CH \equiv C-CH \equiv CH-CH_2OH$$
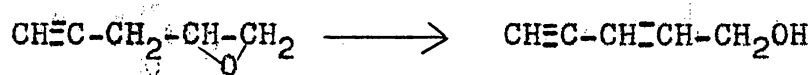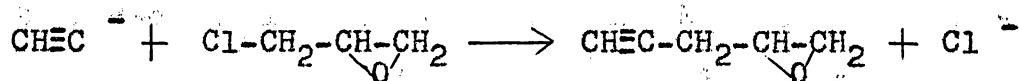
Evidence for their proposed mechanism is based on a similar reaction using 1-bromo-2,3-epoxybutane instead of epichlorohydrin or epibromohydrin. In this case, the product formed was hex-3-en-5-yn-2-ol, $CH \equiv C-CH \equiv CH-CHOH-CH_3$. They reason that this product could be obtained only if direct displacement of bromide ion by acetylide ion was the initial step in the reaction, and thus, by analogy, conclude that halide ion displacement is the first step in the reaction of sodium acetylide with epichloro- or epibromohydrin.

Along the same line, Culvenor and co-workers[9], in a reaction of epichlorohydrin with sodium toluene-p-sulfinate, obtained 3-p-tolylsulfonylprop-2-en-1-ol, as follows:

$$p-CH_3-C_6H_4-SO_2^- \ + \ Cl-CH_2-CH-CH_2 \longrightarrow$$

$$p-CH_3-C_6H_4-SO_2-CH \equiv CH-CH_2OH \ + \ Cl^-$$
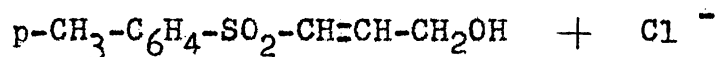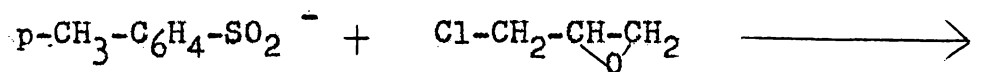
However, if the reaction mixture was kept neutral, they
obtained instead 1-chloro-3-p-tolylsulfonylpropan-2-ol,
$p-CH_3-C_6H_4-SO_2-CH_2-CHOH-CH_2-Cl$. Similarly, in a reaction
between epichlorohydrin and aqueous alkali cyanides re-
ported from this same laboratory[10], 3-cyano-prop-2-en-1-ol,
$NC-CH=CH-CH_2OH$, was isolated, and in this case, a small
amount of 3-cyano-1-chloro-propan-2-ol, $NC-CH_2-CHOH-CH_2-Cl$,
was formed. The yield of the latter product was increased
to 65% by the use of alcohol as the solvent and by the
continuous addition of acetic acid to maintain neutrality.
It was further shown that 3-cyano-1-chloro-propan-2-ol
could be converted to 3-cyano-prop-2-en-1-ol, the prin-
ciple product under basic conditions, by the cautious
addition of less than a molar quantity of sodium hydroxide.
The implication seems to be that initial attack in both
these cases occurs at the terminal carbon atom of the
epoxide ring. These workers propose that the unsaturated
alcohols are formed via an unstable epoxide intermediate.
However, in opposition to the Haynes viewpoint that the
intermediate epoxide was formed by direct displacement of
a halide ion, they believe that attack by the nucleophilic
group occurred at the terminal carbon atom of the epoxide
ring forming an alpha-haloalkoxide ion, which in basic
medium forms an epoxide ring, presumably through displace-
ment of chloride ion by the alkoxide oxygen, in the follow-
ing manner:

$$CN^- + \underset{\underset{O}{\diagdown\diagup}}{CH_2-CH-CH_2-Cl} \longrightarrow \left[NC-CH_2-\underset{\underset{O}{\diagdown\diagup}}{CH-CH_2-Cl}\right]^-$$

$$NC-CH{=}CH-CH_2OH \longleftarrow NC-CH_2-\underset{\underset{O}{\diagdown\diagup}}{CH-CH_2} + Cl^-$$
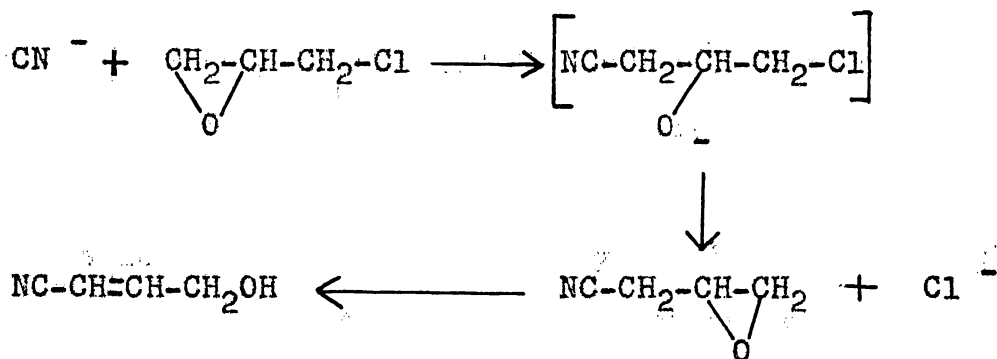
Extensive work has been done on the reactions of epoxides with amines and ammonia and some of this has been conducted using epichlorohydrin as the condensing epoxide. For example, Drozdov and Cherntzov[11] studied the reactions of epichlorohydrin with diethylamine, dimethylamine, and piperidine in aqueous solution and found in all cases that the amine attacked the terminal carbon atom of the epoxide ring forming 1-diethylamino-, 1-dimethylamino-, and 1-piperidino-3-chloro-2-propanol, respectively. They also found products, unidentified, containing ionic chloride. They then obtained by reaction of the chlorohydrins mentioned with caustic alkali the corresponding 1-diethylamino-, 1-dimethylamino-, and 1-piperidino-2,3-epoxypropanes. Later, Gilman, et al[12], in a reaction between epichlorohydrin and diethylamine in water obtained a material, not isolated, which, when treated with excess of aqueous sodium hydroxide gave 1-diethylamino-2,3-epoxypropane. Thus, they felt, particularly in view of the similar results obtained by Drozdov and Cherntzov[11], mentioned above, that the non-isolated material was 1-diethylamino-3-chloro-2-propanol. Bachman and Mayhew[13] conclude also on the basis of the

results obtained by Drozdov and Cherntzov[11] that the pro-
ducts from their reactions of secondary aliphatic amines
with epichlorohydrin were 1-dialkylamino-3-chloro-2-prop-
anols. Davies and Savige[14] similarly obtained 1-(N-methyl-
anilino)-3-chloro-2-propanol from a reaction between N-
methylaniline and epichlorohydrin in ethanol or xylene,
which, by treatment with alkali, formed 1-(N-methylanilino)-
2,3-epoxypropane. In the reaction of an amide, N-phenyl-
p-toluene sulfonamide, with epichlorohydrin, Ohle and
Haessler[15] obtained N-p-tosylphenyl-(3-chloro-2-hydroxy-
propyl)-amine, indicating again attack by the nucleophilic
agent at the terminal carbon atom of the epoxide ring.

Sodium alkoxides and phenoxides, in condensing with
epichlorohydrin, also seem to show preferential attack at
the primary carbon atom of the epoxide ring. A reaction
was reported some time ago by Cohn and Plohn[16] in which
phenol was condensed with epichlorohydrin using sodium
hydroxide or sodium methoxide as catalysts, to form 1-
phenoxy-2,3-epoxypropane. However, later, Boyd and Marle[17],
in duplicating their work, identified the same product as
1,3-diphenoxy-2-propanol, and later[18] extended the reaction
to include other phenols, finding that they gave analogous
products. Bradley and co-workers[19] also studied the re-
actions between phenols and epichlorohydrin, using tertiary
amines as catalysts. They isolated principally 1-aryloxy-
3-chloro-2-propanols, with diaryl ethers of glycerol being
formed only as by-products. Interestingly enough, they

isolated also small amounts of 1,3-dichloro-propan-2-ol.
In order to explain the formation of this product, they
reasoned that arylglycidic ethers were formed by removal
of hydrogen chloride from the first-formed aryloxychloro-
hydrins. This hydrogen chloride, they felt, then under-
went reaction with epichlorohydrin to form the dichloro-
propanol. No arylglycidic ethers were isolated, but the
authors postulated that reaction between the ethers and
unreacted phenol occurred immediately.

Recent studies by Waters and VanderWerf[20] of the re-
actions of 3-bromo-1,2-epoxybutane and 1-bromo-2,3-epoxy-
butane with molar equivalents of sodium methoxide in meth-
anol and sodium ethoxide in ethanol showed the formation in
all cases of the corresponding 1-alkoxy-2,3-epoxybutane,
thus indicating preferential attack at the primary carbon
atom in these nucleophilic displacements, regardless of the
nature of the substituent at that position. These results
cast further doubt on the contention of Haynes and co-
workers[8], mentioned earlier, that reaction between epi-
chlorohydrin and sodium acetylide must proceed via dis-
placement of chloride ion by an acetylide ion, since proof
of the English workers was based on the supposedly anal-
ogous reaction of 1-bromo-2,3-epoxybutane with sodium
acetylide. In the latter case, it was shown that reaction
occurred via displacement of bromide ion by acetylide ion
with subsequent rearrangement of the epoxide grouping. It
appears that the same product would have been obtained had

Haynes used 3-bromo-1,2-epoxybutane rather than 1-bromo-2,3-epoxybutane, thus indicating that in the same reaction with epichlorohydrin, the formation of 2-penten-4-yn-1-ol may well have proceeded by attack of acetylide ion at the primary carbon atom of the epoxide ring.

Another substitution reaction involving epichlorohydrin in which direct displacement of chloride ion was reported to have taken place has been described by Haller and Ramart-Lucas[21]. In this case, epichlorohydrin was treated with the carbanion of isobutyrophenone in ether or benzene suspension. The product isolated was 4-methyl-4-benzoyl-1,2-epoxypentane, with reaction apparently proceeding in the following manner:

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}{}^- \;+\; Cl-CH_2-CH\underset{\diagdown O\diagup}{-}CH_2 \longrightarrow C_6H_5-\overset{\overset{O}{\|}}{C}-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_2-CH\underset{\diagdown O\diagup}{-}CH_2$$
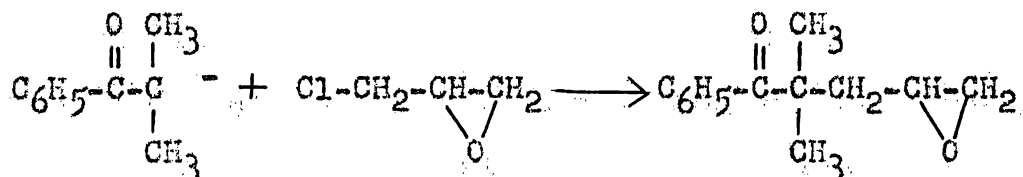
Later, Russell[22], in further work on this reaction, using 3-bromo-1,2-epoxybutane instead of epichlorohydrin, showed that reaction may well have proceeded by initial attack at the primary carbon atom of the epoxide ring with subsequent ring closure through the intermediate alpha-haloalkoxide structure, since the product he isolated was 5-methyl-5-benzoyl-2,3-epoxyhexane. Russell formulated the mechanism of this reaction as follows:

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}{}^- \;+\; H_2C\underset{\diagdown O\diagup}{-}CH-CHBr-CH_3 \longrightarrow$$

$$\underset{\underset{CH_3}{|}}{\overset{\overset{O}{||}\ \overset{CH_3}{|}}{C_6H_5\text{-}C\text{-}C\text{-}CH_2\text{-}CH\text{-}CHBr\text{-}CH_3}}\ \longrightarrow\ \underset{\underset{CH_3}{|}}{\overset{\overset{O}{||}\ \overset{CH_3}{|}}{C_6H_5\text{-}C\text{-}C\text{-}CH_2\text{-}CH\text{-}CH\text{-}CH_3}}$$
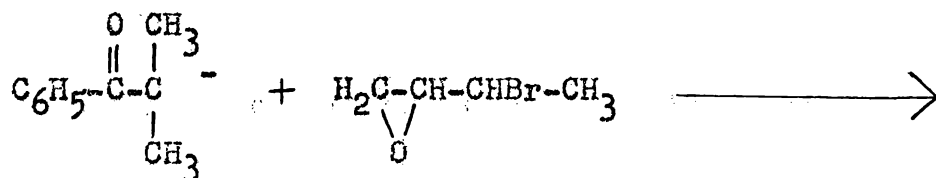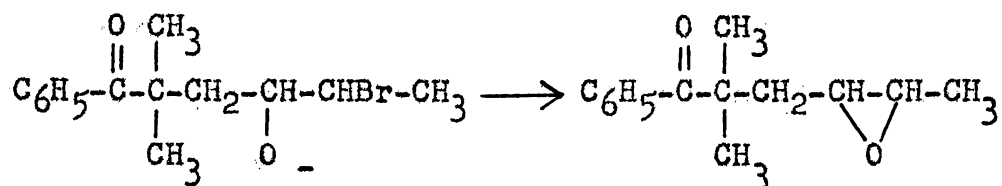
If the reaction had proceeded as suggested by Haller and Ramart-Lucas for epichlorohydrin, by direct displacement of a halide ion, the product would have been 3,4-dimethyl-4-benzoyl-1,2-epoxypentane, $C_6H_5\text{-}\overset{\overset{O}{||}}{C}\text{-}C(CH_3)_2\text{-}CH(CH_3)\text{-}CH\text{-}CH_2$. With epichlorohydrin, the final product would be the same regardless of the mechanism.

Russell[22] also reported the reaction between 1-bromo-2,3-epoxybutane and the carbanion of isobutyrophenone. In this reaction, he claims the formation of 2-methyl-3-benzoyl-isopropyl trimethylene oxide, corresponding to attack by the carbanion at the 2 position with ring closure through displacement of the terminal bromide by the alkoxide oxygen resulting from the cleavage of the epoxide ring, as follows:
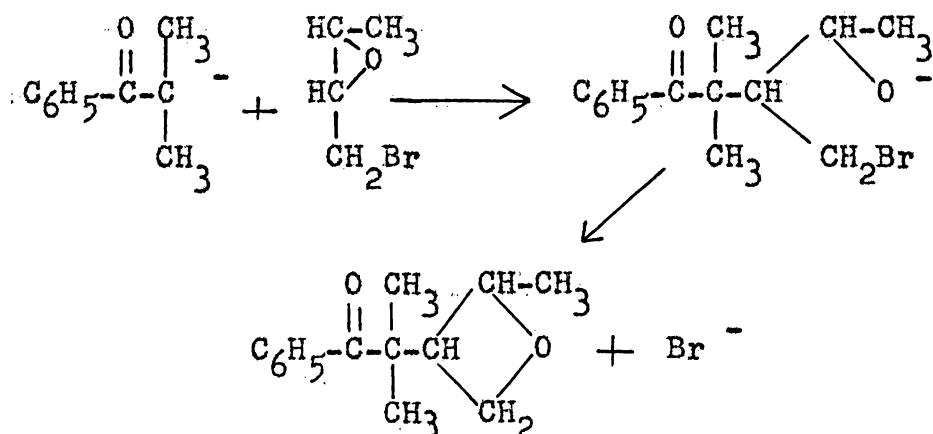
He assumes that the products obtained from the isomeric alpha-bromoepoxides must be structurally different since

the corresponding oximes have different melting points; and since the product obtained from 1-bromo-2,3-epoxybutane forms no 2,4-dinitrophenylhydrazone, as opposed to the formation of such a derivative from the product obtained from 3-bromo-1,2-epoxybutane. In addition, there was found to be a considerable difference in the ease of oxidation of the two products, the product obtained from 3-bromo-1,2-epoxybutane being oxidized at a much more rapid rate. However, the product of oxidation was the same in the two cases, namely, 3-methyl-3-benzoylbutanoic acid. In order to explain the formation of this acid from the trimethylene oxide derivative proposed as the product obtained from 1-bromo-2,3-epoxybutane, he suggests as a possibility the oxidation of the four-membered heterocycle to a derivative of acetoacetic acid which on decarboxylation under the conditions of the oxidation would yield a methyl ketone. This would then undergo further oxidation to the butyric acid derivative, or the oxidation of the acetoacetic acid derivative to a malonic acid derivative, would, on decarboxylation, give the same acid.

$$
\begin{array}{c}
\underset{\substack{\text{O} \ \text{CH}_3 \\ \parallel \ \mid}}{C_6H_5-C-C-CH} \!\!\begin{array}{c} \text{CH-CH}_3 \\ \diagdown \ \text{O} \\ \diagup \\ \text{CH}_2 \end{array} \quad \xrightarrow{[O]} \quad \underset{\substack{\text{O} \ \text{CH}_3 \\ \parallel \ \mid}}{C_6H_5-C-C-CH} \begin{array}{c} \overset{\text{O}}{\overset{\parallel}{C}}-\text{CH}_3 \\ \diagdown \\ \text{COOH} \end{array}
\end{array}
$$

$[O]$ $-CO_2$

$C_6H_5-C-C-CH_2-C-CH_3$ (with O, CH$_3$, CH$_3$, O groups)

$C_6H_5-C-C-CH_2-COOH$ (with O, CH$_3$, CH$_3$)

$-CO_2$

$C_6H_5-C-C-CH$ with COOH, COOH, O, CH$_3$, CH$_3$
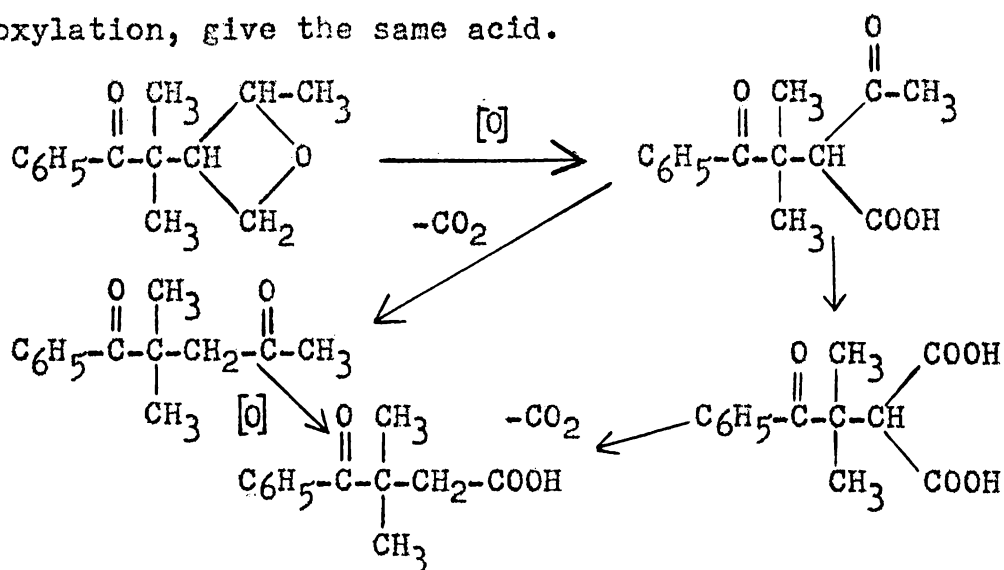
As still another possibility, Russell suggest the rearrangement first of the trimethylene oxide derivative to the ethylene oxide derivative formed from 3-bromo-1,2-epoxybutane, which would then give the same acid on oxidation.

