

EXTENSIONS OF THE PRINS REACTION

EXTENSIONS OF THE PRINS REACTION

By

OTTO STURZENEGGER

MASTER OF SCIENCE

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1950

**Submitted to the Faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1953.**

OKLAHOMA
AGRICULTURAL & MECHANICAL COLLEGE
LIBRARY
FEB 12 1953

EXTENSIONS OF THE PRINS REACTION

OTTO STURZENEGGER
DOCTOR OF PHILOSOPHY
1953

THESIS AND ABSTRACT APPROVED:



Thesis Adviser



Faculty Representative



Dean of the Graduate School

ACKNOWLEDGEMENT

This work was made possible by the financial aid given by the Chemistry Department of Oklahoma A. and M. College in the form of a graduate assistantship.

The author wishes to express his sincere appreciation to Dr. H. P. Johnston and Dr. O. C. Dermer for suggesting and directing this work.

STRATHMORE P.
100 V. 66 U.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
HISTORICAL	3
Classification.	3
Prins-Type Reactions in Aqueous Medium.	4
Prins-Type reactions under Anhydrous Conditions	5
Acetals and olefins.	5
Acetals and α,β -unsaturated ethers	6
Acetals and acetylenes	7
Acetals and ketene	7
Acetals and unsaturated carboxylic acids	7
Acetals and vinyl esters	9
Acetals and nitriles	9
α -Chloro ethers and olefins.	10
α -Chloroalkyl esters and olefins	11
Orthoesters and olefins.	11
Dialkyl carbonates and olefins	13
Alkyl nitrites and olefins	14
Brief Review of Proposed Mechanism.	14
General Aspects and Limitations of Prins-Type Reactions on the Basis of Proposed Mechanisms	17
(1) Formation of a carbonium ion effected by the action of the catalyst on the aldehydic reagent.	18
(2) Polarization of the carbon-carbon double bond by the approaching carbonium ion	19
(3) Addition of the carbonium ion to the olefinic carbon atom of higher electron density	20
(4) Addition of a negative ion to the newly formed carbonium ion	25
Proposed Mechanism for the Formaldehyde Addition to Nitriles	26

	Page
EXPERIMENTAL	28
Methylal and Methyl Oleate.	28
Methylal and Methyl Crotonate	41
Methylal and Methyl Acrylate.	42
Methylal and Vinyl Acetate.	42
Methylal and Valeronitrile.	43
Isobutylene and Methyl Benzyl Ether	44
Isobutylene and <u>n</u> -Butyl Nitrite	44
Isobutylene and Diethyl Carbonate	45
Isobutylene and Ethyl Orthoformate.	46
Isobutylene and Benzaldehyde Diethyl Acetal	47
DISCUSSION	51
SUMMARY.	56
BIBLIOGRAPHY	58

INTRODUCTION

Two types of reaction were pointed out and developed by Prins: the acid-catalyzed addition of an aldehyde to an olefinic double bond, and the similarly catalyzed addition of a polyhalogenated methane to a polyhalogenated olefin. In this thesis the term "Prins reaction" will designate the former type reaction.

With their investigations at the Department of Chemistry at the Oklahoma A. and M. College, Kohn (44) and notably Hawkins (29) have extended the Prins reaction to the addition of acetals to olefins under anhydrous conditions with the formation of 1,3-diethers as primary products. In support of earlier beliefs (34), Hawkins (29) concluded that the acetal is cleaved into an alkoxy group and an alkoxyalkyl group prior to addition. Although two isomers are generally formed in the case of a monoolefin, attachment of the alkoxy group to the olefinic carbon atom of lower electron density was shown to be favored.

The purpose of this study was to contribute to the understanding of the Prins type of addition reaction by investigating various new, but similar addition reactions. Because of limitations both in time and available working equipment it was not possible to exhaustively study any one particular reaction.

The reactions under investigation were of the following two types: (a) acid-catalyzed addition of methylal to unsaturated compounds other than simple olefins or diolefins, and (b) acid-catalyzed addition to isobutylene of compounds other than acetals, but having one or more alkoxy groups in their structures. By undergoing a cleavage involving the formation of an alkoxy group prior to addition, these compounds conceivably might react in the same way that acetals do.

The product of the addition of methylal to methyl oleate may find industrial application as a new surface-active agent. Therefore, considerable time was spent on the isolation and purification of the major reaction product.

HISTORICAL

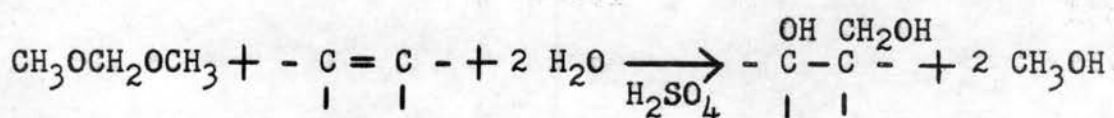
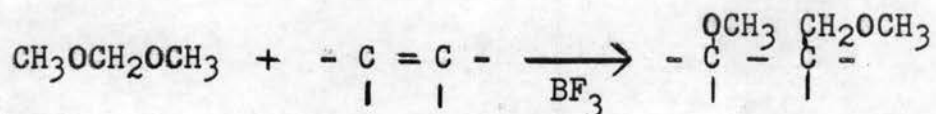
Classification.

In its broader sense the Prins type of condensation may be defined as the acid-catalyzed addition reaction of aldehydes and certain aldehyde derivatives to an olefinic double bond. Concentrated sulfuric acid is the most widely used catalyst, but various Lewis acids, such as stannic chloride, zinc chloride, bismuth trichloride, ferric chloride, and related compounds have a catalytic effect. Boron trifluoride is known to be the most effective catalyst in many cases.

Depending on reagents and solvents used, the products may be glycols, formals, diethers, esters, unsaturated primary alcohols, and chlorinated oxygen compounds. In his dissertation, Hawkins (29) made a thorough search of the literature on these reactions, and it is not the purpose of this paper to repeat the detailed history of all the different addition reactions which may be classified as Prins reactions.

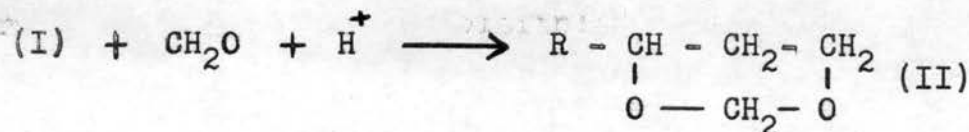
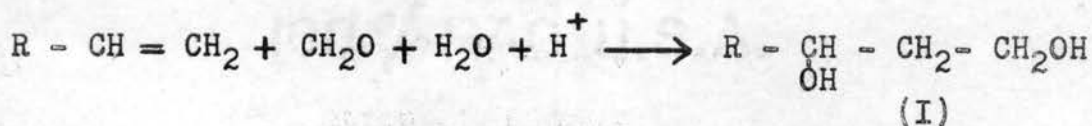
There is no fundamental difference in the way the various reagents add to the olefinic double bond. However, for the purpose of classification, the Prins type of addition reactions may be divided into two classes: (a) reactions performed in an aqueous medium, and (b) reactions performed under anhydrous conditions. A reagent which is hydrolyzable in aqueous acid

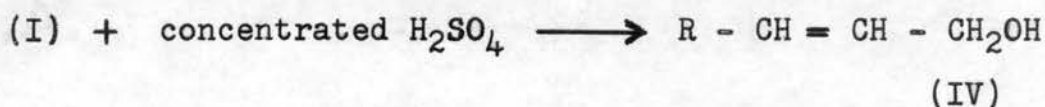
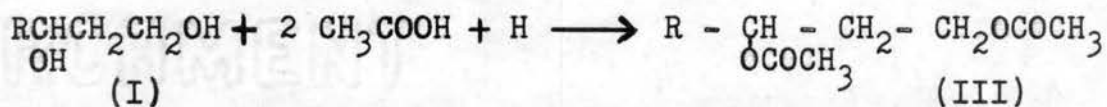
will give different products in aqueous and in nonaqueous media upon reaction with an olefin. Thus the product of the reaction between methylal and a monoolefin under anhydrous conditions is a 1,3-diether, whereas a 1,3-glycol is formed in aqueous medium, the methylal acting simply as a source of formaldehyde:



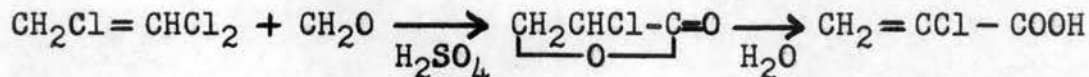
Prins-Type Reactions in Aqueous Medium.

For the history of the Prins-type reaction in aqueous medium the reader is referred to the extensive review in Hawkins' dissertation (29). The following scheme will serve to illustrate the formation of 1,3-glycols (I), formals (II), esters (III), and unsaturated primary alcohols (IV) from formaldehyde and a simple olefin:





The production of 1,3-glycols by the addition of formaldehyde to olefins, and the production of acrylic or α -chloroacrylic acid by the addition of formaldehyde to di- or trichloroethylene, have found industrial application.

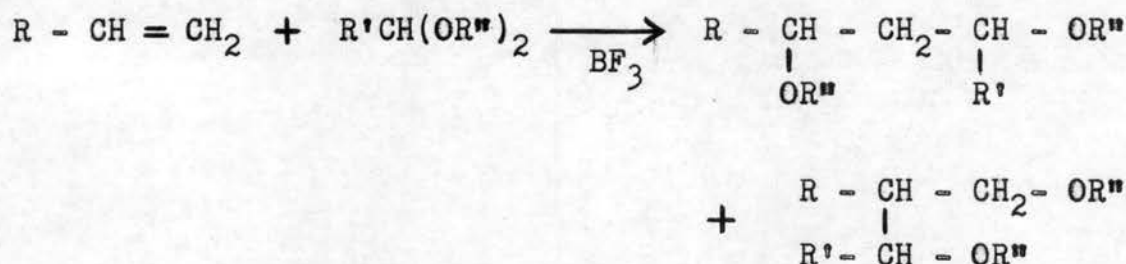


In contrast to extensive investigations on these reactions, little work has been done on the addition of formaldehyde or other aldehydes to carbon-carbon double bonds of molecules containing other functional groups (5, 6, 7, 53, 56), with the exception of ketene. No reference was found on the addition of aldehydes to compounds having another functional group next to the olefinic double bond, such as α, β -unsaturated acids or esters.

Prins-Type Reactions under Anhydrous Conditions.

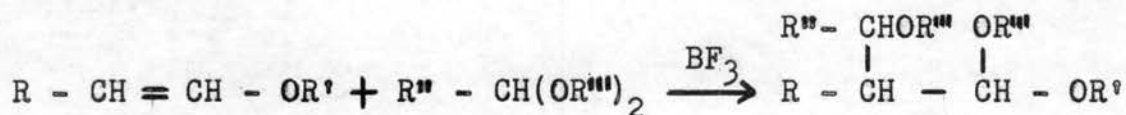
Acetals and olefins.--The acid-catalyzed addition of acetals to olefins was independently investigated by Paul and Tchelitcheff (55) and by Hawkins (29). Owing to differences in reaction conditions, they did not isolate the same final products for the reaction of diethyl acetal with isobutylene.

However, the reaction is of a general nature with regard to the formation of the primary products. It may be represented in the following way:



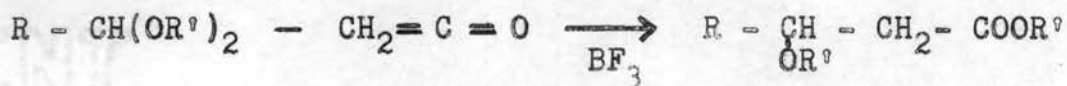
The ratio of the two isomers formed depends on the structure of the olefin. Which one of the two is favored will be discussed during the review of the mechanism of the reaction. For a detailed description of the products formed by the addition of methylal to butadiene, propylene, isobutylene, styrene, cyclohexene, and α -pinene the reader is referred to Hawkins' thesis (29). Although no reference is made in the literature to the addition of ketals or aromatic acetals to olefins, it is reasonable to assume that they do react correspondingly.