The present work includes further studies on these reactions of 3-bromo-1,2-epoxybutane and 1-bromo-2,3-epoxybutane with the carbanion of isobutyrophenone, as well as studies of the reactions of these isomeric alpha-bromoepoxides with other nucleophilic agents, namely diethylamine, sodium alloxide and sodium azide.

Discussion of Results

Reactions of 3-Bromo-1,2-epoxybutane and 1-Bromo-2,3-epoxy-butane with Diethylamine

The reaction of 3-bromo-1,2-epoxybutane, $CH_3-CHBr-CH-CH_2$, with O prepared according to the method of Petrov[23], with diethylamine in a 1 to 2 molar ratio, respectively, in anhydrous ether gave, in addition to diethylamine hydrobromide, m.p. 214.2-216.8°, a 21% yield of 1-diethylamino-2,3-epoxybutane, $CH_3-CH-CH-CH_2-N(CH_2-CH_3)_2$, b.p. 76.5-77.0°. The identity of the diethylamine hydrobromide was determined by a mixed melting point of the material with an authentic sample of diethylamine hydrobromide, m.p. 217.0-218.5°, in which no depression was shown.

The structure of the 1-diethylamino-2,3-epoxybutane was ascertained by its catalytic reduction to 1-diethyl-amino-2-butanol, $CH_3-CH_2-CHOH-CH_2-N(CH_2-CH_3)_2$, b.p. 82-84° at 25 mm. pressure, in an acidified alcoholic medium using a Raney nickel catalyst with hydrogen at 1500 p.s.i. at room temperature. The 1-diethylamino-2-butanol thus pro-duced formed a hydrochloride, m.p. 79.0-80.8°, which showed no depression of the melting point on an authentic sample of the hydrochloride of this material prepared by the re-action of diethylamine with 1,2-epoxybutane. Further, the infrared absorption spectra of the 1-diethylamino-2-butanol from this source and from the authentic source are essen-
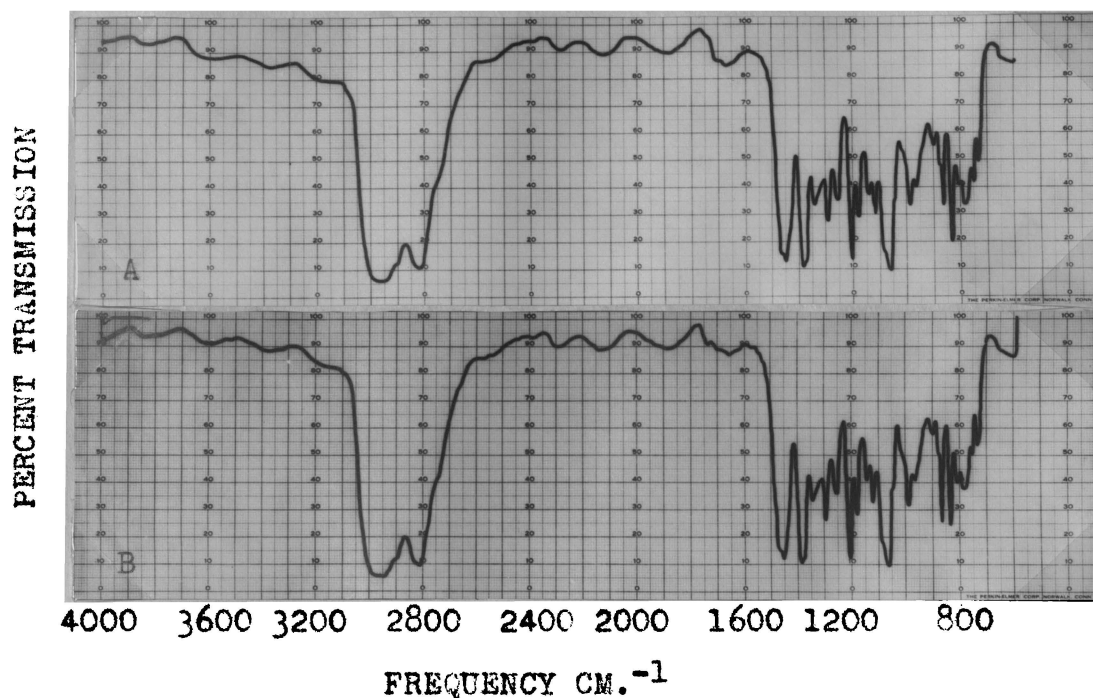
Fig. 1. Infrared absorption spectra: A, of reaction product of 3-bromo-1,2-epoxybutane with diethylamine; B, of reaction product of 1-bromo-2,3-epoxybutane with diethylamine.

tially identical (Fig. 2). That the product of this reaction is not 1-diethylamino-2-butanone, which would also give 1-diethylamino-2-butanol on reduction, was determined by the fact that it formed no derivative with 2,4-dinitrophenylhydrazine and that its infrared spectrum shows no absorption in the region in which strong aliphatic ketone absorption is generally found[24], i.e. 1720-1705 cm.$^{-1}$ (Fig. 1).

The reaction of 1-bromo-2,3-epoxybutane with diethylamine in a 1 to 2 molar ratio, respectively, conducted in
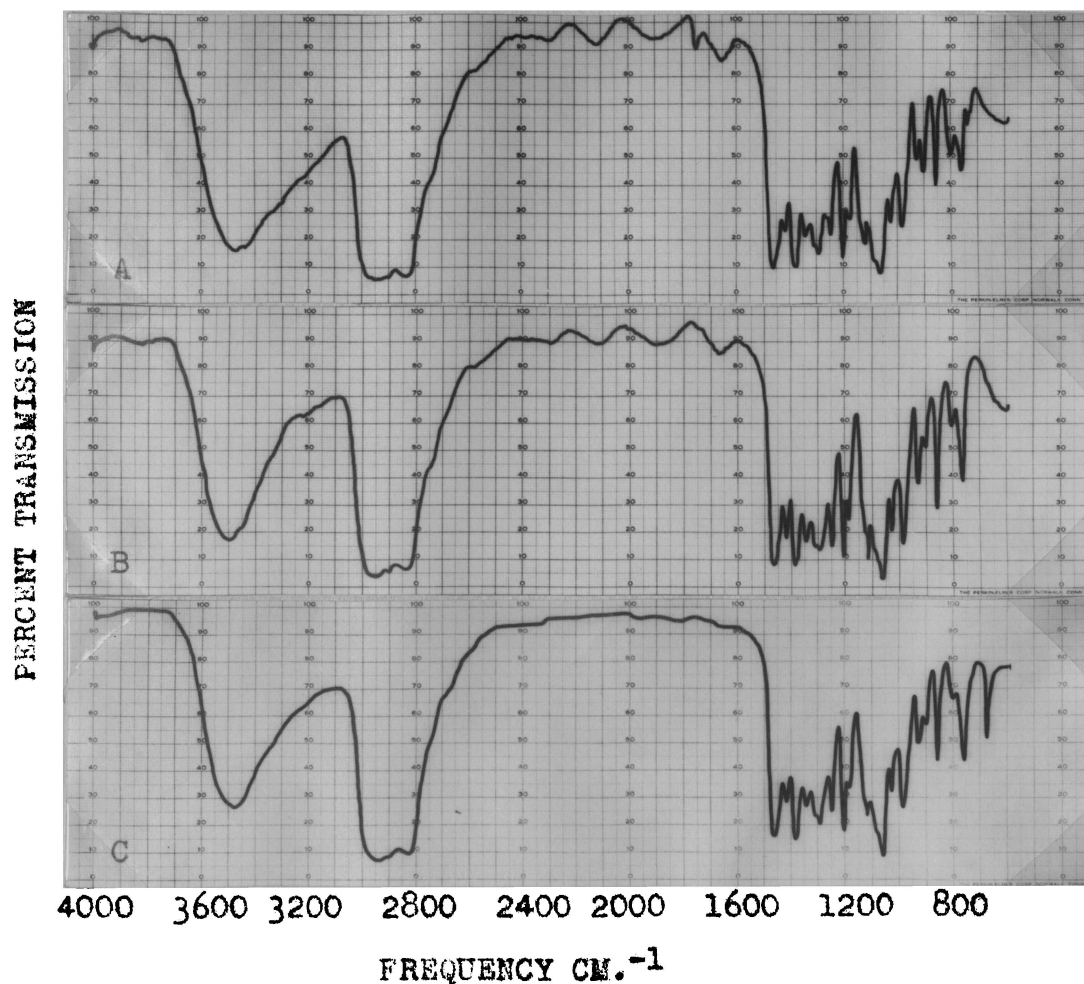
Fig. 2. Infrared absorption spectra: A, of the compound resulting from the catalytic hydrogenation of the reaction product of 3-bromo-1,2-epoxybutane and diethylamine; B, of 1-diethylamino-2-butanol formed by the reaction of 1,2-epoxybutane with diethylamine; C, of the compound resulting from the catalytic hydrogenation of the reaction product of 1-bromo-2,3-epoxybutane and diethylamine.

anhydrous ether, afforded diethylamine hydrobromide, m.p. 217.8-218.4°, which showed no depression of the melting

point of an authentic sample of this material. Also isolated was a 74% yield of 1-diethylamino-2,3-epoxybutane. The infrared spectrum of this material is identical to that of the reaction product of diethylamine with 3-bromo-1,2-epoxybutane (Fig. 1). It gave, on reduction with hydrogen at 1500 p.s.i., using a Raney nickel catalyst, 1-diethylamino-2-butanol, b.p. 82-84° at 25 mm. pressure, the hydrochloride of which, m.p. 80.2-82.6°, showed no depression of the melting point of an authentic sample of 1-diethylamino-2-butanol hydrochloride. Further, the infrared absorption spectrum of this reduced material is essentially identical to that of an authentic sample of 1-diethylamino-2-butanol (Fig. 2).

Thus, reaction of either 3-bromo-1,2-epoxybutane or 1-bromo-2,3-epoxybutane with diethylamine produces 1-diethylamino-2,3-epoxybutane, indicating attack at the terminal carbon atom of the molecule regardless of the substituent present at that position. With 1-bromo-2,3-epoxybutane, the reaction seems to follow a path of simple displacement of bromide ion by diethylamine. Diethylamine is apparently a stronger base than the reaction product, the unreacted diethylamine immediately displacing the 1-diethylamino-2,3-epoxybutane as the free base from its hydrobromide salt. The reaction may be depicted as follows:

$$CH_3-CH-CH-CH_2Br \ + \ HN\!\!\diagup^{C_2H_5}_{\diagdown C_2H_5} \longrightarrow CH_3-CH-CH-CH_2-\overset{+}{N}\!\!\diagup^{C_2H_5}_{H \diagdown C_2H_5} + Br^-$$

$$CH_3-CH-CH-CH_2-\overset{+}{N}\overset{C_2H_5}{\underset{H}{\diagdown}}C_2H_5 \; + \; HN\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}} \longrightarrow CH_3-CH-CH-CH_2-N\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}}$$

$$+ \quad H_2\overset{+}{N}\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}}$$

In the reaction of 3-bromo-1,2-epoxybutane with di-
ethylamine, the mechanism follows a different course. Since
the diethylamino group attaches itself to the terminal
carbon atom, it is apparent that attack at the epoxide ring
rather than direct displacement of bromide ion has occurred.
The formation of 1-diethylamino-2,3-epoxybutane after the
initial ring-opening reaction can occur by the displace-
ment of a bromide ion at the third carbon atom of the chain
through attack by the alkoxide oxygen resulting from the
ring cleavage. This presumably occurs in the same manner
that has been described for reactions of this alpha-bromo-
epoxide with other nucleophilic agents[20]. The total reaction
may be illustrated as follows:

$$CH_3-CHBr-CH-CH_2 \; + \; HN\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}} \longrightarrow \left[CH_3-CHBr-CH-CH_2-\overset{+}{N}\overset{C_2H_5}{\underset{H}{\diagdown}}C_2H_5 \right]$$

$$H_2\overset{+}{N}\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}} \longleftarrow \overset{HN\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}}}{\longleftarrow} CH_3-CH-CH-CH_2-\overset{+}{N}\overset{C_2H_5}{\underset{H}{\diagdown}}C_2H_5 \; + Br^-$$

$$+$$

$$CH_3-CH-CH-CH_2-N\overset{C_2H_5}{\underset{C_2H_5}{\diagdown}}$$

Reactions of 3-Bromo-1,2-epoxybutane and 1-Bromo-2,3-epoxy-
butane with Sodium Azide

The reaction of 3-bromo-1,2-epoxybutane with an equi-
molar amount of sodium azide in a 1 to 5 mixture of water
in dioxane afforded a quantity of material, b.p. 72-82° at
55 mm. pressure, which, despite repeated attempts, was not
separable by distillation into distinct components. Since
a positive Beilstein halogen test was obtained for this
material, and since its boiling range is in the same region
as that obtained for the starting material, i.e., 3-bromo-
1,2-epoxybutane (74-77° at 50 mm. pressure, determined by
this investigator), it is believed that this fraction con-
sists, at least in part, of unreacted 3-bromo-1,2-epoxy-
butane. This fraction may also contain a product resulting
from a monosubstitution reaction between the 3-bromo-1,2-
epoxybutane and sodium azide. According to the results of
various investigators which have been summarized by Boyer
and Canter[25] in a review article, organic azides and the
corresponding organic bromides are quite similar in their
various physical properties, including boiling point. Thus,
it seems that if direct displacement of a bromide ion from
3-bromo-1,2-epoxybutane by an azide ion occurred, the re-
sulting product would very likely be difficult to separate
from the starting material due to similarities of the boil-
ing points of the two substances. If, as seems more likely,
displacement of a bromide ion occurred via initial cleavage

of the epoxide ring by attack of an azide ion at the terminal carbon atom, in a manner analogous to other nucleophilic displacements involving 3-bromo-1,2-epoxybutane, described in this work (see p. 16), 1-azido-2,3-epoxybutane would be formed. This would be expected to have a boiling point in the same range as that of 1-bromo-2,3-epoxybutane, which, in turn, boils in approximately the same temperature range as 3-bromo-1,2-epoxybutane as determined by this investigator and by Petrov[23]. Therefore, it seems likely that the difference in boiling points of 3-bromo-1,2-epoxybutane and 1-azido-2,3-epoxybutane would not be great enough to make easy their separation by distillation.

The only single component isolated from this reaction of 3-bromo-1,2-epoxybutane with sodium azide was a 56% yield, based on sodium azide, of 3,4-diazido-2-butanol, CH_3-CHOH-CHN_3-CH_2N_3. Proof of the identity of this material was obtained by comparison of its infrared absorption spectrum with that of an authentic sample of 3,4-diazido-2-butanol, prepared by the reaction of 3,4-dibromo-2-butanol with sodium azide.(Fig. 3). In addition, a positive iodoform test, conducted according to the method of Shriner and Fuson[26], was obtained for the 3,4-diazido-2-butanol formed in this reaction, indicating the presence of the CH_3-CHOH-fragment in the molecule.

In the reaction of 1-bromo-2,3-epoxybutane with sodium azide, conducted in the same manner as just described for the reaction of 3-bromo-1,2-epoxybutane with sodium azide,
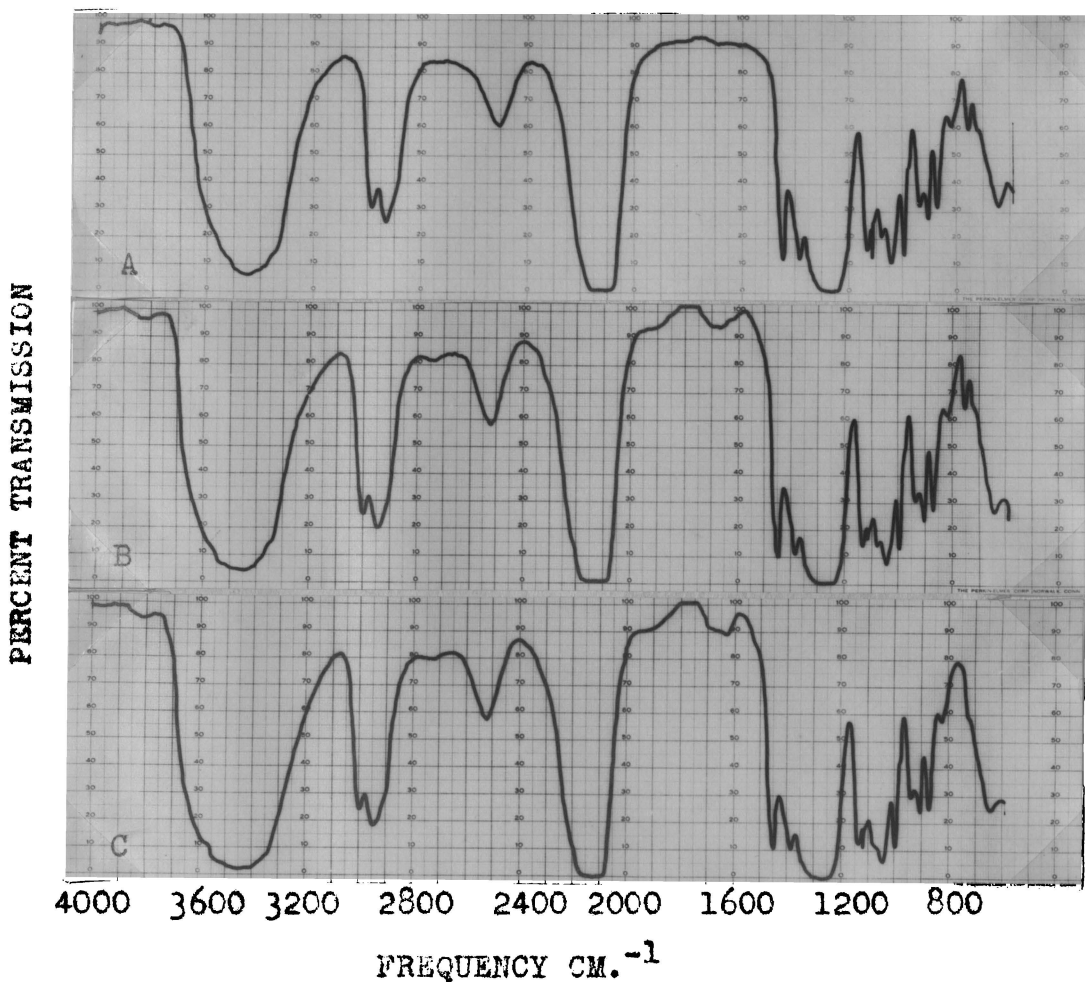
Fig. 3. Infrared absorption spectra: A, of the reaction product of 3-bromo-1,2-epoxybutane and sodium azide; B, of 3,4-diazido-2-butanol formed by the reaction of 3,4-dibromo-2-butanol with sodium azide; C, of the reaction product of 1-bromo-2,3-epoxybutane and sodium azide.

a quantity of material, b.p. 74-82° at 55 mm. pressure, which could not be further purified, was obtained. This fraction gave a positive Beilstein halogen test. Its boiling range was in the same range as that found for the

starting material, 1-bromo-2,3-epoxybutane (69-73° at 50 mm. pressure, determined by this investigator). By an argument analogous to the one advanced above (see p. 17-18) for explaining the impure lower-boiling material obtained from the reaction of 3-bromo-1,2-epoxybutane with sodium azide, one might say that in this case, this lower-boiling fraction represents a mixture of starting material, i.e., 1-bromo-2,3-epoxybutane, and a monosubstituted product, probably 1-azido-2,3-epoxybutane, with boiling points so similar as to make their separation by distillation difficult.

Another component isolated from this reaction of 1-bromo-2,3-epoxybutane with sodium azide was identified as 3,4-diazido-2-butanol, by comparison of its infrared absorption spectrum with that of an authentic sample of 3,4-diazido-2-butanol, prepared by the reaction of 3,4-dibromo-2-butanol with sodium azide (Fig. 3). Also, as was the case for the disubstituted product of the reaction of 3-bromo-1,2-epoxybutane with sodium azide, this diazido-butanol gave a positive iodoform test.

In spite of the fact that monosubstituted products were not isolated, some information regarding the mode of attack of the azide ion in these nucleophilic displacements with 3-bromo-1,2-epoxybutane and 1-bromo-2,3-epoxybutane can be ascertained from a consideration of the disubstituted products which were formed. Thus, two separate and distinct reactions, one of direct displacement of a bromide ion by an

azide ion, and one a cleavage of the epoxide ring by an azide ion, cannot have been the mechanism in the reaction of sodium azide with 3-bromo-1,2-epoxybutane. If this mechanism had obtained, the product would have been most likely 1,3-diazido-2-butanol, rather than 3,4-diazido-2-butanol. Since attack at the terminal carbon atom of the epoxide ring did occur, as indicated by the terminal position of one of the azide functions in the resulting product, and since the other azide function occupies the adjacent position on the carbon chain, it seems feasible to propose that the reaction proceeds according to a mechanism for other nucleophilic displacements of 3-bromo-1,2-epoxybutane referred to earlier in this work (see p. 16). In such a case, attack by an azide ion at the terminal position of the epoxide ring would occur, forming a secondary alkoxide ion at the 2-position. The alkoxide oxygen would then displace the bromine at the 3-position, forming as a result, 1-azido-2,3-epoxybutane. Attack by another azide ion at the second carbon atom of the chain would then occur, opening the newly-formed epoxide ring and producing, as a result, the product isolated, 3,4-diazido-2-butanol. The complete reaction may be illustrated as follows:

$$CH_3-CHBr-CH-CH_2 + N_3^- \longrightarrow \left[CH_3-CHBr-CH-CH_2N_3 \right]$$
(with epoxide O on left structure; right structure with O below and arrow down)

$$CH_3-CHOH-CHN_3CH_2N_3 \xleftarrow[H_2O]{N_3^-} CH_3-CH-CH-CH_2N_3 + Br^-$$
(with epoxide O)
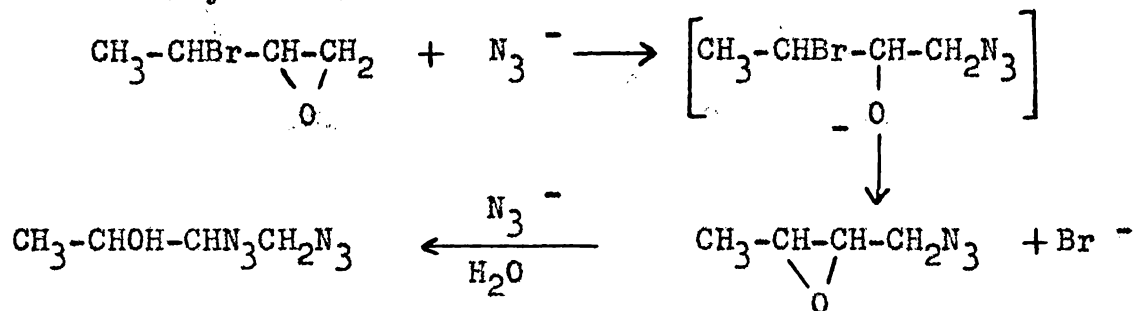
In the reaction of 1-bromo-2,3-epoxybutane with sodium azide, no definite conclusions can be made regarding the order in which the displacement of a bromide ion and epoxide ring cleavage occurs. However, since it was found by this investigator (see p. 15-16), and by Waters and VanderWerf[20], that nucleophilic displacement reactions of 1-bromo-2,3-epoxybutane with other nucleophilic agents occurred by substitution at the primary bromine-bearing carbon atom, we can, by analogy, propose that the reaction of 1-bromo-2,3-epoxybutane with sodium azide occurs via displacement of a bromide ion by an azide ion at the terminal carbon atom, forming 1-azido-2,3-epoxybutane, the same intermediate that was proposed in the reaction of 3-bromo-1,2-epoxy-butane with sodium azide. Further reaction would then proceed as described above in the second stage of the re-action of 3-bromo-1,2-epoxybutane with sodium azide, by attack of another azide ion at the 2-position of the newly-formed 1-azido-2,3-epoxybutane, forming as a result, the product isolated, 3,4-diazido-2-butanol. The complete reaction may be shown as follows:

$$CH_3-CH-CH-CH_2Br \ + \ N_3^- \longrightarrow CH_3-CH-CH-CH_2N_3 \ + \ Br^-$$
$$\underset{O}{\diagdown\diagup} \qquad\qquad\qquad\qquad \underset{O}{\diagdown\diagup}$$

$$CH_3-CH-CH-CH_2N_3 \ + \ N_3^- \ \overset{H_2O}{\longrightarrow} \ CH_3-CHOH-CHN_3-CH_2N_3$$
$$\underset{O}{\diagdown\diagup}$$
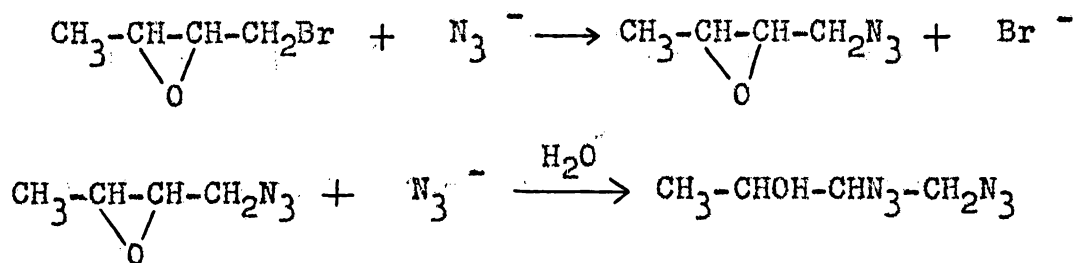
Reactions of 3-Bromo-1,2-epoxybutane and 1-Bromo-2,3-epoxy-
butane with Sodium Alloxide

3-Bromo-1,2-epoxybutane was added to an equimolar
amount of sodium alloxide in allyl alcohol to produce a 19%
yield of 1-alloxy-2,3-epoxybutane, $CH_2=CH-CH_2-O-CH_2-CH-CH-CH_3$,
as well as a 45% yield of a material which is probably
3,4-dialloxy-2-butanol. Oxirane oxygen analysis of the
1-alloxy-2,3-epoxybutane, according to the method of Swern,
et al[27], gave a value of 11.0%, or 88% of the calculated
value. The infrared absorption spectrum of the 1-alloxy-
2,3-epoxybutane shows absorption at 1250 cm.$^{-1}$, which is
likely due to the epoxide function[28] No absorption due to
a ketone function is evident in this spectrum (Fig. 4).

Identity of the 1-alloxy-2,3-epoxybutane was estab-
lished by its reduction with hydrogen at 1500 p.s.i. and at
a temperature of 130°, using a Raney nickel catalyst, to
produce 1-propoxy-2-butanol, $CH_3-CH_2-CH_2-O-CH_2-CHOH-CH_2CH_3$.
The infrared absorption spectrum of this reduction product
was identical to that of an authentic sample of 1-propoxy-
2-butanol, formed from the reaction of sodium propoxide
with 1,2-epoxybutane (Fig. 5). Although these spectra
show absorption in the region of 3100-3700 cm.$^{-1}$, which
can, in this case, be attributed only to the hydroxyl
function[24], difficulty was encountered in obtaining alco-
holic derivatives of these samples of 1-propoxy-2-butanol.
Thus, each was oxidized by chromic acid to 1-propoxy-2-

butanone, from which the 2,4-dinitrophenylhydrazones were formed, according to the method of Shriner and Fuson[29]. Both derivatives gave a melting range of 93-94°. A mixture of equal amounts of the two derivatives showed no melting point depression.

The assignment of the formula 3,4-dialloxy-2-butanol to the disubstituted product formed in this reaction was based primarily on analogy to similar reactions described by Waters and VanderWerf[20], in which sodium methoxide and sodium ethoxide are the condensing alkoxides and in which small amounts of 3,4-dialkoxy-2-butanols are formed. In addition, this dialloxybutanol gave a positive iodoform test.

The reaction of 1-bromo-2,3-epoxybutane with sodium alloxide gave a 29% yield of 1-alloxy-2,3-epoxybutane, and a 22% yield of 3,4-dialloxy-2-butanol. An oxirane oxygen percentage of 11.3 or 90% of the calculated value was obtained for the 1-alloxy-2,3-epoxybutane product of this reaction. The infrared absorption spectrum of this 1-alloxy-2,3-epoxybutane is identical to that of the monosubstituted product of the reaction of 3-bromo-1,2-epoxybutane with sodium alloxide (Fig. 4). Reduction of the 1-alloxy-2,3-epoxybutane obtained from this reaction with hydrogen at 1500 p.s.i. and at a temperature of 130°, using a Raney nickel catalyst, yielded a product, the infrared absorption spectrum of which is identical to that of an authentic sample of 1-propoxy-2-butanol (Fig. 5). Oxidation of this reduced material yielded 1-propoxy-2-butanone,
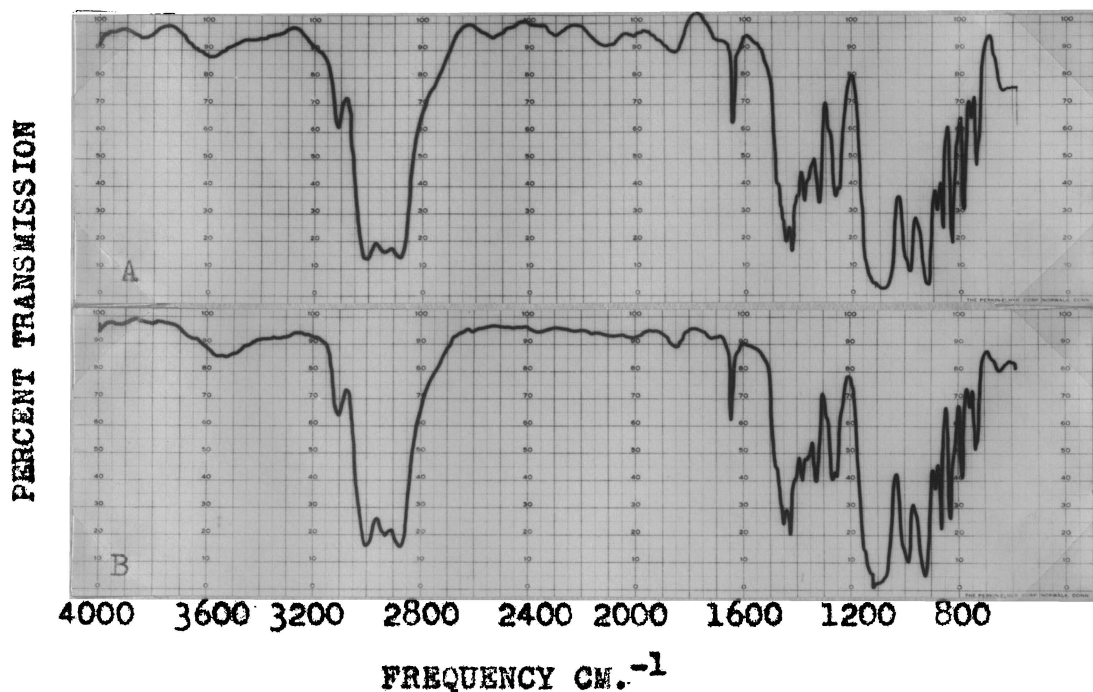
Fig. 4. Infrared absorption spectra: A, of the monosubstituted reaction product of 3-bromo-1,2-epoxybutane and sodium alloxide; B, of the monosubstituted reaction product of 1-bromo-2,3-epoxybutane and sodium alloxide.

as determined by the fact that its 2,4-dinitro-phenylhydrazone, m.p. 93-94°, showed no depression of the melting point of an authentic sample of the 2,4-dinitro-phenyl-hydrazone of 1-propoxy-2-butanone, m.p. 93-94°. The authentic 1-propoxy-2-butanone was prepared by the oxidation by chromic acid of 1-propoxy-2-butanol prepared by the reaction of sodium propoxide with 1,2-epoxybutane.

Identity of the 3,4-dialloxy-2-butanol formed in this reaction was established by comparison of its infrared
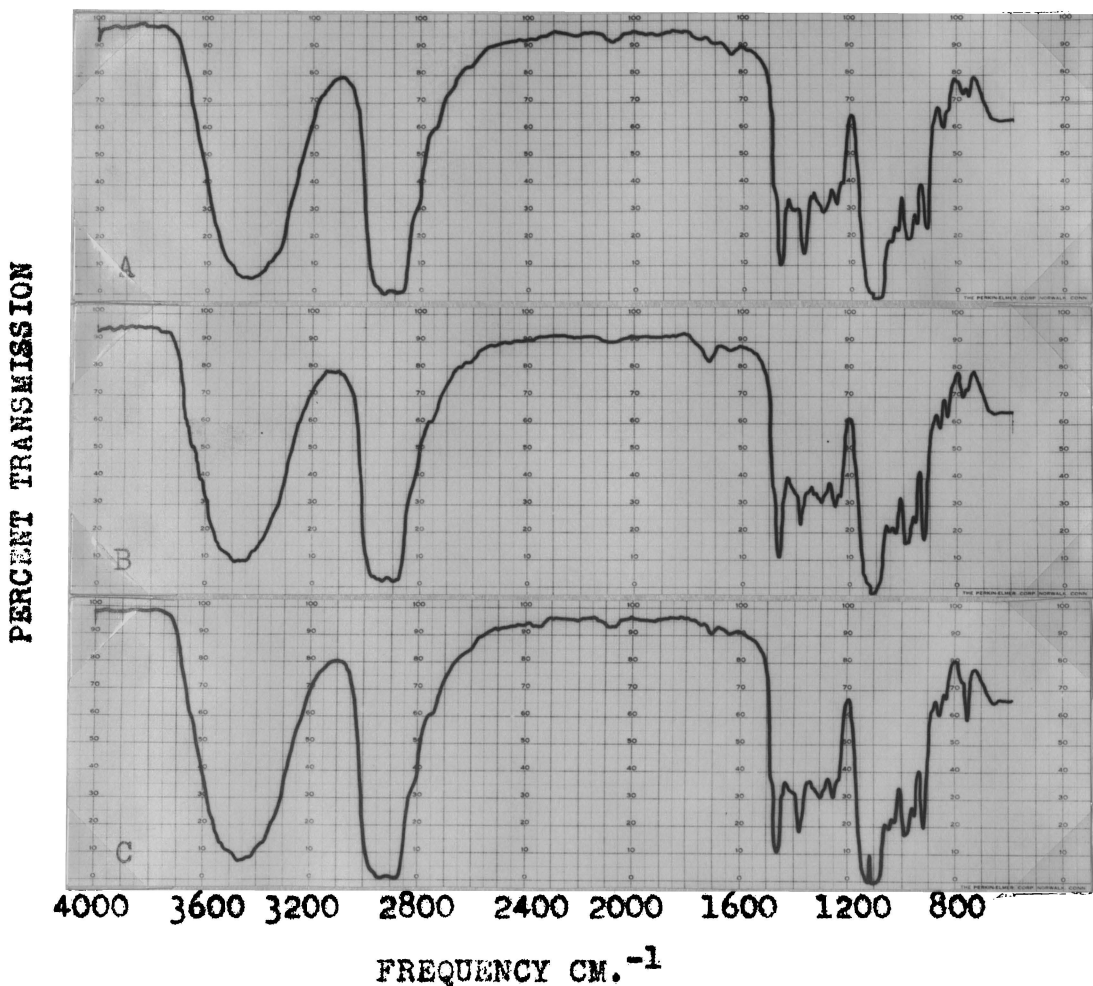
Fig. 5. Infrared absorption spectra: A, of the compound formed from the catalytic hydrogenation of the reaction product (monosubstituted) of 3-bromo-1,2-epoxybutane and sodium alloxide; B, of 1-propoxy-2-butanol formed by the reaction of 1,2-epoxybutane with sodium propoxide; C, of the compound formed from the catalytic hydrogenation of the reaction product (monosubstituted) of 1-bromo-2,3-epoxybutane and sodium alloxide.

absorption spectrum with that of 3,4-dialloxy-2-butanol
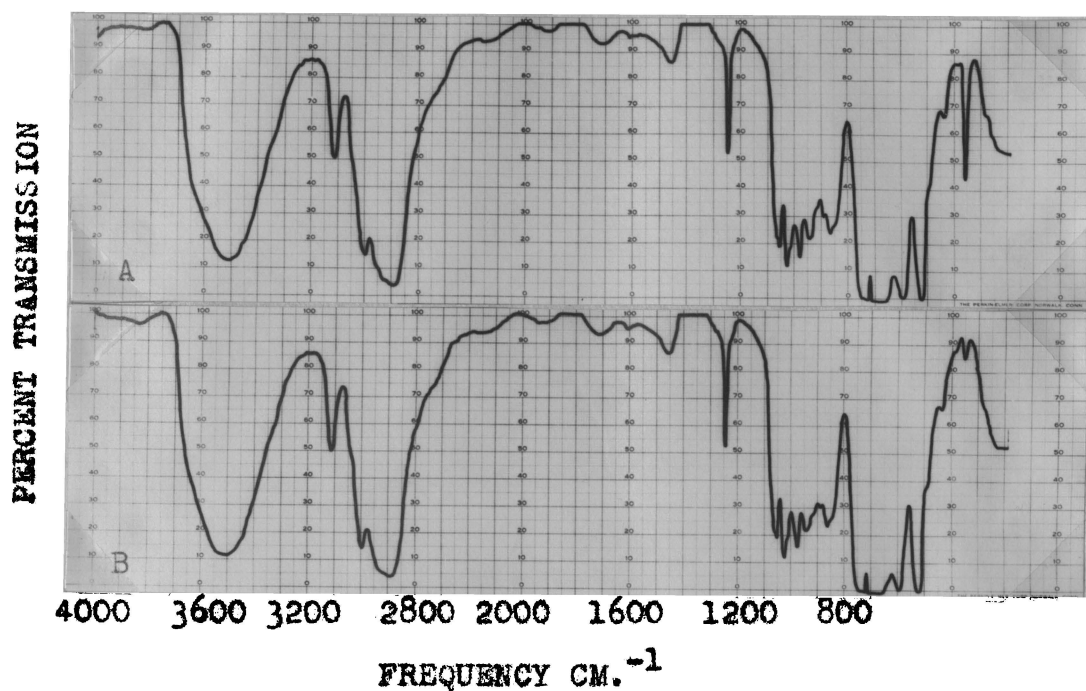
Fig. 6. Infrared absorption spectra: A, of the disubstituted product formed from the reaction of 3-bromo-1,2-epoxybutane with sodium alloxide; B, of the disubstituted product formed from the reaction of 1-bromo-2,3-epoxybutane with sodium alloxide.

believed to have been formed in the reaction just described of 3-bromo-1,2-epoxybutane with sodium alloxide (Fig. 6).