Acetals and α, β -unsaturated ethers.—Mueller-Cunradi and Pieroh (49), Hoaglin and Hirsh (34), and Paul and Tchelitcheff (54) investigated the acid-catalyzed addition of acetals to α, β -unsaturated ethers. The addition of acetals to aliphatic as well as cyclic α, β -unsaturated ethers is general and proceeds like the addition of acetals to monoölefins:



Acetals and acetylenes.--Hawkins (29) attempted the addition of methylal to acetylene with mercuric oxide and boron trifluoride as co-catalysts. Except for the formation of trace amounts of tarry materials no appreciable reaction was accomplished. The same combination of catalysts is used in the synthesis of acetals by alcoholation of acetylene (33, 51, 52). The absorption of acetylene stops quantitatively when all the alcohol is converted to the acetals (51, 76), thus indicating that under the conditions of the synthesis the acetal, which is formed in good yield, does not further react with acetylene. However, addition of acetals to acetylene might be accomplished with different catalysts, or under pressure and at higher temperatures.

Acetals and ketene.--Analogous to the formation of β -lactones from aldehydes and ketene, the addition of acetals and ketals to ketene results in the formation of β -alkoxy esters (16, 17):



Acetals and unsaturated carboxylic acids.--The process of treating unsaturated fatty acids of high molecular weight with formaldehyde, acetone, or other aldehydes or ketones in the presence of an acid condensing agent was patented in 1908 (22, 23, 66). The products obtained were used in alizarin printing, and no attempt was made to suggest possible structures for the

condensation products. They are described as being almost insoluble in water, soluble in dilute alkalis, precipitated from solution by acids, and decomposing when distilled. From these properties and from the knowledge of the Prins type of reaction, it is apparent that the carbonyl compounds reacted with the olefinic double bonds of the unsaturated fatty acids.

In 1950 Pigulevskii and Tatarskaya (56) isolated a small amount of a solid, believed to be oleic acid with $-\text{CH}_2\text{OCHOH}-$ added to the double bond, from the reaction of formaldehyde with oleic acid in the presence of concentrated sulfuric acid.

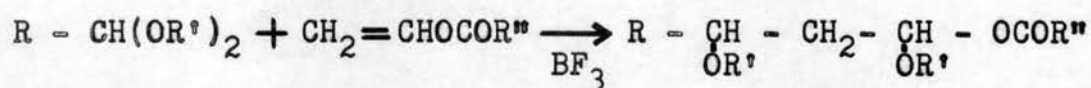
It appears that no work has been done on the addition of acetals to unsaturated acids, such as oleic, linoleic, linolenic, crotonic, or acrylic acid.

Carboxylic acids are known to react at olefinic double bonds to form esters in the presence of boron trifluoride as catalyst (15). However, this undesired side reaction, which might interfere with the addition of acetals to unsaturated fatty acids, can be eliminated by using a fatty acid ester instead of the free acid. Another side reaction, which may always occur in the presence of boron trifluoride, is the polymerization of the olefinic reagent. Unsaturated fatty acids undergo polymerization with boron trifluoride as catalyst (15, 19).

An attempt at reacting acetals with esters of long-chain unsaturated fatty acids is interesting not only from the point of view of investigating the possibilities and limitations of

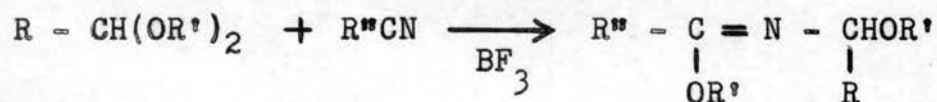
the Prins type of addition reaction, but also from the point of view of industrial application of possible products as new surface-active agents.

Acetals and vinyl esters.--There seems to be no account in the literature on the addition of acetals to vinyl esters. However, acetals readily add to vinyl ethers (34, 49, 54), which are structurally closely related to vinyl esters, thus suggesting the possibility of the reaction:



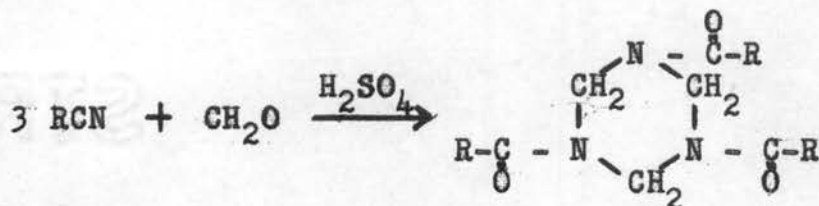
The production of acrolein in 61% yield is claimed in a patent (77), the process involving the reaction of formaldehyde with vinyl acetate in a fatty acid solvent containing a strong mineral acid and a little cupric oxide. Although the reaction mechanism is unknown, classification of this reaction as a Prins type of condensation seems doubtful.

Acetals and nitriles.--A literature search revealed that apparently no work has been done on the addition of acetals to the carbon-nitrogen bond of nitriles. This reaction might succeed in the Prins manner to yield N-substituted iminoethers,

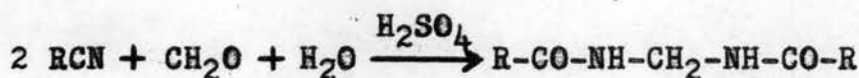


especially since formaldehyde is known to condense with nitriles in an analogous way. The reaction of formaldehyde and

nitriles in the presence of catalytic quantities of concentrated sulfuric acid gives substituted hexahydro-s-triazines (25, 27, 83) according to the equation:

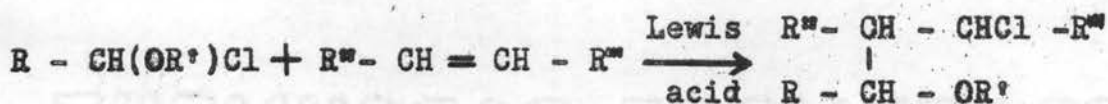


In the presence of five times as much by weight of 85% sulfuric acid as reactants, the corresponding methylene-bis-amides are formed (11, 30, 31, 45, 46, 65, 75):



As will be seen during the discussion of the mechanism of this reaction, formaldehyde reacts with nitriles in a way closely related to the Prins type of condensation.

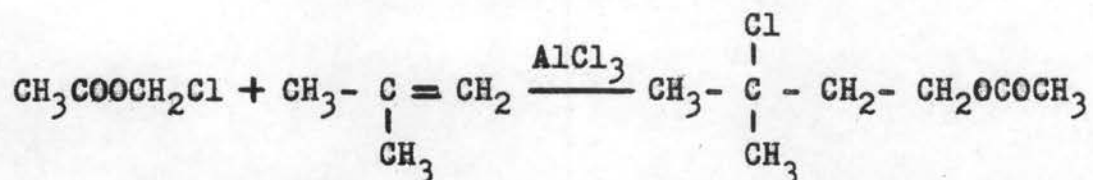
α -Chloro ethers and olefins.--Hawkins (29) carefully reviewed the addition reaction of α -chloroethers to olefins. The reaction is very general and may be represented by the following equation:



The olefin may be an aliphatic or cyclic mono- or diolefin. Dykstra (21) caused addition of chloromethyl methyl ether to vinylacetylene with the formation of 5-methoxy-3-chloro-1,3-pentadiene as final product. Although the structure of this

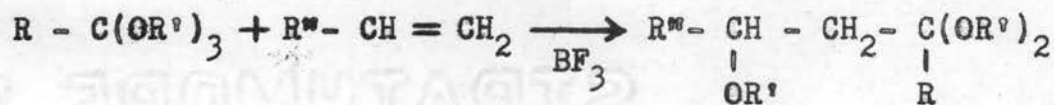
product suggests addition at the triple bond, Dykstra presented strong evidence that 1,4-addition occurs yielding 5-methoxy-1-chloro-2,3-pentadiene as the primary product which isomerizes subsequently.

α -Chloroalkyl esters and olefins.-- α -Chloroalkyl esters may be regarded as derivatives of aldehydes and as such should add to olefins in the same way that acetals and α -chloro ethers do. The following synthesis was effected (50):

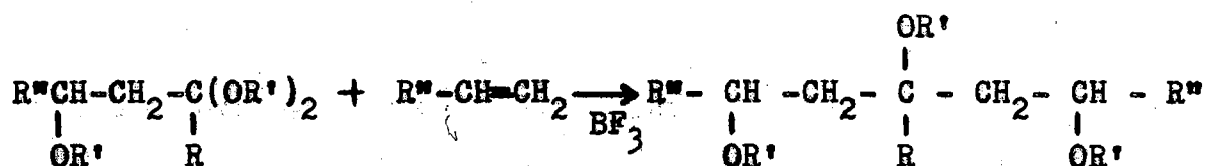


Similarly 1-acetoxymethyl-2-chlorocyclohexane is formed from cyclohexene and chloromethyl acetate. No catalyst appears to be required for either reaction.

Orthoesters and olefins.--The addition of orthoesters to simple olefins appears to be unknown. However, the structural similarity between orthoesters and acetals suggests the possibility of this reaction:

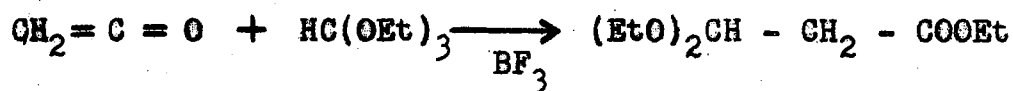


In the presence of an excess of olefin the acetal formed might further react according to the following equation:



Whereas acetals are quite stable in the presence of anhydrous acids, orthoesters are known to react with hydrogen halides, nitric acid, nitrogen sesquioxide, phosphoric anhydride, and phosphorus trichloride with formation generally of the corresponding simple ester and the ester of the inorganic acid (58). With boron trifluoride ethyl orthoformate does not simply form a complex, as would occur for acetals, but instead reacts to form ethyl ether and ethyl formate (48).

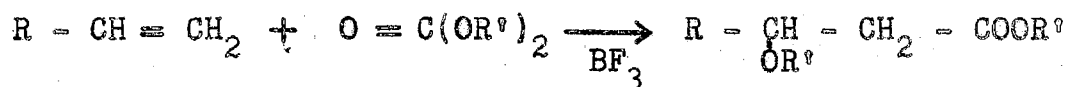
This instability of orthoesters towards acid reagents in anhydrous medium may prevent a Prins type of reaction between orthoesters and olefins. Ketene, which may be regarded as a very reactive olefin, readily undergoes condensation with orthoesters. The synthesis of β -dialkoxy monocarboxylic acid esters in the presence of catalytic amounts of boron trifluoride has been patented (26):



Another extension of the Prins type of condensation is the patented reaction of esters of orthoformic acid with vinyl esters in the presence of an acid-reacting halide catalyst, such as ferric chloride, with the formation of tetraalkoxypropanes (39).

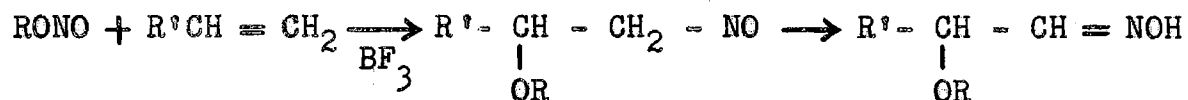
Orthosilicates and orthoborates also appear likely to undergo a Prins type of addition to olefins, although alkyl borates are known to serve as alkylating agents in Friedel-Crafts type of reactions (43), thus exhibiting a tendency to be split into alkyl groups in the presence of Lewis acid catalysts rather than into alkoxy groups. On the other hand $(\text{CH}_3\text{O})_2\text{BF}$ and CH_3OBF_2 are formed upon reaction of trimethyl borate with boron trifluoride (24); here a transfer of methoxy groups must be involved.