From the results just cited, it is evident that these reactions of 3-bromo-1,2-epoxybutane and 1-bromo-2,3-epoxybutane with sodium alloxide proceed by attack of the alloxide ion at the terminal carbon atom of the molecule, regardless of the substituent present at that position. In the reaction of 1-bromo-2,3-epoxybutane with sodium alloxide, the mechanism is one of simple displacement of a bromide ion by

an alloxide ion to form the product, 1-alloxy-2,3-epoxy-
butane.

In the reaction of 3-bromo-1,2-epoxybutane with sodium
alloxide, the mechanism appears to be the same as that
described for the reaction of this alpha-bromoepoxide with
diethylamine, already described in this work (see p. 16),
and with other alkoxide ions, in work reported by Waters and
VanderWerf[20]. By this mechanism, attack by the alloxide
ion at the terminal carbon atom of the epoxide ring first
occurs, resulting in ring cleavage and the formation of an
intermediate alpha-bromo-alkoxide. This is followed by the
displacement of a bromide ion by the alkoxide oxygen to form
a new epoxide ring. The complete reaction may be illus-
trated by the following series of equations:
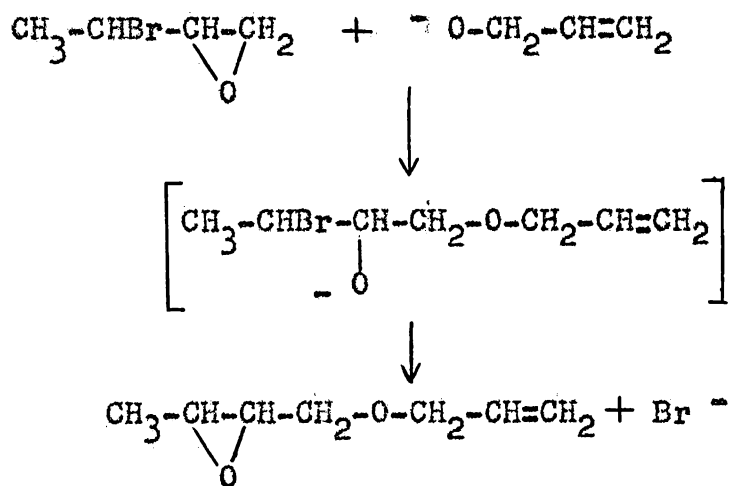
$$CH_3-CHBr-\overset{\displaystyle\diagdown\diagup}{\underset{O}{CH-CH}}_2 \quad + \quad ^{-}O-CH_2-CH{=}CH_2$$

$$\downarrow$$

$$\left[CH_3-CHBr-\underset{\underset{-}{O}}{CH}-CH_2-O-CH_2-CH{=}CH_2 \right]$$

$$\downarrow$$

$$CH_3-\overset{\displaystyle\diagdown\diagup}{\underset{O}{CH-CH}}-CH_2-O-CH_2-CH{=}CH_2 + Br^{-}$$

Reactions of 3-Bromo-1,2-epoxybutane and 1-Bromo-2,3-epoxy-
butane with the Carbanion of Isobutyrophenone

The reaction of 3-bromo-1,2-epoxybutane with the
carbanion of isobutyrophenone was accomplished by refluxing
the two materials in benzene, the latter existing as a
suspension in the solvent. The product obtained has been
identified previously by Russell[22] as 5-methyl-5-benzoyl-
2,3-epoxyhexane, and was represented as being formed in the
following manner:

$$
\begin{array}{c}
\underset{\substack{\displaystyle \| \\ \\}}{\overset{\text{O}}{\text{C}}}
\end{array}
$$

$$C_6H_5-\overset{\displaystyle O}{\overset{\displaystyle \|}{C}}-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{\displaystyle |}{\underset{\displaystyle |}{C}}}}{}^{-} \quad + \quad H_2C\underset{O}{\overset{}{\diagdown\!\diagup}}CH-CHBr-CH_3$$

$$\left[C_6H_5-\overset{\displaystyle O}{\overset{\displaystyle \|}{C}}-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{\displaystyle |}{\underset{\displaystyle |}{C}}}}-CH_2-\underset{\displaystyle O_-}{\overset{\displaystyle |}{CH}}-CHBr-CH_3 \right]$$

$$C_6H_5-\overset{\displaystyle O}{\overset{\displaystyle \|}{C}}-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{\displaystyle |}{\underset{\displaystyle |}{C}}}}-CH_2-CH\underset{O}{\overset{}{\diagup\!\diagdown}}CH-CH_3 \; + \; Br^-$$
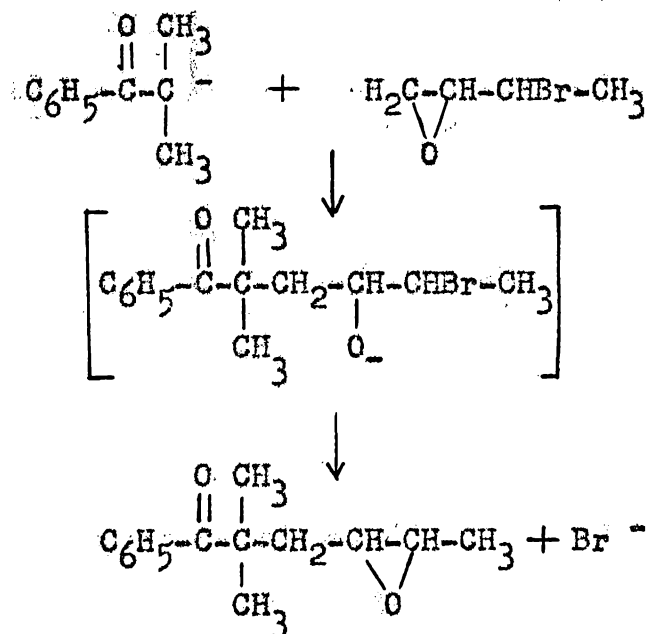
The bases on which this structural assignment was made
are: (1) oxidation of the product by alkaline permanganate
gave 3-methyl-3-benzoylbutanoic acid, prepared also indepen-
dently by the oxidation by alkaline permanganate of 5-methyl-
5-benzoyl-2-hexene and (2) independent synthesis of this
product. This was carried out by preparation and proof of

structure of 5-methyl-5-benzoyl-2-hexene, followed by hypo-
chlorination of this olefin, and subsequent epoxide ring
closure by dehydrohalogenation of the chlorohydrin with
sodium metal in toluene. The synthesis is shown in the
following sequence of equations:

$$C_6H_5\!-\!\overset{\overset{\text{O}}{\|}}{C}\!-\!\overset{\overset{\text{CH}_3}{|}}{\underset{\underset{\text{CH}_3}{|}}{C}}\!-\quad +\quad Br\!-\!CH_2\!-\!CH\!=\!CH\!-\!CH_3 \quad\longrightarrow$$

$$C_6H_5\!-\!\overset{\overset{\text{O}}{\|}}{C}\!-\!\overset{\overset{\text{CH}_3}{|}}{\underset{\underset{\text{CH}_3}{|}}{C}}\!-\!CH_2\!-\!CH\!=\!CH\!-\!CH_3 \quad\xrightarrow{\text{HOCl}}\quad C_6H_5\!-\!\overset{\overset{\text{O}}{\|}}{C}\!-\!\overset{\overset{\text{CH}_3}{|}}{\underset{\underset{\text{CH}_3}{|}}{C}}\!-\!CH_2\!-\!\overset{\overset{\text{O}}{\underset{\text{H}}{|}}}{CH}\!-\!\overset{\overset{\text{Cl}}{|}}{CH}\!-\!CH_3$$

Na

$$C_6H_5\!-\!\overset{\overset{\text{O}}{\|}}{C}\!-\!\overset{\overset{\text{CH}_3}{|}}{\underset{\underset{\text{CH}_3}{|}}{C}}\!-\!CH_2\!-\!CH\!-\!\underset{\diagdown\text{O}\diagup}{CH}\!-\!CH_3$$

Precedent for this method of ring closure of chlorohydrins
to form epoxides has been established[30,31,32].

Interestingly enough, in forming the 2,4-dinitrophenyl-
hydrazone of this product, Russell obtained a derivative
analysis of which corresponded to an empirical formula of
$C_{20}H_{20}N_4O_4$, representing a loss of two moles of water from
a mole for mole reaction of the two compounds. This deriv-
ative was reported as being red in color and as having a
melting point of $233.8\text{--}234.5^\circ$. A duplication of the pre-
paration of this derivative was carried out by this investi-

gator, in which also red crystals were obtained, which, after recrystallization from 95% ethanol, gave a melting point of 233-235°. The formation of such a derivative is reminiscent of the behavior of certain 1,4-diketones toward hydrazine and its derivatives in which substituted pyridazines[33,34,35] or pyrroles[35,36,37] are formed, and thereby suggests the possibility that the product obtained by Russell and by this investigator in this reaction may have been 5-methyl-5-benzoyl-3-hexanone, $C_6H_5-\overset{O}{\overset{||}{C}}-\overset{CH_3}{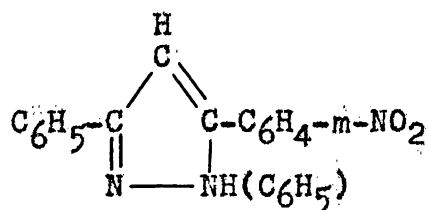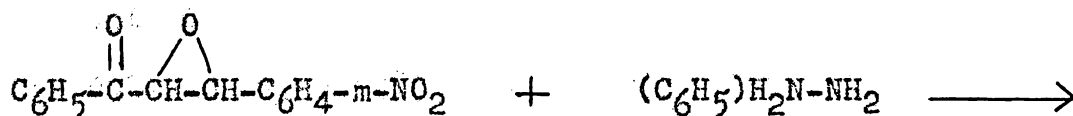\underset{CH_3}{\overset{|}{\underset{|}{C}}}}-CH_2-\overset{O}{\overset{||}{C}}-CH_2-CH_3$. This diketone could also fulfill at least one of the requirements of Russell's structure proof, the oxidation of the product to 3-methyl-3-benzoylbutanoic acid. 5-Methyl-5-benzoyl-2-hexanone would also fulfill this requirement but there are no reports in the literature of the formation of cyclic derivatives of 1,5-diketones with hydrazine or its derivatives.

The independent synthesis of 5-methyl-5-benzoyl-3-hexanone was carried out by the reaction of the carbanion of isobutyrophenone with 1,2-epoxybutane to form 5-methyl-5-benzoyl-3-hexanol, which was subsequently oxidized by chromic acid to the desired diketone. The diketone thus formed gave orange crystals of the di-(2,4-dinitrophenyl-hydrazone), m.p. 236.2-237.0°, rather than the cyclic derivative obtained from the compound in question, when treated with 2,4-dinitrophenylhydrazine according to the directions of Shriner and Fuson[29], the same procedure that was used in obtaining the cyclic derivative.

Alpha-ketoepoxides have been reported to form cyclic
derivatives, involving the removal of two moles of water,
in mole for mole reactions with hydrazine derivatives. For
example, Jorlander[38] reported the formation of 1,5-diphenyl-
3-o-anisylpyrrazole in the reaction of 1-phenyl-2-o-anisoyl-
ethylene oxide with phenylhydrazine in boiling acetic acid.

$$o\text{-}CH_3O\text{-}C_6H_4\text{-}\overset{\overset{O}{\|}}{C}\text{-}\overset{\overset{O}{/\backslash}}{CH}\text{-}CH\text{-}C_6H_5 \quad + \quad H_2N\text{-}NH\text{-}C_6H_5 \quad \longrightarrow$$

$$o\text{-}CH_3O\text{-}C_6H_4\text{-}\underset{\underset{N}{\|}}{C}\overset{\overset{\overset{H}{C}}{/\quad\backslash\backslash}}{}\underset{\underline{\quad\quad}N\text{-}C_6H_5}{\overset{C\text{-}C_6H_5}{|}}$$
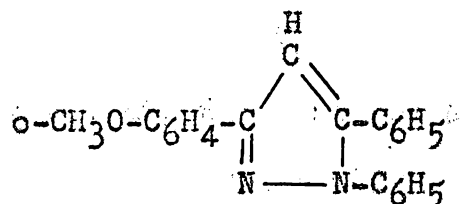
Similarly, Bodforss[39] reported the formation of 1,3-diphenyl-
5-m-nitrophenylpyrrazole in a reaction between 1-benzoyl-
2-m-nitrophenylethylene oxide and phenylhydrazine, and the
formation of 3-phenyl-5-m-nitrophenylpyrrazole in the re-
action of this alpha-ketoepoxide with hydrazine.

$$C_6H_5\text{-}\overset{\overset{O}{\|}}{C}\text{-}\overset{\overset{O}{/\backslash}}{CH}\text{-}CH\text{-}C_6H_4\text{-}m\text{-}NO_2 \quad + \quad (C_6H_5)H_2N\text{-}NH_2 \quad \longrightarrow$$

$$C_6H_5\text{-}\underset{\underset{N}{\|}}{C}\overset{\overset{\overset{H}{C}}{/\quad\backslash\backslash}}{}\underset{\underline{\quad\quad}NH(C_6H_5)}{\overset{C\text{-}C_6H_4\text{-}m\text{-}NO_2}{|}}$$

Though strict analogies of the behavior of the alpha-
ketoepoxides toward hydrazine and its derivatives and that
of the gamma-ketoepoxide proposed by Russell cannot be made,
these reactions of the alpha-ketoepoxides serve at least

to point out the possibility of similar reactions of gamma-ketoepoxides.

The compound was then treated with an equimolar amount of sodium methoxide in methanol with the expectation that if it contained an epoxy linkage, a ring opening reaction by methoxide ion would occur, resulting in the addition of the elements of methanol. A white solid product was obtained, which, even after repeated recrystallization from 95% ethanol and then ethyl acetate, gave a melting point range of 204-212°. Analysis of this product showed it to have the same composition as the starting material and duplicate molecular weight determinations of it gave values of 438 and 442. As the molecular weight of the starting material is 218, it is evident that dimerization occurred. Although this dimerization suggested a base catalyzed aldol-type condensation, examination of the infrared absorption spectrum of the dimer showed no absorption which can be attributed to the hydroxyl function, and absorption due to the ketone had disappeared. (Fig. 7).

An attempt was then made to obtain an oxirane oxygen analysis of this reaction product of 3-bromo-1,2-epoxy-butane with the carbanion of isobutyrophenone according to the method of Swern and co-workers[27], which involves reaction of the epoxide with hydrogen chloride in anhydrous ether. Although a value of 3.2% or only 43% of the calculated value for percent oxirane oxygen was found, the solution which remained after the analysis was complete yielded

a white solid, m.p. 209-215°, after recrystallization from ethyl acetate. A mixed melting point of this solid with the dimer formed on reaction of the compound in question with sodium methoxide showed no depression. Further, the infrared absorption spectrum of the dimer formed by the action of sodium methoxide and that of the product resulting from the hydrogen chloride treatment are identical (Fig. 7). Also, in the attempted synthesis of 5-methyl-5-benzoyl-2,3-epoxyhexane through the epoxidation by peracetic acid of 5-methyl-5-benzoyl-2-hexene, prepared according to the method of Russell[22], no epoxide was isolated, but a white solid, m.p. 207-218°, was formed. This solid was shown to be the same compound as the dimer formed by the action of sodium methoxide or hydrogen chloride on the compound in question by mixed melting points and by the identity of the separate infrared spectra (Fig. 7). Its analysis showed it to have the same composition as the expected product. Thus, it appears evident that epoxidation did occur and was followed by dimerization, and points to the likelihood that the compound in question resulting from the reaction of 3-bromo-1,2-epoxybutane with the carbanion of isobutyrophenone is indeed 5-methyl-5-benzoyl-2,3-epoxyhexane. Further evidence in support of this structure is found in the fact that Haller and Ramart-Lucas[21] observed that 4-methyl-4-benzoyl-1,2-epoxypentane, the next lower homolog of the suggested product, dimerized under the influence of various substances, notably nitric acid, hydrogen

chloride, hydrogen bromide, acetyl chloride, and acetic
anhydride, as well as semicarazide hydrochloride in the
presence of sodium acetate and acetic acid.