Dialkyl carbonates and olefins.---The acid-catalyzed addition of dialkyl carbonates to olefins appears to be unknown. The formation of β -alkoxy esters by this synthesis would represent a very interesting extension of the Prins type of addition reaction:



In organic syntheses, dialkyl carbonates are used as alkylating agents in basic solution (78, 79, 80, 81, 82). The base-catalyzed condensation of acetylene with alkyl carbonates is noteworthy, since products very similar to those expected from a Prins type of addition are obtained (20). Thus, $(\text{EtO})_2\text{CHCH}_2\text{COOEt}$, $\text{EtOCH}=\text{CHCOOEt}$, $\text{EtOCC}(\text{OEt})_2\text{CH}_2\text{COOEt}$, and $\text{EtOCC}(\text{OEt})=\text{CHCOOEt}$ were isolated from the reaction of diethyl carbonate with acetylene in the presence of sodium ethoxide.

Alkyl nitrites and olefins.--

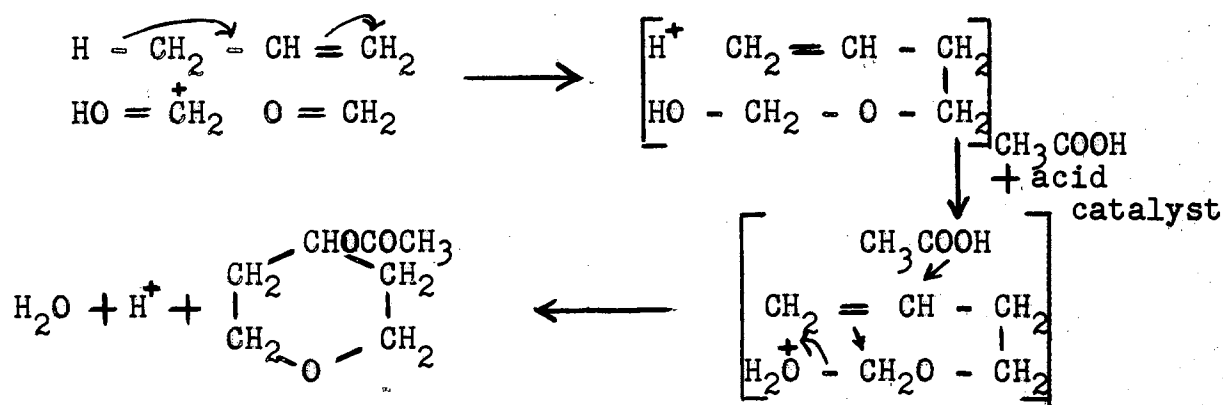


This reaction is suggested by the well-known addition of nitrosyl chloride to olefinic double bonds.

Brief Review of Proposed Mechanism.

In his dissertation, Hawkins (29) has discussed in detail the different theories proposed for the mechanism of the Prins reaction. The review to follow is not intended to include all the details which led to the different reaction mechanisms advanced by the various workers. It is rather a brief summary of existing differences in the beliefs of such workers and an attempt to arrive at some general conclusions which could be applied for the explanation of not just one, but all the known reactions classified as Prins addition reactions. It is also the intention of this review to discuss the limitations of the Prins reaction on the basis of the accepted principles of the reaction mechanism.

Prins (61) was the first to propose a mechanism for the acid-catalyzed addition of formaldehyde to olefins. He believed in the formation of a four-membered cyclic ether as the first intermediate. Because of the resulting bond strains, the formation of such a ring is now considered highly improbable, and this mechanism has been abandoned.

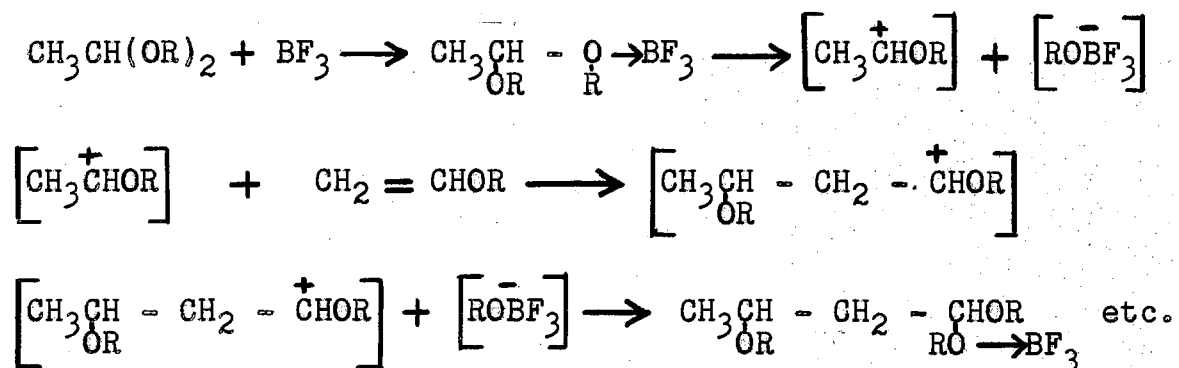


Price (60) does not agree with Baker and maintains that all known reactions follow the same mechanism involving essentially the addition of the methylol carbonium ion to the polarized olefinic double bond.

Baker's evidence and arguments in support of his alternate mechanism and Price's criticism of the postulation of the actual cleavage of an α -methylene hydrogen atom are of no great importance for the understanding of the essential nature of the Prins reaction. Both Price and Baker agree that the main step of the mechanism is the addition of a carbonium ion to the polarized double bond. It is important that polarization of the double bond does occur, but the knowledge of how it is brought about is not essential. It seems reasonable to assume that polarization is effected both by electron-releasing groups adjacent to the double bond and by hyperconjugation, depending on the structure of the olefin.

Mueller-Cunradi and Pieroh (49) suggested a mechanism for the addition of acetals to α,β -unsaturated ethers involving splitting of an α -hydrogen atom from the acetal prior to addition. This mechanism was shown by Hoaglin and Hirsh (34) to be

in error, since it did not explain the structures of all the products obtained during their extensive investigation on this reaction. The latter authors proposed the following mechanism for the boron trifluoride-catalyzed addition of acetals to α,β -unsaturated ethers:



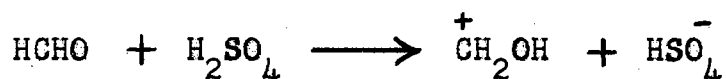
This mechanism also adequately explains the formation of all the products obtained by Hawkins (29) from the boron trifluoride-catalyzed addition of acetals to olefins.

General Aspects and Limitations of Prins-Type Reactions on the Basis of Proposed Mechanisms.

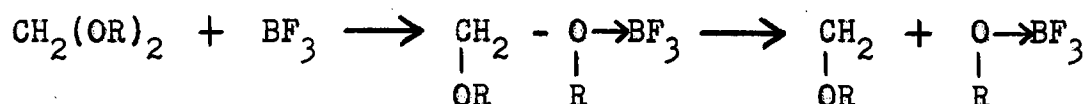
A comparison of the common features of the different mechanisms presented in this brief summary shows that the Prins reaction can be classified as an ionic addition reaction to an olefinic double bond led by the attack of a cation. The following essential steps are involved: (1) formation of a carbonium ion effected by the action of the catalyst on the aldehydic reagent, (2) polarization of the carbon-carbon double bond by the approaching carbonium ion, (3) addition of the carbonium ion to the olefinic carbon atom of higher electron

density, and (4) addition of a negative ion to the newly formed carbonium ion.

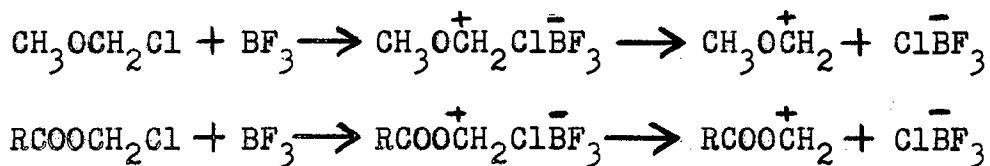
(1) Formation of a carbonium ion effected by the action of the catalyst on the aldehydic reagent.--In the case of aldehydes and sulfuric acid catalyst the carbonium ion is formed by the addition of a proton to the aldehyde:



From acetals the carbonium ion is formed by addition of the Lewis acid catalyst to the ether oxygen followed by dissociation:

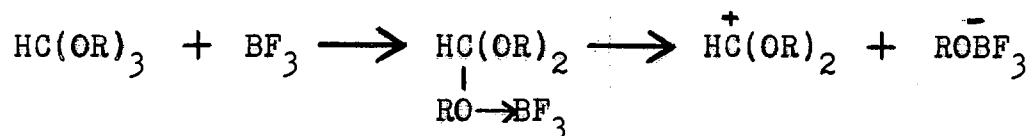


The formation of a carbonium ion from α -chloro ethers and α -chloro esters probably occurs analogously:



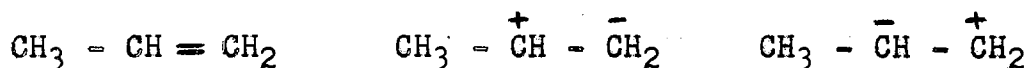
The first step in the mechanism proposed for the acid-catalyzed preparation of acetals and ketals by use of orthoesters is the formation of a carbonium ion from the orthoester (1). It seems reasonable to assume that formation of a carbonium ion from an orthoester is also possible with a Lewis

acid and that it is quite analogous to carbonium-ion formation from acetals:

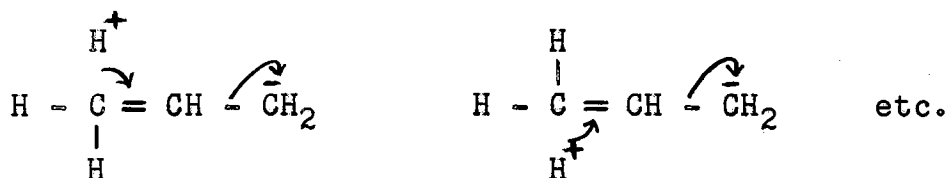


The mechanism for the acid-catalyzed synthesis of tetraalkoxypropanes from vinyl esters and orthoformates may well involve formation of such a carbonium ion.

(2) Polarization of the carbon-carbon double bond by the approaching carbonium ion.—Depending on the structure of the olefin, electronic shifts are possible in the resting state of the molecule. Such electron displacements may be effected in two ways: (a) by resonance; for example, propylene may be represented as a resonance hybrid of the following structures:



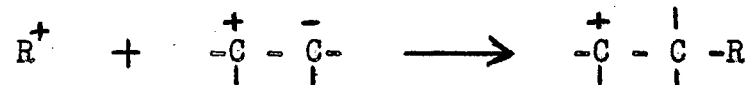
(b) by hyperconjugation; this is a particular kind of resonance involving hydrogen atoms alpha to a double bond. Its effect is electron release from the alpha-carbon atom and an accompanying polarization of the double bond:



The normal electron distribution in the resting state of the molecule will be disturbed by the approach of the carbonium

ion. An additional charge separation is superimposed upon the resonance hybrid, and the polarized structure becomes more important. Except in symmetrical olefins, two different polarized structures are possible. One of the two forms will be more important, owing to the effects of hyperconjugation and electron-releasing power of alkyl groups. Accordingly, the isomer resulting from an addition to the theoretically favored structure of the polarized olefin is expected to be formed in greater yield. This has been demonstrated for all types of Prins reactions, most recently by Hawkins (29) for the addition of acetals to olefins.