Explanation can be made for the tendency for compounds
of this type to dimerize. Petrov[40,41] has reported the
formation of 1,3-dioxolanes from the acid catalyzed con-
densation reactions between epoxides and ketones. Thus,
for example, the reaction between equimolar quantities of
dimethyl ketone and propylene oxide, done in ether with
boron trifluoride as the catalyst, produced 2,2,4-trimethyl-
1,3-dioxolane, as follows:
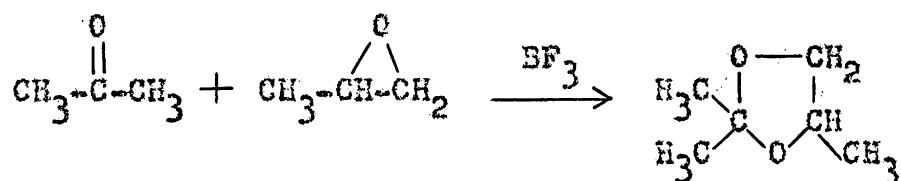
With the reaction product of 3-bromo-1,2-epoxybutane and
the carbanion of isobutyrophenone, assuming it to be 5-methyl-
5-benzoyl-2,3-epoxyhexane, dimerization to form a molecule
containing two dioxolane rings would be expected due to the
presence of both the epoxide and the ketone functions in
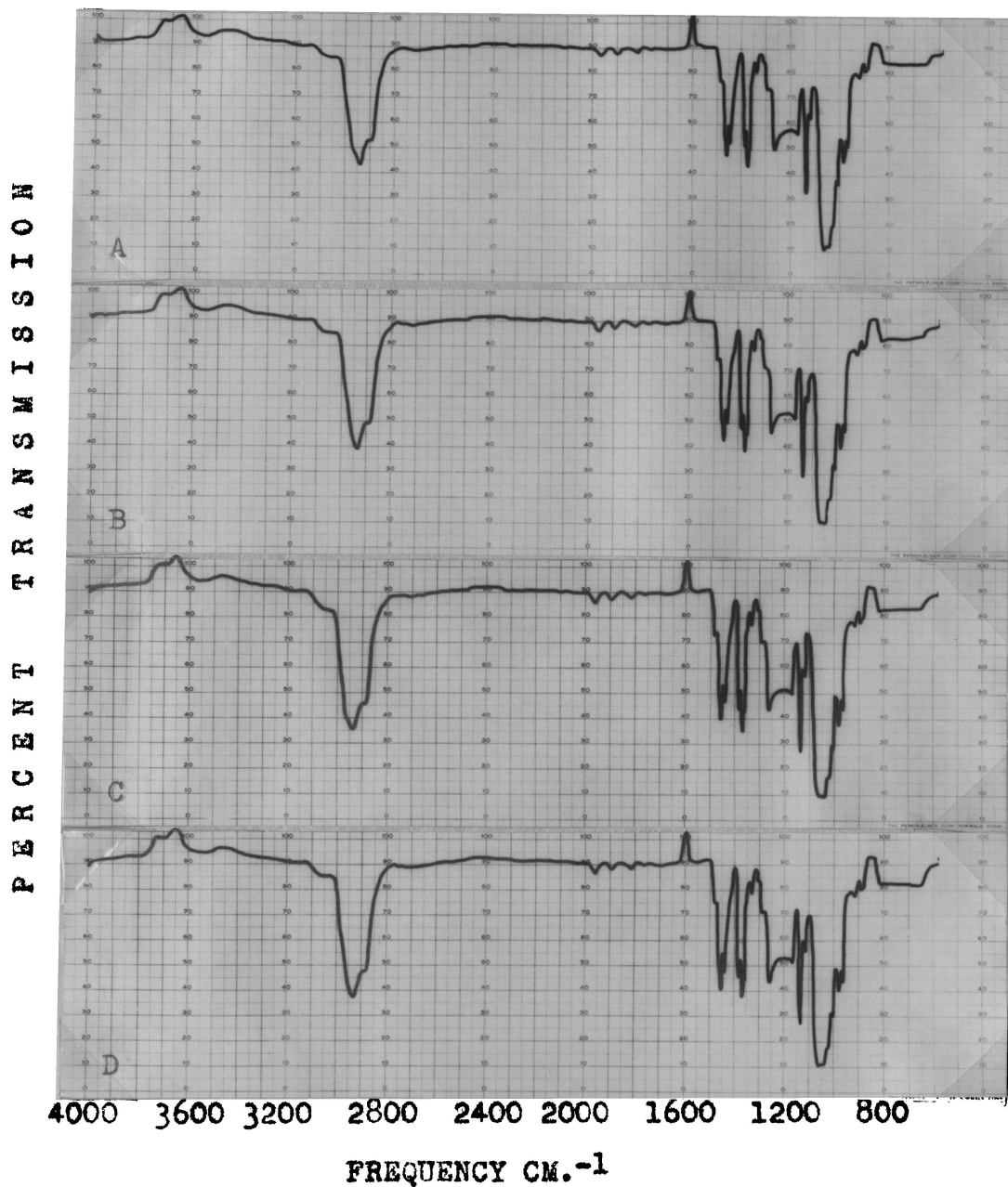the molecule:
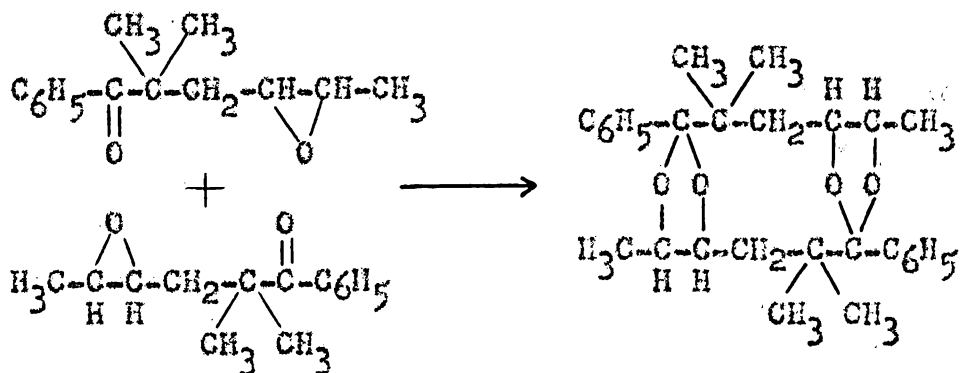
Fig. 7. Infrared absorption spectra (0.46 molar in chloroform): A, of the dimer formed by the action of sodium methoxide on the reaction product of 3-bromo-1,2-epoxybutane and the carbanion of isobutyrophenone; B, of the compound formed by the action of hydrogen chloride on this same reaction product; C, of the compound formed by the action of peracetic acid on 5-methyl-

5-benzoyl-2-hexene; D, of the compound formed by the
action of hydrogen chloride on the reaction product
of 1-bromo-2,3-epoxybutane and the carbanion of iso-
butyrophenone.

Examination of the infrared absorption spectra of this
dimeric material from the various sources (Fig. 7) shows
that there is strong absorption in the region of 1050 cm.$^{-1}$,
which can undoubtedly be attributed to ether functions.[24,42]
No dimerization reactions of 1,4-diketones or 1,5-diketones
which fit the description of the dimerization product formed
in these reactions have been reported in the literature.
Only reports of the formation of furans[43] or gamma-pyrans[44]
and these under strongly acid conditions with the elimi-
nation of water can be found.

The reaction of 1-bromo-2,3-epoxybutane with the
carbanion of isobutyrophenone done in the same way as the
reaction of 3-bromo-1,2-epoxybutane with the carbanion of
isobutyrophenone, yielded a product of the same composition
as that of the latter reaction. Russell[22] found that this
product, like the product formed in the reaction of 3-bromo-
1,2-epoxybutane with the carbanion of isobutyrophenone,
formed 3-methyl-3-benzoylbutanoic acid by oxidation with
alkaline permanganate.

An oxirane oxygen analysis, conducted according to
the method of Swern and co-workers[27], of the product of
this reaction, resulted, as with the product of the reaction

of 3-bromo-1,2-epoxybutane with the carbanion of isobutyro-
phenone, in the formation of a solid, m.p. 206.4-214.6°,
which was shown to be the same compound as the dimer pro-
duced from the product of the latter reaction by a mixed
melting point and by a comparison of their respective infra-
red absorption spectra (Fig. 7). Since the product of the
reaction of 3-bromo-1,2-epoxybutane with the carbanion of
isobutyrophenone was shown to be 5-methyl-5-benzoyl-2,3-
epoxyhexane, it follows that the product of this reaction
of 1-bromo-2,3-epoxybutane with the carbanion of isobutyro-
phenone is also 5-methyl-5-benzoyl-2,3-epoxyhexane.

Thus, again we have a demonstration of preferential
terminal attack in the reactions of 3-bromo-1,2-epoxybutane
and 1-bromo-2,3-epoxybutane with a nucleophilic agent. The
reactions may be formulated as follows:

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^{-} \quad + \quad H_2C-CH-CHBr-CH_3$$
$$\underset{\diagdown\diagup}{O}$$

$$\Bigg[C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-\overset{}{\underset{\underset{O_-}{|}}{CH}}-CHBr-CH_3 \Bigg]$$

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-CH-CH-CH_3 \quad + \quad Br^{-}$$
$$\underset{\diagdown\diagup}{O}$$

and,

$$C_6H_5-\underset{\underset{CH_3}{|}}{\overset{\overset{O}{\|}\;\overset{CH_3}{|}}{C}-C}\;^- \quad + \quad BrCH_2-CH-CH-CH_3$$

$$\downarrow$$

$$C_6H_5-\underset{\underset{CH_3}{|}}{\overset{\overset{O}{\|}\;\overset{CH_3}{|}}{C}-C}-CH_2-CH-CH-CH_3 \;+\; Br^-$$
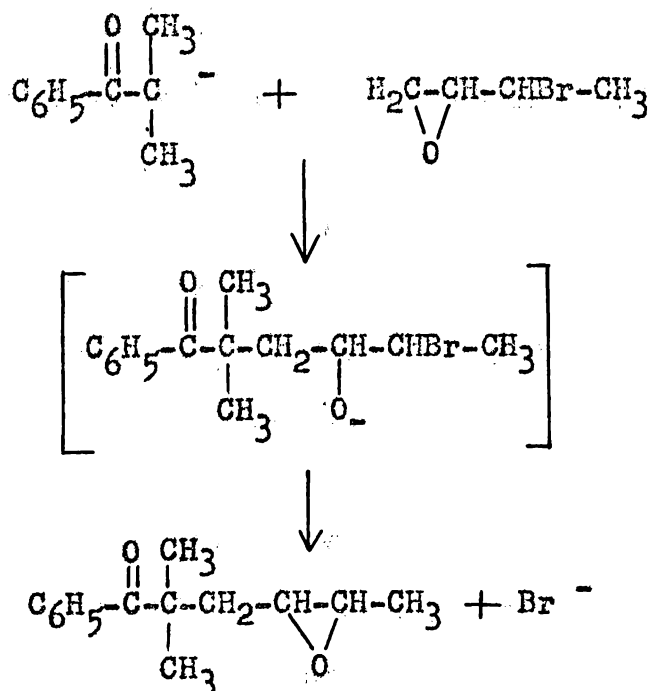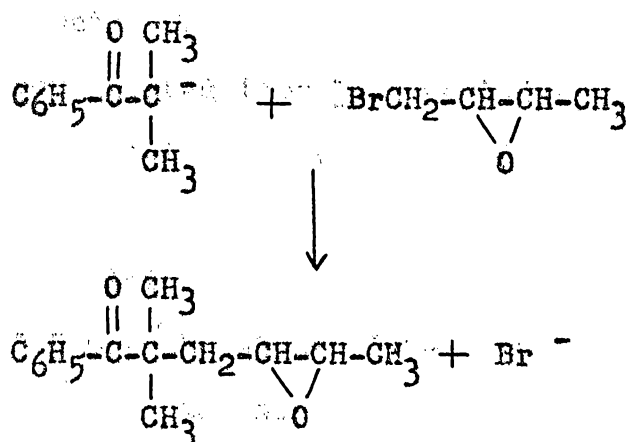
The differences in the melting points of the oximes
of the products of these two reactions, as determined by
Russell[22], may be explained by the stereochemical dissimilar-
ity of the two materials. As discussed by Waters and
VanderWerf[20], the product of the reaction of the 3-bromo-
1,2-epoxybutane with a nucleophilic agent by this mechanism
must be the erythro form, whereas the product of the reaction
of 1-bromo-2,3-epoxybutane with a nucleophilic agent by the
direct displacement of a bromide ion is, in all likelihood,
a racemic mixture. This investigator was unable to form
oximes of either product, and like Russell, was unable to
form the 2,4-dinitrophenylhydrazone of the product of the
reaction of 1-bromo-2,3-epoxybutane with the carbanion of
isobutyrophenone. However, this may, in both cases, have
been a matter of timing. Infrared spectra of both the
products of the reactions of these isomeric alpha-bromo-
epoxides with the carbanion of isobutyrophenone, when taken
on samples which had been standing for some time, showed
much less ketone absorption than would be expected for the

proposed product. On the other hand, the infrared spectrum of the product derived from 3-bromo-1,2-epoxybutane, when freshly prepared and distilled, showed an intensity of absorption in the ketone region which seemed normal for a monoketone of this molecular weight, comparing favorably with that of 5-methyl-5-benzoyl-2-hexene, and incidentally, showing a much less intense absorption band in the strong ketone absorption region, approximately 1700 cm.$^{-1}$, than that of a known diketone of the same molecular weight, 5-methyl-5-benzoyl-3-hexanone. At any rate, the implication of this decrease in absorption due to the ketone function is that dimerization may occur quite easily and that therefore, the ketone function is gradually made unavailable for derivative formation.

Experimental

Reaction of 3-Bromo-1,2-epoxybutane with Diethylamine

$$CH_3-CHBr-CH-CH_2 \quad + \quad HN\begin{smallmatrix}CH_2-CH_3\\CH_2-CH_3\end{smallmatrix} \quad \longrightarrow$$

(30 g., 0.20 mole)   (29 g., 0.40 mole)

$$CH_3-CH-CH-CH_2-N\begin{smallmatrix}CH_2-CH_3\\CH_2-CH_3\end{smallmatrix} \quad + \quad H_2\overset{+}{N}\begin{smallmatrix}CH_2-CH_3\\CH_2-CH_3\end{smallmatrix} \quad + \quad Br^-$$

(6 g., 0.042 mole)   (16 g., 0.10 mole)

21% of theory   50% of theory
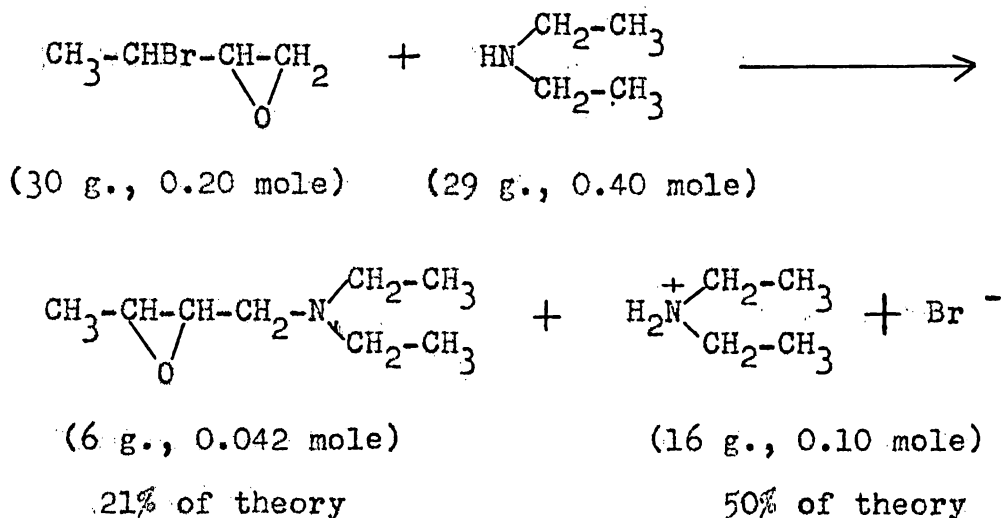
To 30 g. (0.20 mole) of 3-bromo-1,2-epoxybutane, in 150
ml. of anhydrous ether in a 250 ml. glass-stoppered conical
flask, 29 g. (0.40 mole) of diethylamine was added with
mixing. The flask was stoppered and within two minutes
white crystals of diethylamine hydrobromide began to appear.
The mixture was allowed to stand overnight, after which
time the diethylamine hydrobromide was filtered from the
ether solution and washed with several small portions of
anhydrous ether. It was then recrystallized from a 75%
ether-25% absolute ethanol mixture, yielding 16 g. (50% of
theory) of material melting at 214.2-216.8°. An equal
mixture of this material and an authentic sample of diethyl-
amine hydrobromide, m.p. 217.0- 218.5°, gave a melting
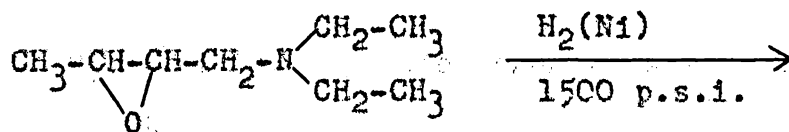point of 216.0-218.4°.

The ether filtrate and washings were combined. The ether was removed by distillation and the residue was distilled under reduced pressure, yielding a principal fraction of 6 g. (21% of theory) of 1-diethylamino-2,3-epoxybutane, b.p. 76.5-77.0° at 25 mm. pressure.

Analysis:* Calculated for $C_8H_{17}ON$: C, 67.09; H, 11.97; N, 9.70.

Found: C, 65.19; H, 11.43; N, 8.39.

Proof of the structure of this product was obtained by its catalytic reduction in acidified alcoholic solution to 1-diethylamino-2-butanol, synthesized independently by the reaction of diethylamine with 1,2-epoxybutane. Difficulty in retaining products of this type in a pure state has been experienced by other workers[12].

Catalytic Reduction of 1-Diethylamino-2,3-epoxybutane Obtained from the Reaction of 3-Bromo-1,2-epoxybutane with Diethylamine

$$CH_3-CH-CH-CH_2-N \begin{array}{c} CH_2-CH_3 \\ CH_2-CH_3 \end{array} \quad \xrightarrow[1500 \text{ p.s.i.}]{H_2(Ni)}$$

(4 g., 0.028 mole)

$$CH_3-CH_2-CHOH-CH_2-N \begin{array}{c} CH_2-CH_3 \\ CH_2-CH_3 \end{array}$$
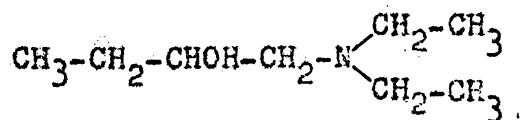
(3.2 g., 0.022 mole)

79% of theory

*All analyses by Weiler and Strauss, 164 Banbury Rd., Oxford.

To 4 g. of 1-diethylamino-2,3-epoxybutane in 50 ml. of 95% ethanol containing 0.5 g. of Raney nickel, was added 1 ml. of concentrated hydrochloric acid. This mixture was subjected to 1500 p.s.i. of hydrogen in a closed bomb at room temperature, with constant shaking for 2 hours. The material was then removed, the Raney nickel removed by filtration and washed with 3-10 ml. portions of 95% ethanol. The filtrate and washings were combined and made basic with 10% sodium hydroxide solution. This solution was then extracted with 5-50 ml. portions of ether. The ether was distilled from the combined extracts and the residue distilled under reduced pressure to give 3.2 g. of 1-diethylamino-2-butanol, b.p. 84.5° at 25 mm. (literature value[45], 74-75° at 22 mm.).

Analysis: Calculated for $C_8H_{19}ON$: C, 66.17; H, 13.19; N, 9.66.

Found: C, 66.32; H, 13.35; N, 8.85.

The hydrochloride of this material was prepared by the addition of excess anhydrous HCl gas to a solution of 1 g. of the compound in 100 ml. of anhydrous ether. The ether and excess HCl gas were evaporated and the solid residue was purified by sublimation at 70° and a pressure of 1 mm., yielding a white, slightly hygroscopic solid melting at 79.0-80.8°. Equal quantities of this derivative and an authentic sample of 1-diethylamino-2-butanol hydrochloride, m.p. 83.2-85.6°, gave a mixed melting point of 82.4-84.4°. The authentic sample of 1-diethylamino-2-butanol was pre-

pared by the reaction of diethylamine with 1,2-epoxybutane.

Analysis: Calculated for $C_8H_{20}ONCl$; C, 52.88;

H, 11.04; N, 7.71; Cl, 19.52.

Found: C, 52.72; H, 11.01; N, 7.65;

Cl, 19.4.

Preparation of 1-Diethylamino-2-butanol

$$CH_3-CH_2-\underset{\underset{O}{\diagdown\diagup}}{CH-CH_2} \quad + \quad HN\diagup\diagdown \begin{matrix} CH_2-CH_3 \\ CH_2-CH_3 \end{matrix} \longrightarrow$$

(37 g., 0.50 mole)   (37 g., 0.50 mole)

$$CH_3-CH_2-CHOH-CH_2-N\diagup\diagdown \begin{matrix} CH_2-CH_3 \\ CH_2-CH_3 \end{matrix}$$

(41.5 g., 0.29 mole)

57% of theory

About 37 g. (0.5 mole) of 1,2-epoxybutane and 37 g.
(0.5 mole) of diethylamine were mixed with 100 ml. of
water and 50 ml. of dioxane in a glass-stoppered 250 ml.
conical flask. The mixture was allowed to stand 5 days,
after which time the solvents and unreacted starting mater-
ials were removed by distillation. The residue was dis-
tilled under reduced pressure to give 42 g. (57% of theory)
of 1-diethylamino-2-butanol, b.p. 80-83° at 25 mm. (liter-
ature value[45], 74-75° at 22 mm.).

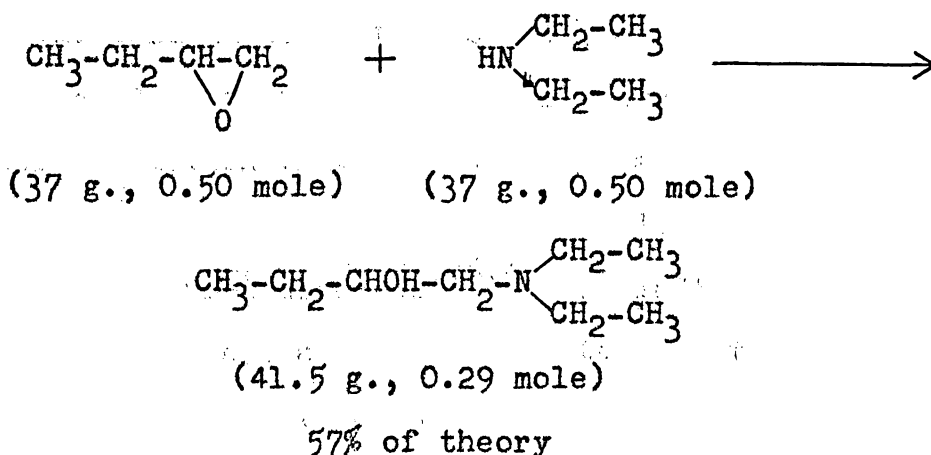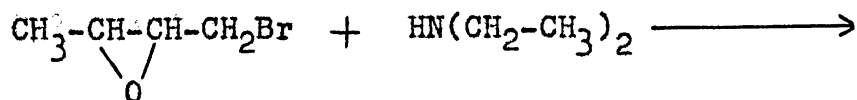Analysis: Calculated for $C_8H_{19}ON$: C, 66.17; H,

13.19; N, 9.66;

Found: C, 66.14; H, 13.16; N, 7.75.

The hydrochloride of this product, purified by sub-limation at 70° and 1 mm. pressure, gave a melting point of $83.2-85.6^\circ$.

Analysis: Calculated for $C_8H_{20}ONCl$: C, 52.88; H, 11.04; N, 7.71; Cl, 19.52.

Found: C, 52.60; H, 11.20; N, 7.50; Cl, 19.3.

The assignment of the formula, 1-diethylamino-2-butanol, to the product of this reaction is based on the validity of the assumption that attack by the amine occurred at the terminal carbon atom of the epoxide ring. Studies on the reactions of various amines[46,47], including diethylamine[46], with propylene oxide, show that attack by the amine occurs exclusively at the terminal carbon atom of the epoxide ring.

Reaction of 1-Bromo-2,3-epoxybutane with Diethylamine

$$CH_3-CH-CH-CH_2Br \quad + \quad HN(CH_2-CH_3)_2 \longrightarrow$$
$$\underset{O}{\diagdown\diagup}$$

(30g., 0.20 mole)   (29 g., 0.40 mole)

$$CH_3-CH-CH-CH_2-N(CH_2-CH_3)_2 \quad + \quad H_2\overset{+}{N}(CH_2-CH_3)_2 + Br^-$$
$$\underset{O}{\diagdown\diagup}$$
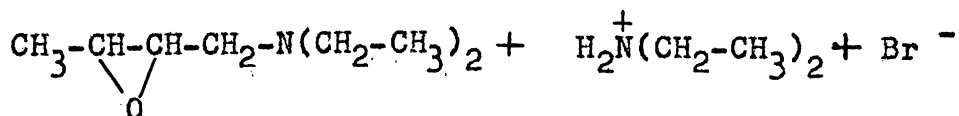
(21 g., 0.15 mole)   (25 g., 0.18 mole)

74% of theory   89% of theory

The procedure was identical to that used for the

reaction of 3-bromo-1,2-epoxybutane with diethylamine (see p.41). The reactants were 30 g. (0.20 mole) of 1-bromo-2,3-epoxybutane and 29 g. (0.40 mole) of diethylamine and 25 g. (89% of theory) of diethylamine hydrobromide, m.p. 217.8-218.4° was obtained. An equal mixture of this material and an authentic sample of diethylamine-hydrobromide, m.p. 217.0-218.5°, gave a melting range of 217.2-218.4°.

On distillation of the ether layer, 21 g. (74% of theory) of 1-diethylamino-2,3-epoxybutane, b.p. 74-78° at 20 mm. pressure, was obtained as the principal fraction.

Analysis: Calculated for $C_8H_{17}ON$: C, 67.09;

H, 11.97; N, 9.78.

Found: C, 65.55; H, 11.67; N, 8.20.

Proof of the structure of this product was obtained by its catalytic reduction to 1-diethylamino-2-butanol, synthesized independently by the reaction of diethylamine with 1,2-epoxybutane.

Catalytic Reduction of 1-Diethylamino-2,3-epoxybutane
Obtained from the Reaction Between 1-Bromo-2,3-epoxybutane
and Diethylamine

$$CH_3-CH-CH-CH_2-N(CH_2-CH_3)_2$$

(4g., 0.028 mole)

$H_2(Ni)$, 1500 p.s.i.

$$CH_3-CH_2-CHOH-CH_2-N(CH_2-CH_3)_2$$
(3.4 g., 0.023 mole)
82% of theory
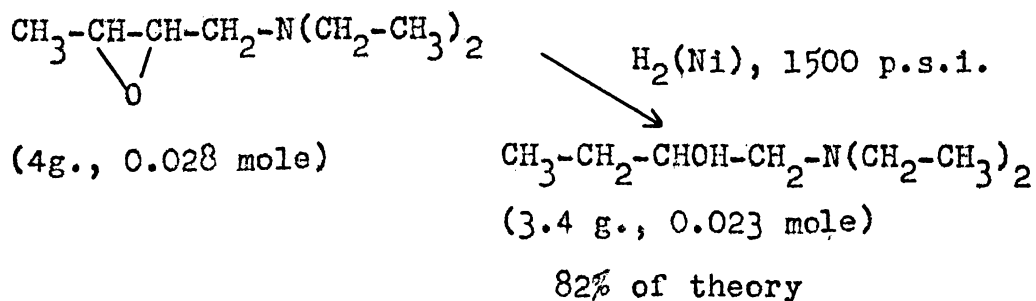
The procedure was identical to that used in the reduction of 1-diethylamino-2,3-epoxybutane derived from 3-bromo-1,2-epoxybutane (see p.42). From 4 g. of this sample of 1-diethylamino-2,3-epoxybutane 3.4 g. of 1-diethylamino-2-butanol, b.p. 82-84° at 25 mm., was obtained.

Analysis: Calculated for $C_8H_{19}ON$: C, 66.17;

H, 13.19; N, 9.66.

Found: C, 66.35; H, 13.17; N, 8.72.

The hydrochloride of this material, purified by sublimation at 70° and 1 mm. pressure, m.p. 80.2-82.6°, when mixed with an equal quantity of an authentic sample of 1-diethylamino-2-butanol hydrochloride, m.p. 83.2-85.6°, gave a melting point of 80.2-82.6°. The authentic sample of 1-diethylamino-2-butanol was prepared by the reaction of diethylamine with 1,2-epoxybutane.

Analysis: Calculated for $C_8H_{20}ONCl$: C, 52.88;

H, 11.04; N, 7.71; Cl, 19.52.

Found: C, 52.72; H, 11.01; N, 7.65;

Cl, 19.4.

Reaction of 3-Bromo-1,2-epoxybutane with Sodium Azide

$$CH_3-CHBr-CH-CH_2 + NaN_3 \longrightarrow CH_3-CHOH-CHN_3-CH_2N_3 + NaBr$$

(75 g., 0.50 mole) (35 g.,   (22 g., 0.14 mole)

                     0.53 mole)   56% of theory

To 500 ml. of dioxane in a 1-liter, 2-necked flask,
equipped with a reflux condenser and dropping funnel, 75 g.
(0.50 mole) of 3-bromo-1,2-epoxybutane was added. The
solution was heated to reflux, then 35 g. (0.53 mole) of
sodium azide in 100 ml. of water was added dropwise. Re-
fluxing was continued for 6 hours, then the mixture was
allowed to cool. Two layers separated, an upper dioxane
layer and a lower aqueous phase containing dissolved sodium
bromide. The dioxane layer was retained, the dioxane dis-
tilled and the residue distilled under reduced pressure.
Approximately 35 g. of material, b.p. 72-82° at 55 mm.
pressure, which could not be separated into fractions and
which gave a positive Beilstein halogen test, was obtained
along with 22 g. (56% of theory) of 3,4-diazido-2-butanol,
b.p. 81-84° at 0.5 mm. pressure.

    Analysis: Calculated for $C_4H_8ON_6$: C, 30.76; H, 5.16;
        N, 53.82.

        Found: C, 30.92; H, 5.80; N, 54.5.

    Proof of the identity of this product was obtained by
the comparison of its infrared obsorption spectrum with

that of an authentic sample of 3,4-diazido-2-butanol, prepared by the reaction of 3,4-dibromo-2-butanol with sodium azide.

Preparation of 3,4-Diazido-2-butanol

$$CH_3-CHOH-CH=CH_2 \quad + \quad Br_2 \longrightarrow CH_3-CHOH-CHBr-CH_2Br$$
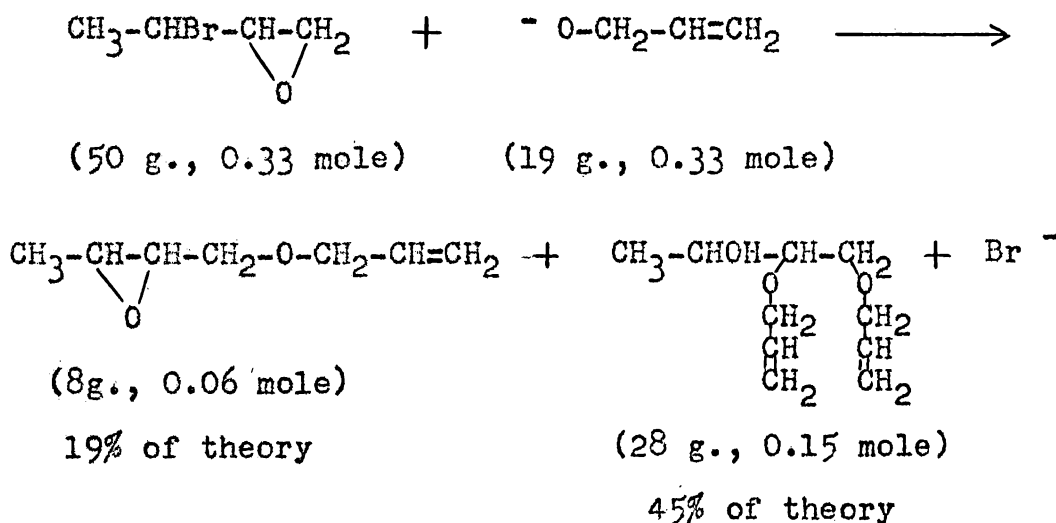
(30 g., 0.20 mole)   (32 g.,

0.20 mole)

$$CH_3-CHOH-CHBr-CH_2Br \quad + \quad NaN_3 \longrightarrow CH_3-CHOH-CHN_3-CH_2N_3 + NaBr$$

                       (65 g.,   (15 g., 0.096 mole)

                        1.0 mole)   48% of theory
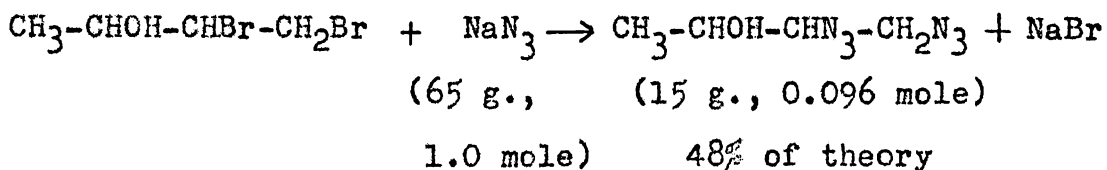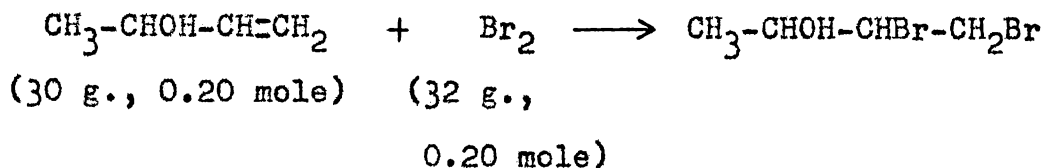
To 30 g. (0.20 mole) of 3-buten-2-ol, prepared according to the method of Petrov[23], in 200 ml. of dioxane in a 3-necked, 1-liter flask, equipped with a motor-driven stirrer, reflux condenser, and dropping funnel, 32 g. (0.20 mole) of bromine was added dropwise with cooling in an ice bath. To this dioxane solution of 3,4-dibromo-2-butanol an additional 100 ml. of dioxane was added. The solution was heated to reflux and 65 g. (1 mole) of sodium azide in 300 ml. of water was added rapidly. Refluxing was continued for 24 hours, after which time most of the dioxane was distilled away, leaving two liquid layers and a solid inorganic residue. Then 800 ml. of water was added, and the solution which resulted was extracted with 3-300 ml. portions of ether. The ether extracts were

retained. The ether was removed by distillation and the residue was distilled under reduced pressure. 3,4-Diazido-2-butanol (15 g., 48% of theory), b.p. 94-96° at 1.3 mm. pressure was obtained.

Analysis: Calculated for $C_4H_8ON_6$: C, 30.76; H, 5.16; N, 53.82.

Found: C, 31.65, 31.21; H, 5.24, 5.62; N, 53.7, 53.5.

Reaction of 1-Bromo-2,3-epoxybutane with Sodium Azide

$$CH_3-CH-CH-CH_2Br \ + \ NaN_3 \longrightarrow CH_3-CHOH-CHN_3-CH_2N_3$$
(with epoxide O bridging the two central carbons)

(75 g., 0.50 mole)   (35 g., 0.53 mole)   (19 g., 0.12 mole) 48% of theory

This experiment was carried out in the same way as was the reaction of 3-bromo-1,2-epoxybutane with sodium azide (see p.48). Reactants were 75 g.(0.50 mole) of 1-bromo-2,3-epoxybutane and 35 g. (0.50 mole) of sodium azide. Approximately 22.5 g. of material, b.p. 74-82° at 55 mm. pressure, which was not separable into fractions, and which gave a positive Beilstein test for halogen, was obtained, along with 19 g. (48% of theory) of 3,4-diazido-2-butanol, b.p. 73-76° at 0.4 mm. pressure.

Analysis: Calculated for $C_4H_8ON_6$: C, 30.76; H, 5.16; N, 53.82.

Found: C, 31.61, 31.41; H, 5.18, 5.72; N, 54.2.

Proof of the identity of this product was obtained by the comparison of its infrared absorption spectrum with that of an authentic sample of 3,4-diazido-2-butanol, prepared by the reaction of 3,4-dibromo-2-butanol with sodium azide.

Reaction of 3-Bromo-1,2-epoxybutane with Sodium Alloxide

$$CH_3-CHBr-\underset{\displaystyle O}{CH-CH_2} \quad + \quad {}^-O-CH_2-CH=CH_2 \quad \longrightarrow$$

(50 g., 0.33 mole)   (19 g., 0.33 mole)

$$CH_3-\underset{\displaystyle O}{CH-CH}-CH_2-O-CH_2-CH=CH_2 \;+\; CH_3-CHOH-\underset{\substack{O\\CH_2\\CH\\CH_2}}{CH}-\underset{\substack{O\\CH_2\\CH\\CH_2}}{CH_2} \;+\; Br^-$$

(8g., 0.06 mole)

19% of theory

(28 g., 0.15 mole)

45% of theory

Exactly 7.7 g. (0.33 atom) of sodium was dissolved in small pieces in 250 ml. of allyl alcohol. To this solution in a 500 ml., 3-necked flask, equipped with a motor-driven stirrer, dropping funnel, and reflux condenser, 50 g. (0.33 mole) of 3-bromo-1,2-epoxybutane was added in the course of 5 minutes with vigorous stirring. No external heating was applied and a slightly exothermic reaction shortly ensued with precipitation of sodium bromide. After 1 hour, the condenser was set for distillation and most of the excess allyl alcohol was distilled leaving an oily residue and a

large solid residue of sodium bromide. The liquid was
decanted and the sodium bromide was washed with ether,
leaving 30 g. (34 g. theoretical) of this material. The
ether washings were combined with the decanted liquid,
the ether was distilled and the residue was then distilled
at reduced pressure. Two fractions were obtained:

(1) 8 g. (19% of theory) of 1-alloxy-2,3-epoxybutane,
b.p. 75-77° at 25 mm.

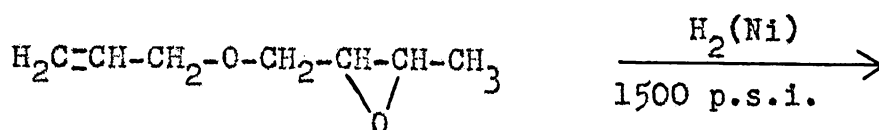Analysis: Calculated for $C_7H_{12}O_2$: C, 65.58; H,
9.44.

Found: C, 64.62; H, 9.17.

(2) 28 g. (45% of theory) of 3,4-dialloxy-2-butanol,
b.p. 128-129° at 25 mm.

Analysis: Calculated for $C_{10}H_{18}O_3$: C, 64.50; H,
9.72.

Found: C, 64.50; H, 9.69.

Proof of the structure of fraction (1) was obtained
by its catalytic reduction to 1-propoxy-2-butanol which
was subsequently oxidized by chromic acid to 1-propoxy-
2-butanone. A mixed melting point of the 2,4-dinitrophenyl-
hydrazone of the latter product with that of an authentic
sample of 1-propoxy-2-butanone showed no depression. The
authentic sample of 1-propoxy-2-butanone was prepared by
the oxidation by chromic acid of 1-propoxy-2-butanol pre-
pared by the reaction of sodium propoxide with 1,2-epoxy-
butane.

Catalytic Reduction of 1-Alloxy-2,3-epoxybutane Obtained
by the Reaction of 3-Bromo-1,2-epoxybutane with Sodium
Alloxide

$$H_2C\underset{}{=}CH-CH_2-O-CH_2-\underset{\underset{O}{\diagdown\diagup}}{CH-CH}-CH_3 \qquad \xrightarrow[\text{1500 p.s.i.}]{H_2(Ni)}$$

(5g., 0.04 mole)

$$CH_3-CH_2-CH_2-O-CH_2-CHOH-CH_2-CH_3$$
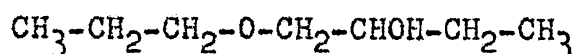
(3g., 0.023 mole)

57% of theory

Exactly 5 g. (0.04 mole) of 1-alloxy-2,3-epoxybutane,
dissolved in 50 ml. of ethyl alcohol to which had been
added 0.5 g. of Raney nickel, was subjected, with shaking,
to 1500 p.s.i. of hydrogen at 130° for 3 hours. After this
time, the Raney nickel was filtered, and washed with 50 ml.
of ethyl alcohol. The washings and filtrate were combined,
and the ethyl alcohol removed by distillation. The residue
was distilled under reduced pressure to give 3 g. (57% of
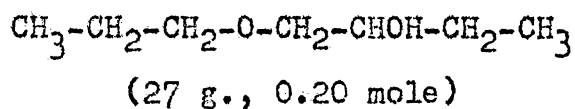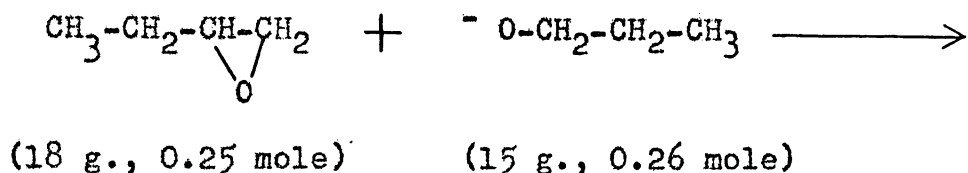theory) of 1-propoxy-2-butanol, b.p. 78-81° at 28 mm.