(3) Addition of the carbonium ion to the olefinic carbon atom of higher electron density.--



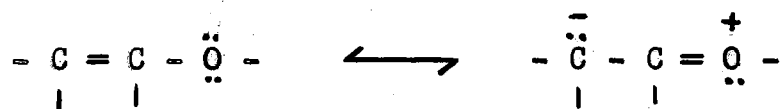
This is the rate-controlling step of olefinic addition reactions in which attack at the double bond seems to be led by a carbonium ion (2). Other such reactions are the Friedel-Crafts addition of alkyl halides to olefins, the self-condensation of olefins, and the alkylation of isoparaffins.

This step occurs through the attraction of unlike electrical charges for each other; the stronger this attraction, the greater will be the rate of the overall reaction. The strength of attraction depends both on the electron-seeking tendency of the positively charged carbonium ion and on the magnitude of

the electron density on the negatively charged olefinic carbon atom.

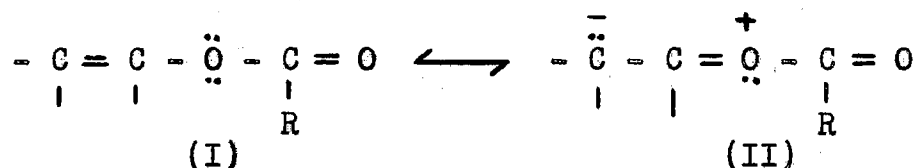
An examination of the requirements for maximum reactivity of the olefin shows that electron-releasing substituents attached to the carbon-carbon double bond increase the nucleophilic character and the electron density of the double bond, whereas the opposite is true for an olefinic linkage attached to a strongly electronegative group. This theory was tested and upheld by an investigation of the relative rates of bromine addition to various olefins (4). It was found that successive introduction of electron-releasing methyl groups into ethylene caused a successive increase in reaction velocity, whereas the reaction rate for acrylic acid was found to be smaller than for ethylene. Hawkins (29) also observed that addition of methylal to isobutylene occurred faster than addition of the same acetal to cyclohexene.

An explanation is in order for the known addition of acetals to unsaturated ethers. At first it seems that the success of such a reaction would be doubtful because of the electronegative substituent attached to the olefinic linkage. However, the electron-withdrawing tendency of the ether oxygen may be overcome by the electromeric displacement effected by the approaching carbonium ion. Of the two resonance forms pictured,

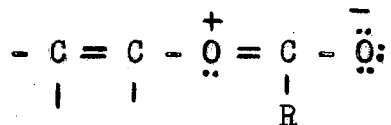


both of which are important in the resting state of the molecule, the one on the right becomes more important as the carbonium ion is approaching. This theory is supported by the fact that the carbonium ion becomes attached to the carbon atom in the beta position to the ether oxygen (34).

For vinyl esters, similar resonance forms can be written:

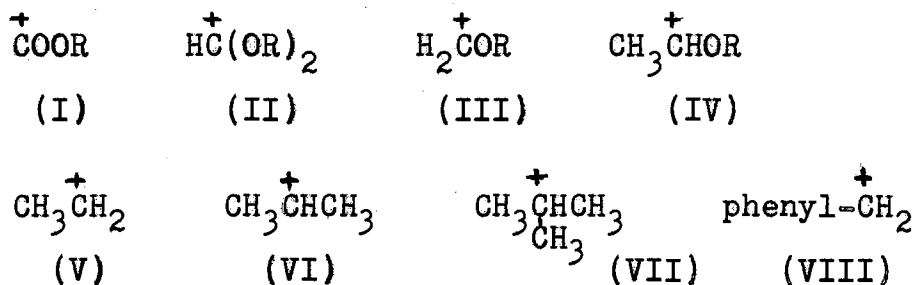


However, form (II) probably contributes very little to the actual structure of the vinyl ester, the following form being more important:

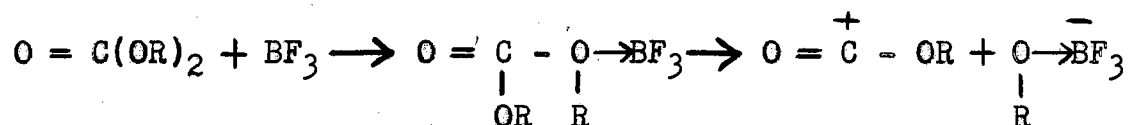


The Prins type of addition of acetals to the olefinic double bond of vinyl esters is unknown, and its occurrence seems doubtful in view of the above considerations.

Examination of the conditions for maximum reactivity of the carbonium ion reveals that the lower the electron density on the positively charged carbon atom of the carbonium ion the stronger will be its attraction by a negatively charged particle. Therefore, the reactivity of the carbonium ion is increased by electron-withdrawing substituents, whereas it is decreased by electron-repelling groups. The following carbonium ions are pictured in the order of decreasing reactivity:



(I) is the hypothetical carbonium ion formed by the action of a Lewis-acid catalyst on a dialkyl carbonate:



This carbonium ion is extremely unstable and therefore very reactive.

(II) is the carbonium ion formed from an orthoformate. Owing to its two negative substituents it should be more reactive than (III) or (IV).

(III) and (IV) are the carbonium ions obtained by the action of boron trifluoride on acetals of formaldehyde and acetaldehyde, respectively. They are also formed from chloromethyl alkyl ethers and α -chloroethyl alkyl ethers, respectively. The methyl group is more electron-repelling than the hydrogen atom, and the rate of a Prins type of addition reaction with methylal should accordingly be higher than with dimethyl acetal.

The reactivity decreases further from (V) to (VII) owing to the increasing number of hyperconjugation resonance structures which contribute to the stability of the ion (3).

(VIII) is considered the least reactive in the series because of stabilization by resonance involving the aromatic nucleus.

It should be noticed, however, that the order of ease of formation of these carbonium ions is just the reverse of that of their reactivities, and that formation of (I) and (II) may not occur under ordinary Prins conditions.

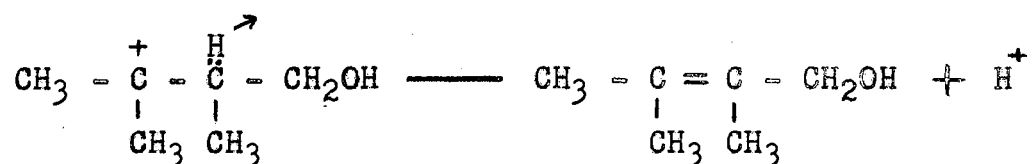
At this point the question should be answered why ethers do not appear to undergo addition to olefins under Prins conditions. There is no doubt that ethers react with Lewis acids to form carbonium ions. The well-known Friedel-Crafts type of alkylation of aromatic compounds by the use of aliphatic ethers and the Lewis acid-catalyzed rearrangement of benzyl phenyl ethers (40, 69, 74) and alkyl phenyl ethers (70,72) to substituted phenols are sufficient proof. Both reactions are explained by a carbonium ion mechanism.

As shown above the reactivity of an alkyl or benzyl carbonium ion is smaller than the reactivity of the carbonium ion derived from an acetal. The effect of low carbonium ion reactivity is twofold. Not only does it decrease the attraction between the two unlike electrical charges because of the low electropositive nature of the carbonium ion, but it also decreases the reactivity of the olefinic reagent. Polarization of the carbon-carbon double bond with formation of a center of high electron density is effected mainly by the approaching positive particle. The more electron-seeking the carbonium ion, the more pronounced will be the resulting polarization.

(4) Addition of a negative ion to the newly formed carbonium ion.--This last step results in the formation of only one product provided there is only one negative ion present in the reaction mixture. Thus for the addition involving acetals, the only negative ion present is the alkoxy ion complexed to the boron trifluoride molecule. With α -chloro ethers and α -chloro esters it is the chlorotrifluoroborate ion that will undergo addition.

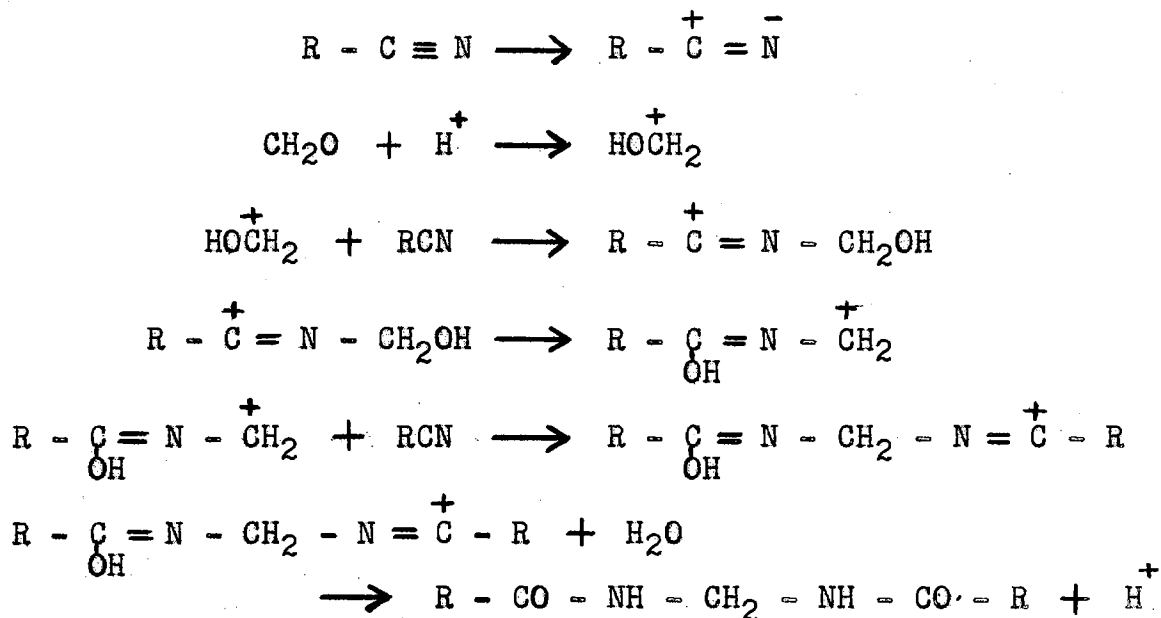
The Prins reaction with formaldehyde can be performed in aqueous solution or in glacial acetic acid solution. In the first case a 1,3-glycol is formed owing to addition of the hydroxyl ion. In the second case addition of the acetate ion results in the formation of an ester.

It should be mentioned that the carbonium ion, instead of reacting with a free electron pair of another ion, can also stabilize itself by intramolecular attraction of an electron pair from a neighboring carbon atom with resulting elimination of a proton and formation of a carbon-carbon double bond. This explains the production of unsaturated alcohols by addition of formaldehyde to highly branched olefins:



Proposed Mechanism for the Formaldehyde Addition to Nitriles.

For the formation of methylene-bis-amides by the addition of formaldehyde to nitriles in the presence of aqueous sulfuric acid, the following mechanism was proposed (46):

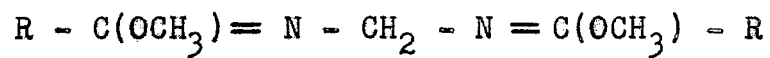


Although no mechanism appears to have been suggested for the formation of acyl-substituted hexahydro-s-triazines in the absence of water, it seems reasonable to assume that the first three steps are alike for both reactions.

It is interesting to notice that these first three steps are the same in principle as the ones outlined in the previous section of this paper for the Prins type of condensation:

(1) formation of a carbonium ion, (2) polarization of the unsaturated linkage, and (3) addition of the carbonium ion to the polarized linkage.

Application of the above mechanism to the unknown addition of methylal to nitriles would give a N-methylene-bis-iminoester as the final product:



The N-methoxymethyl-substituted iminoester also appears to be a likely product:



EXPERIMENTAL

Methylal and Methyl Oleate.