Analysis: Calculated for $C_7H_{16}O_2$: C, 63.59; H,
12.20.

Found: C, 63.47; H, 12.23.

Oxidation by chromic acid of this product, produced a
ketone, the 2,4-dinitrophenylhydrazone of which gave a
melting point of 93-94°. A mixed melting point of this
derivative with that of an authentic sample of 1-propoxy-

2-butanone, prepared by the oxidation of 1-propoxy-2-butano formed by the reaction of sodium propoxide with 1,2-epoxy-butane, showed no depression.

Reaction of 1,2-Epoxybutane with Sodium Propoxide

$$CH_3-CH_2-CH-CH_2 \quad + \quad {}^- O-CH_2-CH_2-CH_3 \quad \longrightarrow$$
$$\diagdown\!\!\diagup$$
$$O$$

(18 g., 0.25 mole)   (15 g., 0.26 mole)

$$CH_3-CH_2-CH_2-O-CH_2-CHOH-CH_2-CH_3$$

(27 g., 0.20 mole)

80% of theory

Exactly 6 g. (0.26 atom) of sodium was added to 250 ml. of dry propyl alcohol. To this solution in a 500 ml., 3-necked flask, equipped with a motor-driven stirrer, re-flux condenser, and dropping funnel, 18 g. (0.25 mole) of 1,2-epoxybutane was added in the course of 10 minutes with vigorous stirring. External heating was begun and the material was refluxed for 3 hours. After this time, the excess allyl alcohol was removed by distillation. The residue was washed with 300 ml. of water, and the oily liquid which separated was taken up in ether. The aqueous layer was extracted with 3-200 ml. portions of ether. All ether extracts were combined, the ether was removed by distillation and the residue was distilled under reduced pressure to give 27 g. (80% of theory) of 1-propoxy-2-
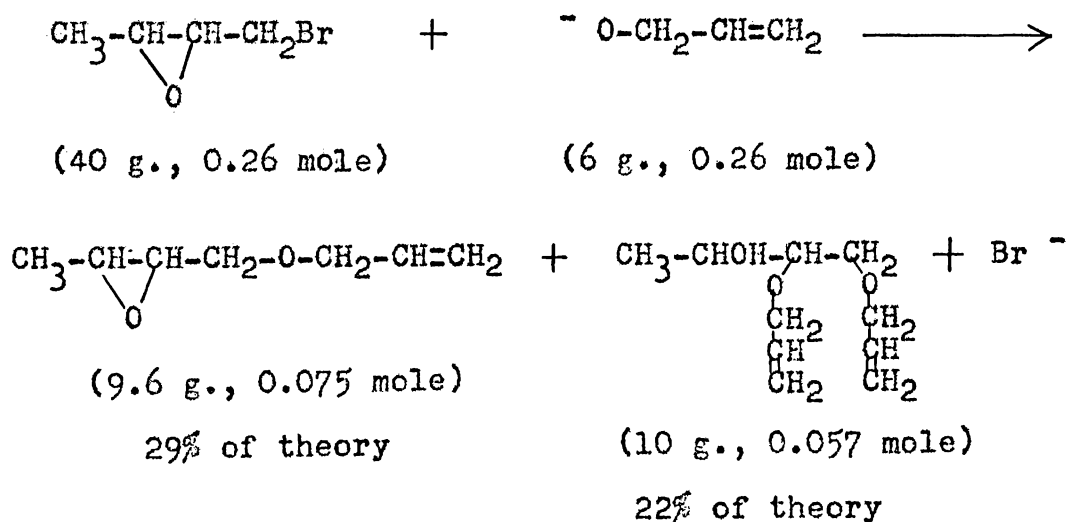
butanol, b.p. 74.5-77.0° at 25 mm.

Analysis: Calculated for $C_7H_{16}O_2$: C, 63.59,

H, 12.20.

Found: C, 63.19; H, 11.76.

Assignment of the structure, 1-propoxy-2-butanol, to the product of this reaction is based on the validity of the assumption that attack by the propoxide ion occurred at the terminal carbon atom of the epoxide ring of 1,2-epoxybutane. All reports in the literature dealing with base-catalyzed condensations of propylene oxide with alcohols[48],[49] and phenols[50],[51] show that exclusive attack at the terminal carbon atom of the epoxide ring occurred. Also, in a study by Swern and co-workers[52], it was shown that exclusive terminal attack occurred in the reaction of propylene oxide and of 3,4-epoxy-1-butene with sodium alloxide.

Reaction of 1-Bromo-2,3-epoxybutane with Sodium Alloxide

$$CH_3\text{-}CH\text{-}CH\text{-}CH_2Br \quad + \quad {}^-O\text{-}CH_2\text{-}CH{=}CH_2 \quad \longrightarrow$$

(40 g., 0.26 mole)   (6 g., 0.26 mole)

$$CH_3\text{-}CH\text{-}CH\text{-}CH_2\text{-}O\text{-}CH_2\text{-}CH{=}CH_2 \quad + \quad CH_3\text{-}CHOH\text{-}CH\text{-}CH_2 \quad + \quad Br^-$$

(9.6 g., 0.075 mole)

29% of theory

(10 g., 0.057 mole)

22% of theory

Exactly 6 g. (0.26 atom) of sodium was dissolved in 200 ml. of allyl alcohol. To this solution, in a 500 ml., 3-necked flask, equipped with a motor-driven stirrer, dropping funnel, and condenser set for distillation, 40 g. (0.26 mole) of 1-bromo-2,3-epoxybutane was added in the course of 5 minutes with vigorous stirring. Heating was begun at once, and the excess allyl alcohol was distilled over as rapidly as possible. The residue was washed with 300 ml. of water to remove the sodium bromide which precipitated. The oily upper layer was taken up in 200 ml. of benzene, and the aqueous layer was extracted with 3-100 ml. portions of benzene. The benzene extracts were combined, the benzene was removed by distillation, and the residue was distilled at reduced pressure. Two fractions were obtained:

(1) 9.6 g. (29% of theory) of 1-alloxy-2,3-epoxybutane, b.p. 74.5-76.0° at 25 mm.

Analysis: Calculated for $C_7H_{12}O_2$: C, 65.58;
H, 9.44.

Found: C, 65.80, 65.35; H, 9.51, 9.46.

(2) 10 g. (22% of theory) of 3,4-dialloxy-2-butanol, b.p. 72.5° at 0.75 mm.

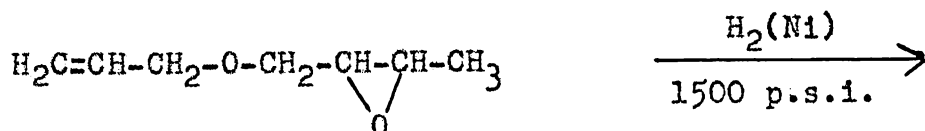Analysis: Calculated for $C_{10}H_{18}O_3$: C, 64.50;
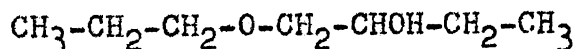H, 9.72.

Found: C, 64.38; H, 9.74.

Proof of the structure of fraction (1) was obtained by its catalytic reduction to 1-propoxy-2-butanol which was

subsequently oxidized by chromic acid to 1-propoxy-2-butanone. A mixed melting point of the 2,4-dinitrophenyl-hydrazone of the latter product, m.p. 93-94°, with that of an authentic sample of 1-propoxy-2-butanone, m.p. 93-94°, showed no depression. The authentic sample of 1-propoxy-2-butanone was prepared by the oxidation by chromic acid of 1-propoxy-2-butanol prepared by the reaction of sodium propoxide with 1,2-epoxybutane.

Catalytic Reduction of 1-Alloxy-2,3-epoxybutane Obtained by the Reaction of 1-Bromo-2,3-epoxybutane with Sodium

Alloxide

$$H_2C=CH-CH_2-O-CH_2-CH-CH-CH_3 \qquad \xrightarrow[\text{1500 p.s.i.}]{H_2(Ni)}$$

(4 g., 0.03 mole)

$$CH_3-CH_2-CH_2-O-CH_2-CHOH-CH_2-CH_3$$

(3 g., 0.023 mole)

77% of theory

Here, 4 g. (0.03 mole) of 1-alloxy-2,3-epoxybutane was used. The procedure was identical to that described for the reduction of 1-alloxy-2,3-epoxybutane derived from 3-bromo-1,2-epoxybutane (see p.53). About 3 g. (77% of theory) of 1-propoxy-2-butanol, b.p. 75-77° at 25 mm. was obtained.

Analysis: Calculated for $C_7H_{16}O_2$: C, 63.59; H, 12.20.

Found: C, 63.34, 63.24; H, 12.01, 12.15.

Oxidation by chromic acid of this product, produced a ketone, the 2,4-dinitrophenylhydrazone of which gave a melting point of 93-94°. A mixed melting point of this derivative with that of an authentic sample of 1-propoxy-2-butanone, prepared by the oxidation of 1-propoxy-2-butanol formed by the reaction of sodium propoxide with 1,2-epoxybutane, showed no depression.

Oxidation of 1-Propoxy-2-butanol to 1-Propoxy-2-butanone

$$CH_3-CH_2-CH_2-O-CH_2-CHOH-CH_2-CH_3 \xrightarrow[H_2SO_4]{K_2Cr_2O_7}$$
(1g., 0.0076 mole)
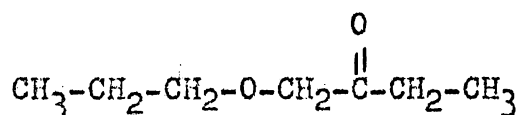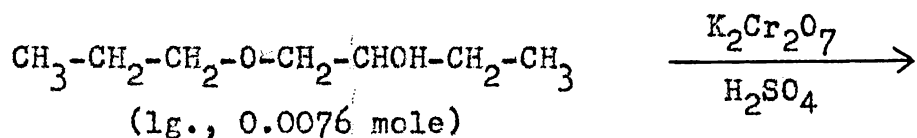
$$CH_3-CH_2-CH_2-O-CH_2-\overset{\overset{\textstyle O}{\|}}{C}-CH_2-CH_3$$
(Not isolated, 2,4-dinitrophenyl-

hydrazone formed directly)

About 1 g. (0.0076 mole) of 1-propoxy-2-butanol was added to a solution of 1.49 g. (0.0051 mole) of potassium dichromate and 13.1 g. of concentrated sulfuric acid in 78.5 ml. of water in a 250 ml. conical flask fitted with a reflux condenser. The mixture was heated on a steam bath for 1 hour or until the solution had turned green. After this time, the mixture was allowed to cool and was extracted with 3-100 ml. portions of petroleum ether. The combined extracts were washed with 100 ml. of 5% sodium hydroxide solution and then with 100 ml. of water. The petroleum
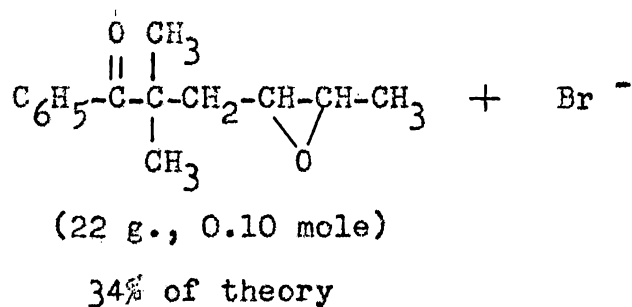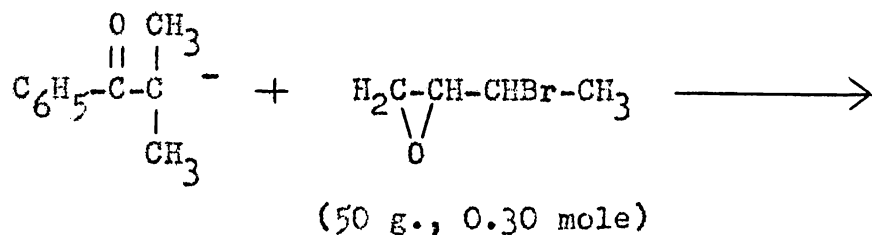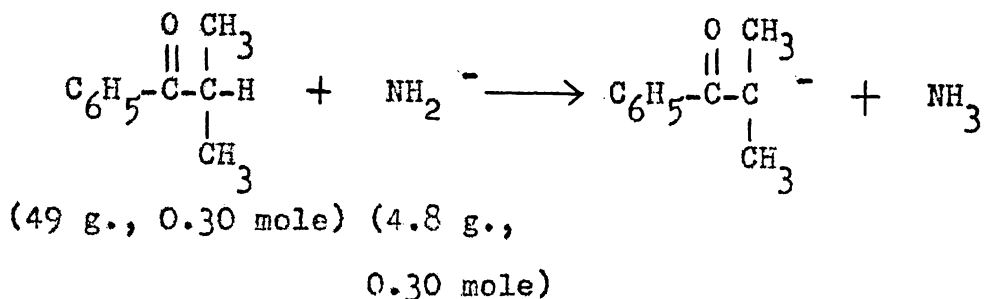
ether was removed by distillation. The residue, which consisted of 1-propoxy-2-butanone, was dissolved in 20 ml. of alcohol and to this solution was added 15 ml. of 2,4-dinitrophenylhydrazine solution prepared according to the directions of Shriner and Fuson[29]. The yellow crystals which formed were filtered and recrystallized from 20 ml. of 95% alcohol.

This oxidation was conducted on three separate samples of 1-propoxy-2-butanol: an authentic sample, prepared by the reaction of sodium propoxide with 1,2-epoxybutane, and two samples prepared by the catalytic reduction of 1-alloxy-2,3-epoxybutane, derived respectively from the reaction of sodium alloxide with 3-bromo-1,2-epoxybutane and with 1-bromo-2,3-epoxybutane. Melting points of the 2,4-dinitrophenylhydrazones of the resulting oxidation products were in all three cases 93-94°. Mixed melting points showed no depression.

Analysis: Calculated for $C_{13}H_{18}N_4O_5$: C, 50.32; H, 5.83; N, 18.05.

Found (for two of the samples): C, 51.00; H, 6.16; N, 18.2. C, 49.70; H, 5.86; N, 17.7.

Reaction of 3-Bromo-1,2-epoxybutane with the Carbanion

of Isobutyrophenone

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-H \;+\; NH_2^- \longrightarrow C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^- \;+\; NH_3$$

(49 g., 0.30 mole) (4.8 g.,

0.30 mole)

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^- \;+\; H_2C\overset{}{\underset{\diagdown\!\!O\!\!\diagup}{-CH-}}CHBr-CH_3 \longrightarrow$$

(50 g., 0.30 mole)

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-CH\overset{}{\underset{\diagdown\!\!O\!\!\diagup}{-}}CH-CH_3 \;+\; Br^-$$

(22 g., 0.10 mole)

34% of theory

To a mixture of 13 g. (0.30 mole) of sodamide and
250 ml. of benzene contained in a 1-liter, 3-necked flask,
equipped with a motor-driven stirrer, a reflux condenser
fitted with a drying tube containing calcium chloride, and
a dropping funnel, 49 g. (0.30 mole) of isobutyrophenone
was added rapidly with vigorous stirring. The mixture was
refluxed on a steam bath until the evolution of ammonia
ceased. This required about 12 to 16 hours. After this
time, 50 g. (0.30 mole) of 3-bromo-1,2-epoxybutane was
added rapidly. Refluxing and stirring were continued for

4 hours, during which time the mixture assumed a muddy appearance due to tar formation and the precipitation of sodium bromide.
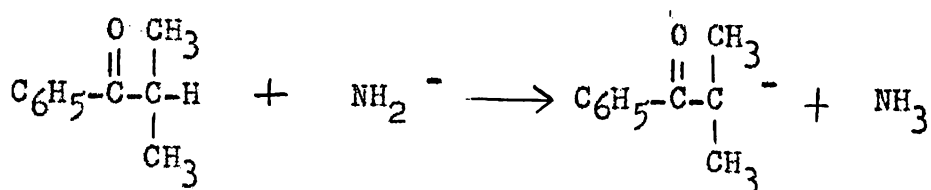
The mixture was allowed to cool and and was then washed with 3-100 ml. portions of water. The benzene layer was retained, the benzene removed by distillation, and the residue distilled under reduced pressure. Two principle fractions were obtained: 21 g. of unreacted isobutyrophenone, b.p. 86-91° at 5 mm. pressure, and 22 g. (34% of theory) of 5-methyl-5-benzoyl-2,3-epoxyhexane, b.p. 126-132° at 5 mm. pressure. On redistillation, the latter fraction yielded 17.5 g. (24% of theory) of 5-methyl-5-benzoyl-2,3-epoxyhexane, b.p. 87,5-89.5° at 0.20 to 0.25 mm. pressure. In addition, 10 to 15 g. of tarry residue remained in the distilling flask.

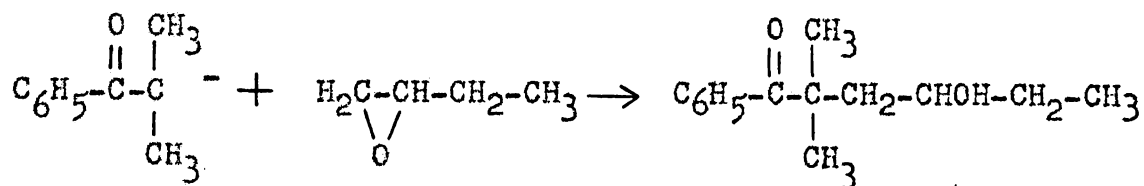Analysis: Calculated for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31.

Found: C, 76.95; H, 8.53.