From preliminary runs on the boron trifluoride-catalyzed reaction of methylal with oleic acid of 90% purity, a pale yellow liquid product was isolated by distillation. Its boiling range of 160-240° at 1 mm. pressure indicated that addition of methylal to the olefinic double bond of oleic acid had occurred, since the boiling point of oleic acid at that pressure is lower. The reaction with free oleic acid was abandoned, however, and the methyl ester was used instead in order to avoid the undesired esterification of the carboxylic acid by its addition to the double bond of another molecule.

The source of the fatty acid for the first two runs was a 90% technical oleic acid (Eimer and Amend). Purification was accomplished by low-temperature crystallization from acetone either of the free acid or of its methyl ester, as outlined by Brown and Shinowara (18), and by Wheeler and Riemenschneider (84). For all successive runs, an oleic acid of higher purity (White Oleic Acid, Armour Chemical Division) was used. Chemical and physical constants of the methyl ester prepared therefrom showed that the ester contained less than 5% di- and triolefinic esters as impurities. The methyl ester was prepared by refluxing oleic acid with two to three times its

weight of methanol in the presence of 2-3% concentrated sulfuric acid as catalyst.

Methylal was obtained by extraction of methanol from the methylal-methanol azeotrope (Cities Service Oil Co.) with a concentrated aqueous calcium chloride solution. The methylal layer was then purified by treatment with metallic sodium until hydrogen evolution stopped and the methylal was clear and colorless.

The procedure outlined by Jamieson (41) was followed for the determination of the acid value, the iodine number (Wijs), and the saponification value.

A typical run of the reaction between methyl oleate and methylal was conducted in the following manner:

Through a gas diffuser boron trifluoride was added to 600 ml. of methylal, cooled by a brine-ice bath to -10° . Addition of boron trifluoride was continued until the color of the mixture began to darken rapidly; at this point, 35-45 g. of boron trifluoride had been absorbed. The mixture was then transferred to a one-liter, three-necked flask, equipped with mercury-sealed glass stirrer, thermometer, and reflux condenser carrying a calcium chloride tube. After rapid addition of 74 g. of methyl oleate the mixture was allowed to attain room temperature. Despite rapid stirring, the reaction temperature remained $2-3^{\circ}$ above room temperature for a period of two to three hours, thus indicating an exothermic reaction. Stirring was continued for another 24 hours at reflux temperature.

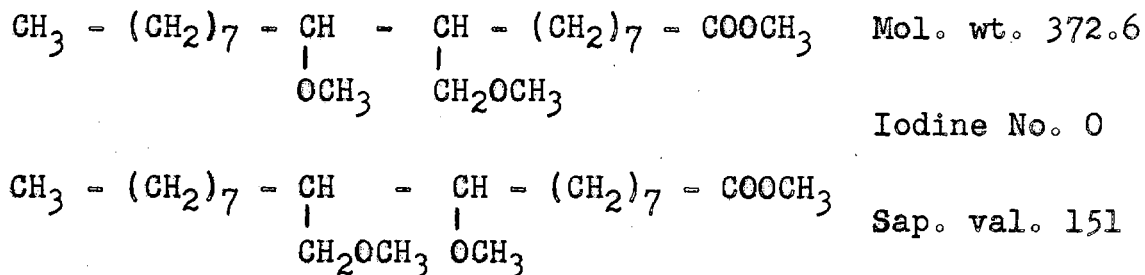
The dark-colored reaction mixture was subsequently neutralized by slowly adding an aqueous slurry of potassium carbonate to the rapidly stirred solution. After the neutralization, which was accompanied by evolution of carbon dioxide, the reaction mixture was dried with anhydrous potassium carbonate or anhydrous sodium sulfate. The solid salts were filtered, the residue was extracted with ether, and the ether extract was combined with the methylal solution. Methylal and ether were removed by distillation from a water bath, and the residue was taken up in ether, washed with water until neutral, and dried with anhydrous sodium sulfate. After evaporation of the ether, a red-brown oily liquid was obtained; its weight varied between 85 g. and 90 g. for the different runs, depending on losses encountered during the working-up procedure.

This method of neutralization had the advantage of preventing hydrolysis of the esters present in the reaction mixture. Only trace amounts of free acids were found to be present by a determination of the acid value. On the other hand, it was found that use of an aqueous solution of potassium hydroxide resulted in partial hydrolysis of the esters. Another alternative process of neutralization, the use of anhydrous ammonia gas, was found by Hawkins (29) to be slow and inefficient and was therefore not tried.

The product was purified by low-pressure distillation from a Claisen flask. Iodine numbers and saponification values of the main colorless fractions were determined. Contrary to all

expectations, the iodine numbers were never found to be zero.

The following two isomeric products are to be expected from an addition of methylal to the double bond of methyl oleate:



Whereas the iodine number of the theoretical product is zero, the iodine number actually determined for the raw product of different runs varied from 23 to 32. Table I summarizes the distillation data and the values found for saponification value and iodine number in two typical runs. The weights of the residues were 15.5 g. and 17.1 g., respectively.

The saponification values and the molecular weights calculated therefrom clearly indicate that addition of methylal to methyl oleate did occur. The product, however, was not uniform, but a mixture of unsaturated and saturated compounds. The conclusion that the unsaturated component is simply unreacted methyl oleate is contradicted by the following facts: (1) the boiling points of the main fractions are considerably higher than the boiling point of methyl oleate at the same pressure. In one particular run methyl oleate, which was distilled at 160-165° at a manometer pressure of 1.0-1.5 mm., upon

TABLE I
 PROPERTIES OF DISTILLED PRODUCTS FROM ADDITION
 OF METHYLAL TO METHYL OLEATE

Pressure, mm. Hg	B.p.	Weight, g.	Iodine No.	Sap. Val.	Mol. wt.
0.3	130-170	17.6	23.2	180	312
0.4	175-187	40.0	32.9	156	360
0.5	193-200	18.2	15.9	148	379

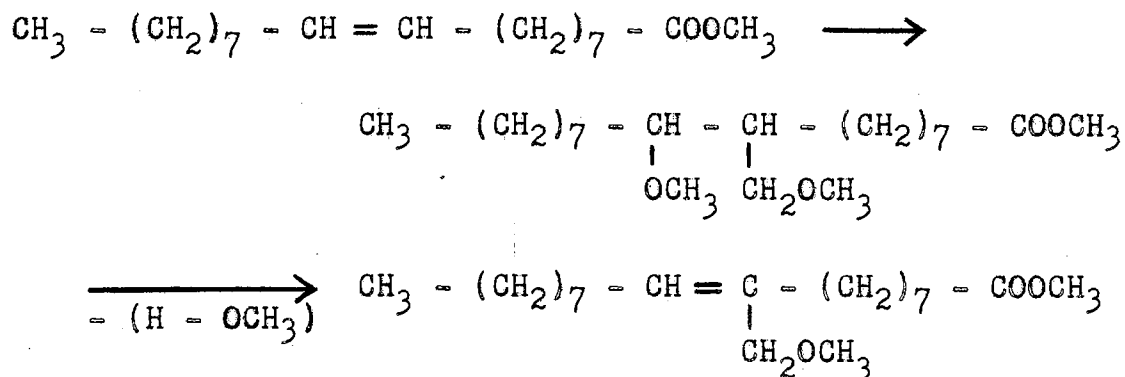
0.4	130-150	7.4	14.7		
0.4	150-166	8.2	21.9		
0.5	166-180	11.4	24.9		
0.6	180-190	16.5	19.9	152	369
0.7	190-197	12.0	16.8	145	387

reaction with methylal gave a main fraction boiling at 175-187° at 0.4 mm. pressure; (2) the greater weight of the product compared to the methyl oleate, even neglecting small losses during the working-up procedure, cannot be explained on the assumption that part of the methyl oleate did not undergo addition. Thus, from 84.5 g. of methyl oleate a high-boiling product weighing 101.0 g. and having an iodine number of 32 was obtained.

(3) Methyl oleate, having a straight-chain structure, forms an adduct with urea; as will be described later, the product did not undergo adduct formation with urea.

In analogy to other Prins type of additions which result in the formation of unsaturated compounds, the unsaturated

component of the mixture obtained by the reaction of methylal and methyl oleate might be formed in the following way:



This postulation is supported by results obtained by Hawkins (29) for the addition of methylal to cyclohexene. Besides the two expected saturated compounds, Hawkins isolated a third unsaturated compound which he expected to be 1-methoxymethylcyclohexene. However, evidence pointed towards 1-methoxy-2-hydroxymethylcyclohexene as the correct structure.

The methyl methoxymethyloleate postulated above seems likely to be formed as a decomposition product of the saturated component during the distillation. However, redistillation did not alter the iodine number, and unsaturation of the distilled product was not higher than unsaturation of the raw product. This clearly shows that the unsaturated component was already present in the original reaction mixture.

Various attempts were made to separate the saturated from the unsaturated components in order to prove the structure of the main addition product of the reaction. The success of separation by fractional distillation was considered doubtful.

Even with a highly efficient column a separation without decomposition of the distillate would probably only succeed under low pressure.

Various separation methods depending on the relative solubilities of the two components or of derivatives thereof were investigated. Fractional crystallization of the mixture at low temperatures failed. Even after long standing at -60° a 10% solution of the mixture in acetone or low-boiling petroleum ether only produced a very slight turbidity, but no crystals.

Separation of the bromo derivatives of the unsaturated component by crystallization from ether was also unsuccessful. Bromination was carried out by dissolving the mixture in dry ethyl ether to form a 10% solution. The solution was cooled to -20° and bromine was added from a finely drawn pipette under constant shaking until the yellow color persisted. Even after long standing at -60° no separation of crystals occurred. The bromo derivative was found to be very unstable at higher temperatures. Evaporation of the solvent on the waterbath resulted in decomposition. Consequently, the iodine number of the brominated product after distillation at 0.2 mm. pressure was found to be the same as the one of the original mixture.

The preparation of solid derivatives, fractional crystallization of which might permit resolution, was also attempted. The procedure of Pool, Harwood, and Ralston (57) was followed for the preparation of 2-substituted benzimidazoles by the reaction of α -phenylenediamine with the free acids. However,

crystallization of the derivatives could not be accomplished. The phenylhydrazides were prepared according to a procedure of Strache and Iritzer (73). Although a small amount of a solid derivative was obtained initially, the white solid could not be recrystallized. The same negative results were obtained with hydroxamic acids as derivatives. Following the procedure of Powell (59), these derivatives were prepared by the reaction of the esters with hydroxylamine hydrochloride and sodium ethoxide in absolute alcohol. While the hydroxamic acids did not crystallize, precipitation of their green-colored copper salts succeeded (42). However, the regenerated hydroxamic acids still would not crystallize.

Urea is known to give crystalline adducts with straight-chain, but not with branched-chain compounds (12, 63, 64, 67, 68, 71, 85, 86). If one of the components of the reaction mixture were an unsubstituted straight-chain fatty acid ester, it could easily be separated from the branched-chain components as the urea adduct. Repeated attempts at causing adduct formation between urea and the reaction mixture completely failed. This result is further evidence that the unsaturated component is also a branched-chain fatty acid ester, and not simply unreacted methyl oleate.

Isolation and purification of the saturated components of the reaction mixture was further attempted by oxidative cleavage of the unsaturated component, followed by removal of the low-boiling oxidation products by vacuum distillation. For the

determination of structure of olefinic compounds potassium permanganate and ozone are the most widely used oxidizing agents. Ozonization occurs smoothly and with the formation of much less secondary oxidation products than is the case with the more vigorous permanganate oxidation. In view of the fact that an ozonizer was not available, a method involving alkaline potassium permanganate was used (13).