Proof of the structure of this product was obtained, (1) by its acid or base catalyzed dimerization, a phenomenon observed in 4-methyl-4-benzoyl-1,2-epoxypentane, its next lower homolog, by Haller and Ramart-Lucas[21], (2) by the formation of this same dimer in the epoxidation by peracetic acid of 5-methyl-5-benzoyl-2-hexene, its olefin analog, and (3) by its independent synthesis by Russell[22] from its corresponding chlorohydrin using sodium metal in toluene.
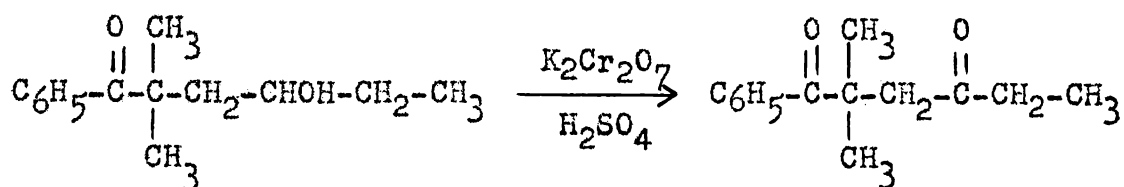
Preparation of 5-Methyl-5-benzoyl-3-hexanone

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-H \quad + \quad NH_2^- \quad \longrightarrow \quad C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^- \quad + \quad NH_3$$

(51.7 g., 0.35 mole) (5.6 g.,

0.35 mole)

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^- \quad + \quad H_2C-\overset{}{\underset{\diagdown O \diagup}{C}}H-CH_2-CH_3 \longrightarrow \quad C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-CHOH-CH_2-CH_3$$

(25 g., 0.35 mole) (8 g., 0.035 mole)

10 % of theory

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-CHOH-CH_2-CH_3 \quad \xrightarrow[\text{H}_2\text{SO}_4]{\text{K}_2\text{Cr}_2\text{O}_7} \quad C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-\overset{\overset{O}{\|}}{C}-CH_2-CH_3$$

(5g., 0.023 mole) (3g., 0.014 mole)

61% of theory

To 13.7 g. (0.35 mole) of sodamide in 200 ml. of
benzene in a 1-liter, 3-necked flask, equipped with a
motor-driven stirrer, dropping funnel, and reflux con-
denser, 51.7 g. (0.35 mole) of isobutyrophenone was added.
The mixture was refluxed 24 hours, after which time the
evolution of ammonia had ceased. To this slurry, 25 g.
(0.35 mole) of 1,2-epoxybutane was then added dropwise
with vigorous stirring. Refluxing was then continued for
12 hours, after which time the mixture was allowed to cool.
It was then shaken with 200 ml. of water. The benzene

layer was retained. The benzene was removed by distillation, and the residue was distilled under reduced pressure to give 41 g. of unreacted isobutyrophenone, b.p. 53-57° at 0.2 mm. pressure. The temperature rose after collection of the isobutyrophenone and the distillate began to solidify in the condenser. The distillation was discontinued, and the solid residue was purified by sublimation at 2.5 mm. pressure and at a temperature of 90°. Further purification of this material was accomplished by recrystallization from water. Over 8 g. (ca. 10% of theory) of 5-methyl-5-benzoyl-3-hexanol, m.p. 122-123° was obtained.

To 5 g. (0.023 mole) of this 5-methyl-5-benzoyl-3-hexanol in 90 ml. of benzene in a 500 ml., 3-necked flask, equipped with a motor-driven stirrer, dropping funnel, and reflux condenser, a solution of 9 g. (0.32 mole) of potassium dichromate and 16 ml. of concentrated sulfuric acid in 54 ml. of water was added with vigorous stirring, at such a rate as to prevent excessive heating. The mixture was stirred an additional 18 hours. The benzene layer was retained and washed successively with 100 ml. of water, 100 ml. of 10% sodium hydroxide solution, and again with 100 ml. of water.

The benzene was removed by distillation and the residue was distilled under reduced pressure to give 3 g. of 5-methyl-5-benzoyl-3-hexanone, b.p. 107-109° at 0.3 mm. pressure.

Analysis: Calculated for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31.

Found: C, 75.91; H, 8.36.

The di-(2,4-dinitrophenylhydrazone) of this material
was prepared according to the directions of Shriner and
Fuson[29]. After recrystallization from dioxane, this bright
orange derivative gave a melting point of 236.2-237.0°.

Analysis: Calculated for $C_{26}H_{26}O_8N_8$: C, 53.79;

H, 4.49; N, 19.38.

Found: C, 54.23; H, 4.68; N, 19.3;

Reaction of 5-Methyl-5-benzoyl-2,3-epoxyhexane with Sodium

Methoxide

(10 g., 0.046 mole)   (2.8 g., 0.09 mole)

(3 g., 0.007 mole)

30% of theory
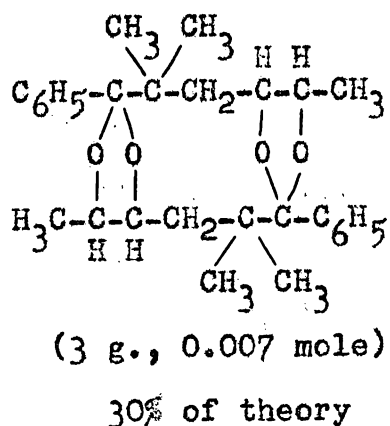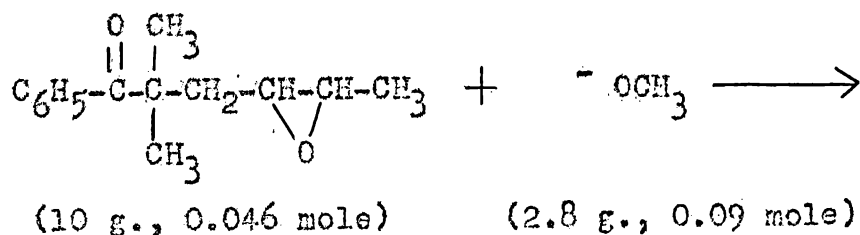
Exactly 2.00 g. (0.090 atom) of sodium was dissolved
in 100 ml. of anhydrous methanol, contained in a 500 ml.
flask equipped with a reflux condenser which was fitted
with a drying tube of calcium chloride. To this solution,

there was added all at once, 10 g. (0.046 mole) of 5-methyl-
5-benzoyl-2,3-epoxyhexane. The mixture was refluxed for
forty-eight hours. After this time, the methanol was re-
moved by distillation. The residue was washed with 100 ml.
of 5% sulfuric acid, and the oil which separated was taken
up in 200 ml. of ether. The ether was removed by distil-
lation, and the residue was distilled under reduced pressure.
In addition to 5 g. of material, b.p. 123-128° at 5 mm.
pressure, consisting essentially of unchanged epoxide,
there was obtained 3 g. of a solid, m.p. 204-212° after
recrystallization from ethyl acetate.

Analysis* (liquid): Calculated for $C_{14}H_{18}O_2$: C, 77.03;
H, 8.31.

Found: C, 76.09; H, 8.34.

(solid): Calculated for $C_{15}H_{22}O_3$ (methan-
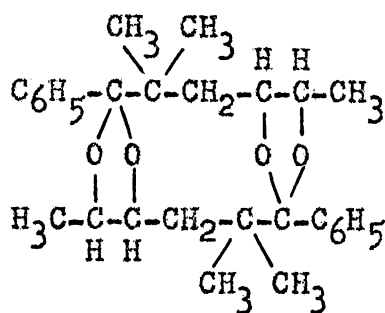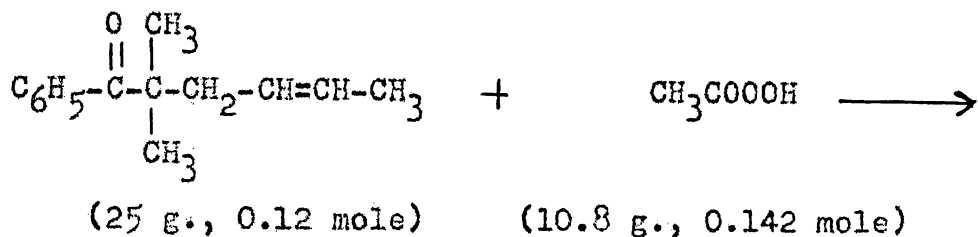olysis): C, 72.00; H, 8.80.

for $C_{14}H_{18}O_2$ (starting material):
C, 77.03; H, 8.31.

Found: C, 76.97; H, 8.40.

Values of 438 and 442 were obtained for the molecular
weight of the solid product*. This is representative of a
dimer of the starting material, 5-methyl-5-benzoyl-2,3-
epoxyhexane. The assignment of the dimeric structure shown
at the heading of this description is based on the fact
that epoxides with ketones have been observed to form
dioxolane derivatives[40,41].

*Clark Microanalytical Laboratory, Urbana, Illinois.

Reaction of 5-Methyl-5-benzoyl-2-hexene with Peracetic

Acid

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-CH=CH-CH_3 \quad + \quad CH_3COOOH \longrightarrow$$

(25 g., 0.12 mole)   (10.8 g., 0.142 mole)

$$C_6H_5-\overset{\overset{CH_3}{\diagdown}\overset{CH_3}{\diagup}}{C}-\overset{}{C}-CH_2-\overset{\overset{H}{|}}{C}-\overset{\overset{H}{|}}{C}-CH_3$$

(5g., 0.012 mole)

9.6% of theory

Exactly 25 ml. of a 40% solution of peracetic acid in gla-
cial acetic acid, analyzing 0.43 g. of peracetic acid per
ml. of solution, and containing 1.6 g. of fused sodium
acetate, was added over the period of 1 hour to 25 g.
(0.12 mole) of 5-methyl-5-benzoyl-2-hexene, prepared accord-
ing to the method of Russell[22], in 50 ml. of glacial acetic
acid contained in a 500-ml., 2-necked flask, fitted with a
reflux condenser protected from external moisture and a
50-ml. dropping funnel. The mixture was maintained at a
temperature of 15° for 7 hours, after which time analysis
indicated no further consumption of peracetic acid. The
decrease in peracetic acid amounted to 0.05 mole. The
reaction was then terminated by pouring of the mixture into

500 ml. of a saturated salt solution. The oil which sep-
arated was taken up in 100 ml. of ether. The ether was
evaporated and the residue was distilled under reduced
pressure to give 10.3 g. of material, b.p. 109-111° at
3 mm. pressure consisting essentially of unreacted olefin,
along with 9.8 g. of a solid residue, which after recrystal-
ization from 95% ethanol, gave 5 g. of material melting at
206.6-218.2°.

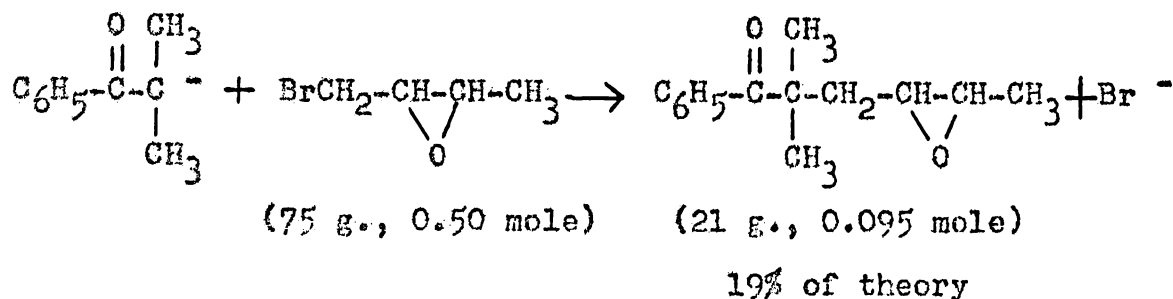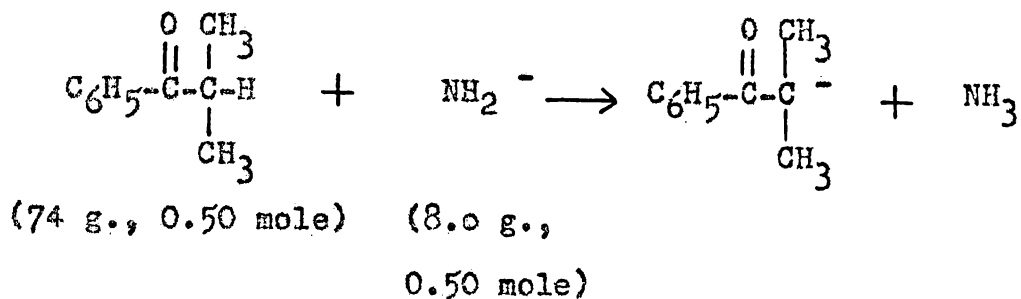Analysis (liquid): Calculated for $C_{14}H_{18}O$: C, 83.14;
H, 8.95.

Found: C, 81.89; H, 8.93.

(solid): Calculated for $C_{14}H_{18}O_2$: C, 77.03;
H, 8.31.

Found: C, 76.73; H, 8.31.

Although analysis of the solid was satisfactory for the
expected product, 5-methyl-5-benzoyl-2,3-epoxyhexane, it was
shown by a mixed melting point and a comparison of the
infrared absorption spectra to be identical to the dimer
formed by the action of sodium methoxide on 5-methyl-5-
benzoyl-2,3-epoxyhexane.

Reaction of 1-Bromo-2,3-epoxybutane with the Carbanion

of Isobutyrophenone

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-H \;+\; NH_2^- \longrightarrow C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^- \;+\; NH_3$$

(74 g., 0.50 mole) (8.0 g.,

0.50 mole)

$$C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}{}^- \;+\; BrCH_2-CH-CH-CH_3 \longrightarrow C_6H_5-\overset{\overset{O}{\|}}{C}-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-CH-CH-CH_3 + Br^-$$

(75 g., 0.50 mole) (21 g., 0.095 mole)

19% of theory

This reaction was carried out in the same manner as
that described for the reaction of 3-bromo-1,2-epoxybutane
with the carbanion of isobutyrophenone. Exactly 74 g.
(0.50 mole) of isobutyrophenone, 20 g. (0.50 mole) of
sodamide, and 75 g. (0.50 mole) of 1-bromo-2,3-epoxybutane
were used. The reaction was conducted in 250 ml. of an-
hydrous benzene. Two principle fractions were obtained;
39 g. of unreacted isobutyrophenone, b.p. 68-72° at 0.75 mm.
pressure, and 21 g. (19% of theory) of 5-methyl-5-benzoyl-
2,3-epoxyhexane, b.p. 93.5° at 0.75 mm. pressure.

Analysis: Calculated for $C_{14}H_{18}O_2$; C, 77.03;

H, 8.31.

Found: C, 76.72; H, 8.33.

This product is identical to the product of the re-
action of 3-bromo-1,2-epoxybutane with the carbanion of

isobutyrophenone, as shown by the fact that both form the same dimeric derivative under the influence of hydrogen chloride in ether and that, as shown by Russell[22], both on oxidation by alkaline permanganate yield 3-methyl-3-benzoyl-butanoic acid.

Bibliography

(1) C. Frederick Koelsch and S. M. McElvain, J. Am. Chem. Soc., 51, 3390 (1929).

(2) C. Frederick Koelsch and S. M. McElvain, ibid., 52, 1164 (1930).

(3) E. Tapia and Maria A. Hernandez, Anales soc. espan. fis. quim., 28, 691 (1930).

(4) Henri Normant, Compt. rend., 219, 163 (1944).

(5) J. K. Margrane and D. L. Cottle, J. Am. Chem. Soc., 64, 434 (1942).

(6) Costin P. Nenitzescu and Nicolae Scarlatescu, Ber., 68B, 587 (1935).

(7) Bertil Sjoberg, Svensk. Kem. Tid., 50, 250 (1938).

(8) L. J. Haynes, Sir Ian Heilbron, E. R. H. Jones, and F. Sondheimer, J. Chem. Soc., 1583 (1947).

(9) C. C. J. Culvenor, W. Davies, and W. E. Savige, ibid., 2198 (1949).

(10) C. C. J. Culvenor, W. Davies and F. G. Haley, ibid., 3123 (1950).

(11) N. S. Drozdov and O. M. Cherntzov, J. Gen. Chem. (U. S. S. R.), 4, 969 (1934).

(12) Henry Gilman, C. S. Sherman, Charles C. Price, Robert C. Elderfield, John T. Maynard, Robert H. Reitsema, L. Tolman, S. P. Massie Jr., F. J. Marshall and Leon Goldman, J. Am. Chem. Soc., 68, 1291 (1946).

(13) G. Bryant Bachman and Raymond L. Mayhew, J. Org. Chem., 10, 243 (1945).

(14) W. Davies and W. E. Savige, J. Chem. Soc., 890 (1950).

(15) Heinz Ohle and Georg Haessler, Ber., 69B, 2324 (1936).

(16) Paul Cohn and Robert Plohn, ibid., 40, 2597 (1907).

(17) David Runciman Boyd and Ernest Robert Marle, J. Chem. Soc., 93, 838 (1908).

(18) David Runciman Boyd and Ernest Robert Marle, ibid. 95, 1807 (1909).

(19) William Bradley, James Forrest and Oliver Stephenson, ibid., 1589 (1951).

(20) Russell C. Waters and Calvin A. VanderWerf, J. Am. Chem. Soc., 76, 709 (1954).

(21) A. Haller and Mme. Ramart-Lucas, Compt. rend., 158, 1304 (1914).

(22) Robert R. Russell, Ph. D. Thesis, University of Kansas, (1949).

(23) A. A. Petrov, J. Gen. Chem. (U.S.S.R.), 11, 713 (1941).

(24) Henry Gilman, Organic Chemistry, Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1953, p. 140-141.

(25) J. H. Boyer and F. C. Canter, Chem. Rev., 54, No. 1, p. 21-22 (1954).

(26) Ralph L. Shriner and Reynold C. Fuson, The Systematic Identification of Organic Compounds, third ed., John Wiley and Sons, Inc., New York, N. Y. (1948), p. 138.

(27) Daniel Swern, Thomas W. Findley, Geraldine N. Billen, and John T. Scanlan, Anal. Chem., 19, 414 (1947).

(28) J. E. Field, J. O. Cole and D. E. Woodford, J. Chem. Physics, 18, 1298 (1950).

(29) Ralph L. Shriner and Reynold C. Fuson, The Systematic Identification of Organic Compounds, third ed., John Wiley and Sons, Inc., New York, N. Y. (1948), p. 171.

(30) R. Delaby, Compt. rend., 176, 589 (1923).

(31) H. Pariselle, ibid., 149, 295 (1909).

(32) A. E. Favorskii and P. A. Tikhomolov, ibid., 203, 726 (1936).

(33) Salvatore Capuano, Gazz. chim. Ital., 68, 521 (1938).

(34) E. E. Blaise, Compt. rend., 170, 1324 (1920).

(35) G. Korshun and Mrs. K. Roll, Bull. Soc. Chim., 39, 1223 (1926).

(36) E. E. Blaise, Compt. rend., 171, 34 (1920).

(37) E. E. Blaise, ibid., 172, 221 (1921).

(38) Hendrick Jorlander, Ber., 49, 2782 (1916).

(39) Sven Bodforss, ibid., 49, 2795 (1916).

(40) A. A. Petrov, J. Gen. Chem. (U.S.S.R.), 10, 981 (1940).

(41) A. A. Petrov, ibid., 16, 61 (1946).

(42) R. Bowling Barnes, Robert C. Gore, Urner Liddel, and Van Zandt Williams, Infrared Spectroscopy, Reinhold Publishing Corporation, New York, N. Y. (1944) p. 65-70.

(43) Henry Gilman, Organic Chemistry, Vol. IV, John Wiley and Sons, Inc., New York, N. Y. (1953), p. 732-733.

(44) Henry Gilman, ibid., p. 818.

(45) Walter T. Olson, Francis M. Whiteacre, J. Am. Chem. Soc., 65, 1019 (1943).

(46) K. A. Krasuskii and G. T. Pilyugin, Ukrainskii Khem. Zhur., 5, Sci. Pt., 135 (1930).

(47) K. A. Krasuskii, and G. T. Pilyugin, _ibid._, 5, Sci. Pt., 237 (1930).

(48) H. C. Chitwood and B. T. Freure, _J. Am. Chem. Soc._, 68, 680 (1946).

(49) A. A. Petrov, _J. Gen. Chem._ (U.S.S.R.), 14, 1038 (1944).

(50) A. R. Sexton and E. C. Britton, _J. Am. Chem. Soc._, 70, 3606 (1948).

(51) G. P. Sweeney, L. F. Wiggins and D. J. C. Wood, _J. Chem. Soc._, 37 (1952).

(52) D. Swern, G. N. Billen, and H. B. Knight, _J. Am. Chem. Soc._, 71, 1152 (1949).