The ester mixture to undergo oxidation had the following properties: iodine number 28.1, average molecular weight 366.7 (calculated from the saponification value), boiling point 175-195°. The oxidation was conducted in the following way:

A solution of 52.5 g. of the ester in 200 ml. of ethyl alcohol containing 12.0 g. of potassium hydroxide was refluxed for one hour and then evaporated to dryness on a steam bath. Evaporation to dryness was repeated after addition of 50 ml. of water to ensure removal of all the alcohol. The solid soap was dissolved in 300 ml. of water and combined in one addition and under powerful stirring with a solution of 100 g. of potassium permanganate in 1.2 liters of water. The temperature quickly increased from 30° to 75°. After one hour all the permanganate had been used up. The mixture was cooled and acidified with 50% sulfuric acid. Enough solid sodium bisulfite was added to decolorize the solution. A dark-colored tarry residue was shaken with a mixture of ether and an acidic sodium bisulfite solution until all of the residue had dissolved and both layers were clear. The aqueous solution was saturated with sodium

chloride and extracted with a total of 1.3 liters of ether. The ether extracts were combined, washed neutral, and dried with anhydrous sodium sulfate. After evaporating the ether, 45.0 g. of an orange product with an irritating odor was obtained.

This mixture of carboxylic acids was esterified by refluxing its solution in 200 ml. of absolute methanol containing 2 g. of concentrated sulfuric acid. After the regular working-up procedure, 35.0 g. of a yellow ester mixture was obtained.

An explanation is in order for the amount of potassium permanganate chosen for the oxidation. The required amount of oxidizing agent was calculated on the assumption that the unsaturated component of the mixture was a methoxymethyl-substituted oleic acid and that its cleavage products were nonanoic and azelaic acid. It was assumed that the ether side chain was completely oxidized to carbon dioxide and water. From a preliminary run, however, it was found that oxidative cleavage of the double bond did not go to completion by the action of an amount of oxidizing agent calculated on the above assumptions. Instead, at least a 50% excess of potassium permanganate was required. This indicated that the major reaction, oxidative cleavage of the olefinic double bond, was accompanied by secondary oxidation reactions, and that the saturated component of the mixture was also attacked.

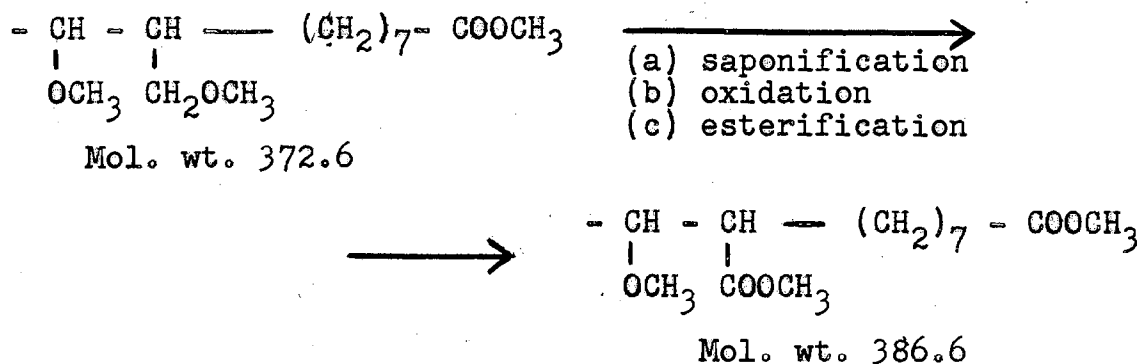
Vacuum distillation gave 11.0 g. of a colorless fraction boiling at 197-202° under 0.5-1.0 mm. pressure. Iodine number

and saponification value of this fraction were determined. Table II summarizes the changes effected by the oxidation.

TABLE II
 PROPERTIES BEFORE AND AFTER OXIDATION OF DISTILLED
 PRODUCT FROM ADDITION OF METHYLAL
 TO METHYL OLEATE

	Original ester	Oxidized ester
B.p.	175-195°/0.4-0.7 mm.	197-202°/0.6-1.0 mm.
Iodine No.	28.1	0.9
Sap. Value	153.0	168.5
Mol. Wt. (calcd. from Sap. Value)	366.7	333.0

The low iodine number shows that oxidation was successful as far as removal of the unsaturated components is concerned. However, the average molecular weight had decreased and differed considerably from the molecular weight of the expected saturated product (Mol. wt. 372.6). The high boiling point rules out any explanation for the low molecular weight assuming contamination of the product by some low-molecular-weight fatty acid ester. The only reasonable explanation appears to be the assumption that the expected saturated ester contained a relatively small percentage of a high-molecular-weight dicarboxylic acid ester, the formation of which is illustrated by the following equation:



A mixture of these two compounds would be expected to boil within a short temperature range, since the boiling points of the individual compounds probably differ very slightly. In order to determine the molecular refraction, the refractive index and the density were measured: n_D^{25} 1.4512, d_4^{25} 0.933 g./ml. On the assumption that the product is composed of the two proposed esters, the average molecular weight of the mixture is 374.3, as calculated from the saponification value. When this molecular weight for the evaluation of the observed molecular refraction is used, a value of 108.1 is obtained. This value checks fairly well with 108.7, the value for the molecular refraction of the same compound calculated from atomic refractions. It should be noted that the structures of the two proposed compounds are such that the calculated molecular refractions are the same for both compounds. However, the close agreement between the observed and the calculated value does not necessarily present strong evidence in support of the postulated composition of the mixture, since the observed

power was found to be insufficient for complete adsorption of the fatty acids dissolved in petroleum ether. Activated alumina (Merck) was also found unsuitable as an adsorbent because of its chemical reaction with the fatty acids to form soaps. With 60-200 mesh activated silica gel (The Davison Chemical Corp.) a partial separation was accomplished. A minute amount of a white crystalline solid melting at $47.5-57.5^{\circ}$ was obtained by elution with benzene. Subsequent elution with benzene-acetone mixtures resulted in a series of impure liquid products. Each successive product had a slightly higher refractive index than the previous one, the indices ranging from n_D^{25} 1.4582 to n_D^{25} 1.4698. The refractive index of the original mixture was n_D^{25} 1.4597.

In view of the difficulties encountered in finding an efficient adsorbent together with a suitable solvent, the project of separating the fatty acid mixture was discontinued.

Methylal and Methyl Crotonate.

The condensation of methylal with methyl crotonate was conducted according to the procedure described previously for the reaction of methylal with methyl oleate. To 400 ml. of methylal containing 27 g. of boron trifluoride were added 88 g. of freshly prepared methyl crotonate (b.p. $118-120^{\circ}/745$ mm.). The reaction was run for 24 hours at room temperature, and then for another 24 hours at the boiling point of the mixture. After neutralization with potassium carbonate the mixture was distilled. Recovery of methyl crotonate was almost

molecular refractions for mixtures of different composition might not be constant.

Separation of the saponified mixture into its components was attempted by chromatographic methods. As a result of the difference in polarity between the two components believed present in the mixture (a monocarboxylic and a dicarboxylic acid), the degree of adsorption of the two components should be different enough to permit separation. Chromatographic separation of fatty acids has been applied by many workers with varying degrees of success (47, 62). The most effective adsorbents appear to be activated alumina, silica gel, and activated carbon; the most widely used solvents are petroleum ether and benzene. Recently, Holman and co-workers (28, 35, 36, 37, 38) have successfully investigated the method of displacement chromatography for the separation of fatty acids and their derivatives.

The column used for the chromatographic separation of the fatty acid mixture was 9.0 cm. in length and 1.4 cm. in diameter. Slight air pressure had to be applied on the top of the column in order to provide for a sufficient flow of the solvent. The original solvent, by which the fatty acids were brought on the column, was low-boiling petroleum ether. Benzene, benzene-acetone mixtures, and benzene-methanol mixtures were used as eluants.

The first adsorbent used was Magnesol (a magnesium silicate from Westvaco Chlorine Products Corp.). Its adsorbing

complete. Only a few drops of a distillate boiling between 120° and 128° were obtained; there was no residue. A duplicate run gave the same negative result.

Methylal and Methyl Acrylate.

Reaction of 400 g. of methylal with 116 g. of freshly distilled methyl acrylate (b.p. $77-79^{\circ}/745$ mm.) in the presence of 22 g. of boron trifluoride apparently resulted in the formation of 5 g. of a methyl acrylate polymer as the only reaction product. The rest of the methyl acrylate was recovered by distillation of the reaction mixture, which did not contain any high-boiling products. The reaction was repeated, but addition of methylal to methyl acrylate again did not take place.

Methylal and Vinyl Acetate.

Vinyl acetate (84 g., b.p. $71-73^{\circ}$) was distilled at a rapid rate directly into the reaction flask containing 380 g. of methylal and 38 g. of boron trifluoride. Despite rapid stirring and cooling with ice-water, the reaction temperature slowly increased during the addition. The exothermic reaction finally became so vigorous that a small amount of the mixture was lost through overflow at the top of the condenser. Cooling was continued for five more minutes after which time the reaction temperature remained at $40-42^{\circ}$ without cooling. Within two hours room temperature was attained, and stirring was continued for 10 more hours at room temperature. After neutralization of the catalyst, the dried mixture was distilled. A

fraction (10 ml.) of boiling range 60-90° had a very strong aldehyde odor and gave a positive Schiff test. At 90° the distillation had to be discontinued because of decomposition. A brown-red, glassy, almost solid residue weighing 57 g. remained in the flask.

The only reaction taking place apparently was polymerization of the vinyl acetate. The small amount of low-boiling aldehydes was probably formed either by hydrolysis of vinyl acetate during the working-up procedure, or by thermal decomposition of the polymer during the distillation. The competitive polymerization of vinyl acetate appears to have prevented the attempted addition reaction with methylal.

In order to increase the likelihood of a reaction with methylal, the unsaturated ester was added very slowly from a dropping funnel in a second run. However, the result was the same as for the first run, polymerization of vinyl acetate apparently being the only reaction occurring.

Methylal and Valeronitrile.

From the reaction of 91 g. of valeronitrile with 400 ml. of methylal containing 23 g. of boron trifluoride, the only product obtained was 10 g. of a sticky, brown solid of partly crystalline, partly glass-like appearance. Recrystallization from alcohol-water and acetone-water was attempted, but failed. While a large part of the valeronitrile was recovered unchanged, the presence of the solid product indicated that reaction with

methylal might take place under the proper conditions. However, the reaction was not investigated further.

Isobutylene and Methyl Benzyl Ether.

Attempts to add methyl benzyl ether into the double bond of isobutylene in the presence of boron trifluoride were unsuccessful. A reaction mixture consisting of 100 g. of methyl benzyl ether, 41 g. of isobutylene, and 22 g. of boron trifluoride was stirred for 12 hours at room temperature. After neutralization, ether extraction, and drying, a high-boiling product weighing 125 g. was obtained, thus indicating that 25 g. of the 41 g. of isobutylene originally absorbed had undergone some kind of a reaction. Distillation of the product through a semimicro Todd column resulted in the recovery of 92 g. of methyl benzyl ether. The almost solid residue probably consisted of a high-molecular-weight hydrocarbon polymer.

Isobutylene and n-Butyl Nitrite.

Boron trifluoride was the first catalyst used for the attempted addition of n-butyl nitrite to isobutylene. Introduction of 7.5 g. of boron trifluoride at -10° into 150 g. of freshly prepared (14) n-butyl nitrite resulted in the formation of a slightly yellow mixture of gelatine-like consistency. Upon removal of the brine-ice cooling bath, the mixture warmed up quickly. Despite renewed cooling, vigorous decomposition accompanied by the evolution of brown vapors occurred.

In the presence of small quantities of boron trifluoride, decomposition of the nitrite did not take place. However, addition of the nitrite to isobutylene could not be accomplished. Thus, after shaking a mixture of 109 g. of n-butyl nitrite, 38 g. of isobutylene, and 0.2 g. of boron trifluoride in a low-pressure bottle for 12 hours, the nitrite was recovered unchanged. The same negative results were obtained in the presence of catalytic quantities of concentrated sulfuric acid and of stannic chloride.

Isobutylene and diethyl carbonate.

The boron trifluoride-catalyzed reaction between isobutylene and diethyl carbonate was conducted in the following way: into a mixture of 117 g. of freshly distilled diethyl carbonate (b.p. 126-127°) containing 18.5 g. of boron trifluoride were introduced 54 g. of isobutylene by means of a gas diffuser. Despite cooling with a brine-ice bath, and despite rapid stirring, the reaction temperature during the addition was 15-20°. The mixture was transferred to a low-pressure bottle and shaken for 30 hours at room temperature. After neutralization of the catalyst with aqueous potassium hydroxide, the high-boiling product was subjected to fractional distillation through a semimicro Todd column. Contrary to results in other boron trifluoride-catalyzed reactions involving isobutylene, which resulted in the formation of high polymers, only trace amounts of non-distillable materials remained in the distilling flask.

None of the three different fractions collected was found to be the expected β -ethoxy ester. The lowest-boiling fraction (b.p. 124.5-126.0°/747 mm.) was identified by its refractive index and by its boiling point as unreacted diethyl carbonate. A total of 86 g. of this starting material was collected. The other two fractions, 18 g. of boiling point 175.5-177.0°/745 mm., and 14 g. of boiling point 99-103°/1 mm., gave evidence of consisting of the trimer and tetramer, respectively, of isobutylene. Both fractions gave a negative hydroxamic acid test and decolorized bromine and permanganate solutions. The properties of the two fractions are summarized in Table III, where M.R. calc. stands for the values of the molecular refractions calculated for $C_{12}H_{24}$ and $C_{16}H_{32}$, respectively.

TABLE III
 PROPERTIES OF PRODUCTS FROM ADDITION OF DIETHYL
 CARBONATE TO ISOBUTYLENE

	n_D^{30}	d_4^{30} g ³ /ml.	M.R. obs. ml.	M.R. calc. ml.
Cut with b.p. 175.5- 177.0° at 745 mm.	1.4253	0.752	57.2	57.1
Cut with b.p. 99.0- 103.0° at 1 mm.	1.4449	0.788	75.8	75.6

Isobutylene and Ethyl Orthoformate.

A reaction mixture consisting of 100 g. of ethyl orthoformate, 45 g. of isobutylene, and 32 g. of boron trifluoride

was shaken for 18 hours at room temperature in a low-pressure bottle. Whereas the isobutylene was recovered unchanged, the orthoester was found to have reacted in the presence of boron trifluoride to give diethyl ether and ethyl alcohol. The same result was obtained with 14 g. of sulfuric acid as catalyst.

The attempt to add the orthoester into the double bond of the olefin was repeated with only a small amount (0.2-0.5 g.) of boron trifluoride as catalyst. Both reagents, ethyl orthoformate (120 g.) and isobutylene (66 g.), were recovered unchanged.

Isobutylene and Benzaldehyde Diethyl Acetal.

The addition of benzaldehyde diethyl acetal to the olefinic linkage of isobutylene was attempted in the following way: to 161.0 g. of the freshly prepared (32) acetal, cooled by a brine-ice bath, were slowly added 24.5 g. of boron trifluoride. The rate of addition had to be kept low in order to prevent the reaction temperature from increasing above 0°. At the end of the addition two layers had formed. The mixture was transferred to a three-necked flask equipped with stirrer, thermometer, and gas inlet tube. A total of 51 g. of isobutylene was added under constant stirring; the temperature during the addition was kept at 5-10°. After 16 hours of shaking in a low-pressure bottle, the reaction mixture was neutralized with an aqueous solution of potassium hydroxide, and the organic material was extracted with ether. Upon

evaporating the solvent, 175 g. of a dark-red, viscous product was obtained.

Fractional distillation through a Todd column did not give any constant-boiling fractions. A total of 127 ml. of distillate was collected. The first 62 ml. distilled between 40° and 165° at 60 mm. pressure, the next 65 ml. between 155° and 216° at 5 mm. pressure. Slight decomposition started at 195° . The almost solid residue weighed 56 g.

Redistillation of the lower-boiling product at atmospheric pressure resulted in three fractions. Chemical and physical tests showed that the two lower-boiling fractions (b.p. $98-101^{\circ}$ and $174-177^{\circ}$) consisted of a dimer and trimer, respectively, of isobutylene. The fraction boiling at $216-219^{\circ}$ was unreacted acetal (36 g.).

Boiling point and refractive index of the high-boiling product indicated that it did not consist of the expected addition product, 1,3-diethoxy-1,1-dimethyl-3-phenylpropane. The boiling point of this 1,3-diether is expected to be only slightly higher than $167.8^{\circ}/85$ mm., the known boiling point of 1,3-diethoxy-1-phenylpropane (29). The refractive indices for the high-boiling product (n_D^{32} 1.4927 for 12 ml. of boiling point $158-160^{\circ}/5$ mm., increasing to n_D^{32} 1.5312 for the last 10 ml. of boiling point $212-216^{\circ}/5$ mm.) were found to be considerably higher than n_D^{22} 1.4772, the refractive index of 1,3-diethoxy-1-phenylpropane.

These data indicated that the aromatic acetal, instead of undergoing the expected addition to isobutylene, reacted in some other way, probably without involving the olefin. In order to prove this, the acetal was caused to react with boron trifluoride in the absence of the olefin.

Boron trifluoride was introduced into 80 g. of benzaldehyde diethyl acetal cooled by a brine-ice bath. Upon removal of the cooling bath, an unexpected vigorous decomposition took place so that most of the tarry, black product was lost. In a second attempt the rate of introduction of boron trifluoride was kept low. The slow addition was stopped after 15 g. of boron trifluoride had been added to 76 g. of the acetal. Cooling was continued for 15 minutes; the reaction mixture was then allowed to attain room temperature. When a reaction temperature of 45° was reached cooling was renewed. The temperature again slowly increased upon removal of the cooling bath, then remained at 38° for 30 minutes without cooling. The mixture was shaken at room temperature for 12 hours.

A dark-brown, viscous liquid (46 g.) was obtained after neutralization and extraction. Vacuum distillation from a Claisen flask resulted in 11 g. of a substance boiling at $90-120^{\circ}/5$ mm. and 4 g. of a substance boiling at $120-210^{\circ}/5$ mm. and with refractive index n_D^{31} 1.5380. The residue was an amorphous solid. The higher-boiling fraction had the same characteristic odor as the high-boiling fraction ($155-216^{\circ}/5$ mm.) previously obtained by distillation of the acetal-

isobutylene reaction product. Purification of these high-boiling products was not attempted.

DISCUSSION

Whereas methylal was found to undergo addition to the olefinic linkage of methyl oleate, the same acetal did not add to the esters of α,β -unsaturated acids, such as methyl acrylate and methyl crotonate. These results are readily explainable on the basis of the proposed mechanism for the acid-catalyzed addition of acetals to carbon-carbon double bonds. While the ester group in oleic acid at best has a very weak influence on the nucleophilic character of the olefinic linkage, the neighboring electron-withdrawing ester group of methyl acrylate and of methyl crotonate renders the carbon-carbon double bond less reactive as a nucleophilic reagent. The resonance form with the negative charge on the carbonyl oxygen contributes significantly to the true structure of these conjugated double bond systems ($-\overset{+}{\text{C}}=\overset{-}{\text{C}}-\overset{-}{\text{C}}=\overset{-}{\text{O}}$). The decrease in reactivity is demonstrated by the much lower rate of halogen addition to α,β -unsaturated acids compared to the rate of addition to simple olefins. Theory does not predict, however, that a Prins-type reaction with esters of α,β -unsaturated acids is impossible. Under more drastic conditions, addition of methylal to such esters might be accomplished. Addition to the double bond of β,γ -unsaturated esters, although not attempted in this study, should be possible. In the absence of the conjugated double bond system, the electron-withdrawing

influence of the ester group is weak and should not prevent the reaction from taking place.

For the reaction of methylal with methyl oleate, experimental evidence clearly indicated that the major saturated product was formed as expected by the addition of methoxymethyl and methoxy groups to the olefinic linkage. On the basis of theoretical considerations, this saturated product was believed to be a mixture composed of the two possible isomers. No attempt was made to separate these isomers. A third product, this one unsaturated, was formed by a side reaction, probably involving removal of a small-molecular-weight compound, such as methanol, from the saturated product originally formed. This side reaction was shown not to occur during the distillation; the products were stable up to 200^o, and the degree of unsaturation was not affected by distillation. Separation of the unsaturated from the saturated components presented difficulties. While all methods of separation based on different physical properties of the components failed, removal of the unsaturated component by oxidative cleavage of its olefinic linkage with potassium permanganate succeeded. The saturated product, however, was found to be contaminated; the impurity was believed to be an ester of a high-molecular-weight dicarboxylic acid. Separation of this mixture into its components by chromatographic methods failed.

While a separation based on oxidative cleavage by means of a selective oxidizing agent, such as ozone, appears promising,

the success of physical methods of separation within a reasonable period of time seems doubtful. Chromatography and countercurrent distribution methods are very effective tools of separation. The success of these methods, however, depends on the time-consuming empirical selection of adsorbent and solvent, respectively.

Spectrographic analysis, either with infrared or with ultraviolet light, would have been of little help in proving the structures of the different components of the mixture. The functional groups present in the mixture were already known, and neither a pure sample nor the absorption curve of any one of the components believed to be present was available.

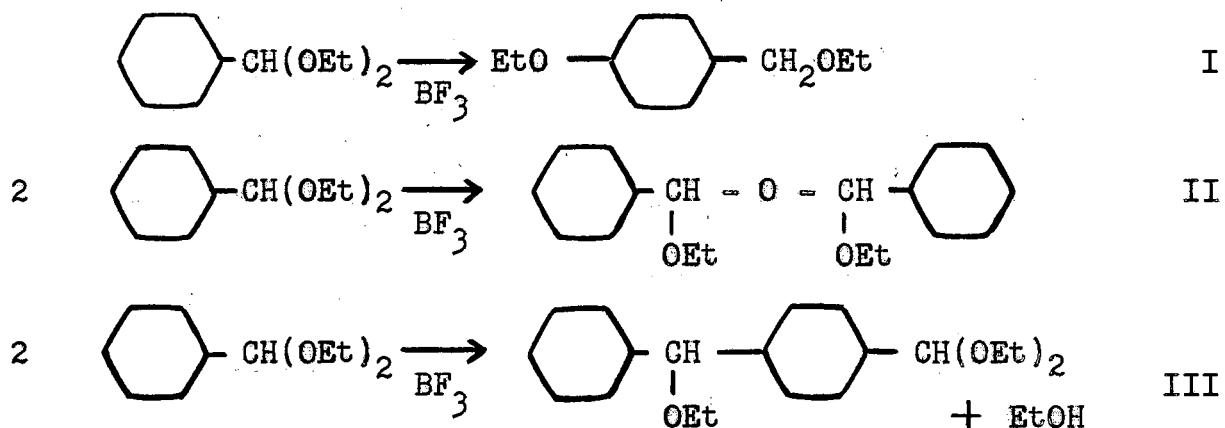
The likelihood for success or failure of the different Prins-type reactions attempted during the course of this investigation has already been discussed in the historical part of this paper. While the success of most of these reactions seemed doubtful on the basis of theoretical considerations, the negative experimental results should not be construed as presenting conclusive evidence for the impossibility of these reactions. While the results only show that addition does not take place under conditions which are favorable for the acetal addition to simple olefins, some general conclusions can be drawn. A Prins type of reaction is not likely to succeed unless (a) the polarized olefinic reagent has a center of high electron density located at one of the two carbon atoms of the double bond, and (b) the aldehydic reagent can yield a

carbonium ion of structure ROCHR' where R' is a hydrogen atom or an alkyl radical and R is an alkyl or acyl radical. Whether or not the aldehydic reagent has an alkoxy group in its structure appears to be of little importance. Thus orthoesters, alkyl carbonates, and alkyl nitrites were found not to undergo addition, although they all have an alkoxy group in their structures.

Definite conclusions on the possibility of the reactions under investigation should only be made after extensive studies involving variation in reaction conditions, such as temperature, pressure, type and amount of catalyst, reaction time, way of mixing the reagents, ratio of reagents, etc. Such an extensive study, however, was beyond the scope of this work. Rather than to vary the reaction conditions for any one particular reaction, the intention was to investigate a variety of reactions conducted at room temperature, under atmospheric pressure, and in the presence of boron trifluoride as catalyst. These are the conditions under which high yields of addition products are obtained from the reaction of acetals and simple olefins.

The results obtained for the attempted addition of benzaldehyde diethyl acetal to isobutylene were rather unexpected. Instead of adding to the olefinic linkage of isobutylene, the aromatic acetal was found to undergo some kind of rearrangement in the presence of boron trifluoride. The products of this reaction consisted partly of a very high boiling-material, partly

of an amorphous non-distillable solid. At first it appears that several explanations for the formation of these high-molecular-weight substances are possible. However, an examination of the reactions illustrated by equations I, II, and III



shows that ethoxylation of the aromatic ring (equation I) is highly improbable, since a nucleophilic attack by the ethoxide ion in strongly acidic medium would be involved. The formation of the mixed acetal (equation II), although possible under the reaction conditions applied, would not account for the high-molecular-weight products obtained. Thus it appears that the best explanation is the Friedel-Crafts type of reaction (equation III) involving an electrophilic attack of the aromatic nucleus by the ethoxy-substituted benzyl carbonium ion. The formation of high-molecular-weight products by such a reaction is possible, since substitution may occur in ortho and para positions, and since the primary products, still being acetals, may undergo renewed reaction.

SUMMARY

Whereas methylal was found to undergo addition to the olefinic linkage of methyl oleate, there was no evidence for a similar reaction of the same acetal with methyl acrylate, methyl crotonate, or vinyl acetate. Apparently, addition of methylal to a carbon-carbon double bond conjugated with an electron-withdrawing ester group does not take place.

For the reaction of methylal with methyl oleate, the major product was formed as expected by the addition of methoxymethyl and methoxy groups to the olefinic linkage. However, the reaction mixture also yielded a little unsaturated product of about the same molecular weight as the saturated adduct and physically inseparable from it. Oxidative destruction of this unsaturated impurity with potassium permanganate produced a new impurity, saturated but apparently dicarboxylic, which could not be removed from the desired adduct either. Ozone might make this possible.

The results obtained for the attempted addition of benzaldehyde diethyl acetal to isobutylene indicate that the α -ethoxybenzyl carbonium ion undergoes a Friedel-Crafts reaction with the aromatic ring rather than addition to the olefin.

From the results of the attempted addition of methylal to unsaturated esters, and from other results obtained for reactions involving compounds other than acetals, the conclusion

can be drawn that a Prins-type reaction is not likely to succeed unless (a) the polarized olefinic reagent has a center of high electron density located at one of the two carbon atoms of the double bond and (b) the aldehydic reagent can yield a carbonium ion of structure $ROCHR'$ where R' is a hydrogen atom or an alkyl radical and R is an alkyl or acyl radical. Orthoesters, alkyl carbonates, alkyl benzyl ethers, and alkyl nitrites apparently do not undergo addition, although they all have alkoxy groups in their structures.

BIBLIOGRAPHY

- (1) Alexander, "Principles of Ionic Organic Reactions," p. 216, John Wiley and Sons, Inc., New York, 1950.
- (2) Ibid., p. 137.
- (3) Ibid., p. 41.
- (4) Anantakrishnan and Ingold, J. Chem. Soc., 1935, 984; idem, 1396; Anantakrishnan and Venkataraman, ibid., 1939, 224.
- (5) Arundale and Mikeska (to Standard Oil Development Co.), U. S. 2,253,342 (1941), via C. A., 35, 7974.
- (6) Arundale and Mikeska (to Standard Oil Development Co.), U. S. 2,312,743 (1943), via C. A., 37, 4749.
- (7) Arundale and Mikeska (to Standard Oil Development Co.), U. S. 2,384,268 (1945), via C. A., 40, 613.
- (8) Baker, J. Chem. Soc., 1944, 296.
- (9) Baker, ibid., 1948, 89.
- (10) Baker, Nature, 1948, 171.
- (11) Batt and Woodcock, J. Chem. Soc., 1948, 2322.
- (12) Bengen and Schlenk, Experientia, 5, 200 (1949).
- (13) Blatt, "Organic Synthesis," Coll. Vol. II, pp. 53-55, John Wiley and Sons, Inc., New York, 1943.
- (14) Ibid., p. 108.
- (15) Booth and Martin, "Boron Trifluoride and its Derivatives," p. 187, John Wiley and Sons, Inc., New York, 1949.
- (16) Brooks (to du Pont), U. S. 2,436,286 (1948), via C. A., 42, 3431.
- (17) Brooks (to du Pont), U. S. 2,449,447 (1948), via C. A., 43, 1055.

- (18) Brown and Shinowara, *J. Am. Chem. Soc.*, 59, 6 (1937).
- (19) Cann and Amstutz, *ibid.*, 66, 839 (1944).
- (20) Croxall and Schneider, *ibid.*, 71, 1257 (1949).
- (21) Dykstra, *ibid.*, 58, 1747 (1931), and (to du Pont), U. S. 2,119,531 (1938).
- (22) Farbwerke vorm. Meister Lucius und Bruning, Höchst a/M, Germany, Brit. 13,790 (1908), via C. A., 3, 2490.
- (23) Farbwerke vorm. Meister Lucius und Bruning, Höchst a/M, Germany, Ger. 226,222 (1908), via C. A., 5, 1196.
- (24) Gasselín, *Ann. chim. phys.* (7) 3, 22 (1894), via Beilstein 1, 287.
- (25) Gradsten and Pollock, *J. Am. Chem. Soc.*, 70, 3079 (1948).
- (26) Gresham (to du Pont), U. S. 2,449,471 (1948), via C. A., 43, 1055.
- (27) Gresham and Steadman, *J. Am. Chem. Soc.*, 71, 1872 (1949).
- (28) Hagdahl and Holman, *ibid.*, 72, 701, (1950).
- (29) Hawkins, Dissertation, Okla. A. and M. College, 1952.
- (30) Hepp and Spiess, *Ber.*, 9, 1424 (1876).
- (31) Hepp, *ibid.*, 10, 1649 (1877).
- (32) Hickinbottom, "Reactions of Organic Compounds," p. 182, Longmans, Green and Co., New York, 1948.
- (33) Hinton and Nieuwland, *J. Am. Chem. Soc.*, 52, 2892 (1930).
- (34) Hoaglin and Hirsh, *ibid.*, 71, 3468 (1949).
- (35) Holman, *ibid.*, 73, 3337 (1951).
- (36) Holman and Williams, *ibid.*, 73, 5285 (1951).
- (37) Holman and Hagdahl, *Arch. Biochem.*, 17, 301 (1948).
- (38) Holman and Hagdahl, *J. Biol. Chem.*, 182, 421 (1950).
- (39) Hultquist (to American Cyanamid Co.), U. S. 2,459,076 (1949), via C. A., 43, 4291.

- (40) Iddles, Caughey, Mayor, Perry, and Pike, *J. Am. Chem. Soc.*, 74, 545 (1952).
- (41) Jamieson, "Vegetable Fats and Oils," Reinhold Publishing Corp., New York, 1943.
- (42) Jones and Wallis, *J. Am. Chem. Soc.*, 48, 176 (1926).
- (43) Kaufmann, *Ger.* 555,403 (1930), via *C. A.*, 26, 5101.
- (44) Kohn, Master's Thesis, Okla. A. and M. College, 1948.
- (45) Kraut, *Ann.*, 258, 109 (1890).
- (46) Magat, Faris, Reith, and Salisbury, *J. Am. Chem. Soc.*, 73, 1028 (1951).
- (47) Markley, "Fatty Acids," pp. 615-618, Interscience Publishers, Inc., New York, 1947.
- (48) McKenna and Sowa, *J. Am. Chem. Soc.*, 60, 124 (1938).
- (49) Mueller-Cunradi and Pieroh (to I. G. Farbenindustrie A.-G.), *U. S.* 2,165,962 (1939), via *C. A.*, 33, 8210.
- (50) Nenitzescu and Przemetski, *Ber.*, 74B, 676 (1941).
- (51) Niewland, Vogt, and Foohey, *J. Am. Chem. Soc.*, 52, 1018 (1930).
- (52) O'Leary and Wenzke, *ibid.*, 55, 2117 (1933).
- (53) Olsen, *Acta. Chem. Scand.*, 5, 1339 (1951).
- (54) Paul and Tchelitcheff, *Bull. soc. chim. France*, 1950, 1155.
- (55) Paul and Tchelitcheff, *ibid.*, 1951, 125.
- (56) Figulevskii and Tatarskaya, *Zhur. Obsheei Khim.*, 20, 1456 (1950), via *C. A.*, 45, 2480.
- (57) Pool, Harwood, and Ralston, *J. Am. Chem. Soc.*, 59, 178 (1937).
- (58) Post, "The Chemistry of the Aliphatic Orthoesters," Chapter 3, Reinhold Publishing Corp., New York, 1943.
- (59) Powell, *J. Am. Chem. Soc.*, 51, 2438 (1929).
- (60) Price, "Reactions at Carbon-Carbon Double Bonds," p. 45, Interscience Publishers, Inc., New York, 1946.

- (61) Prins, *Rec. trav. chim.*, 51, 469 (1932).
- (62) Ralston, "Fatty Acids and Their Derivatives," pp. 913-914, John Wiley and Sons, Inc., New York, 1948.
- (63) Redlich, et. al., *J. Am. Chem. Soc.*, 72, 4153 (1950).
- (64) Redlich, et. al., *ibid.*, 72, 4161 (1950).
- (65) Ritter and Minieri, *ibid.*, 70, 4045 (1948).
- (66) Rossner and Cotton (to Farbwerke vorm. Meister Lucius und Bruning), U. S. 988,032 (1911), via C. A., 5, 2000.
- (67) Schiessler and Flitter, *J. Am. Chem. Soc.*, 74, 1720 (1952).
- (68) Schlenk, *Ann.*, 565, 204 (1949).
- (69) Short, *J. Chem. Soc.*, 1928, 528; Short and Stewart, *ibid.*, 1929, 553.
- (70) Smith, *J. Am. Chem. Soc.*, 55, 849, 3718 (1933); *ibid.*, 56, 717 (1934).
- (71) Smith, *J. Chem. Phys.*, 18, 150 (1950).
- (72) Sowa, Nieuwland, and Hinton, *J. Am. Chem. Soc.*, 54, 2019 (1932); *ibid.*, 55, 3402 (1933).
- (73) Strache and Iritzer, *Monatsh.*, 14, 33 (1893), via ref. 62, p. 309.
- (74) Tarbell and Petropoulos, *J. Am. Chem. Soc.*, 74, 244 (1952).
- (75) Thiesing, *J. prakt. Chem.*, (2) 44, 570 (1891).
- (76) Wagner, Goldstein, and Peters, *Anal. Chem.*, 19, 103 (1947).
- (77) Walker (to du Pont), U. S. 2,478,989 (1949), via C. A., 44, 2012.
- (78) Wallingford, Homeyer, and Jones, *J. Am. Chem. Soc.*, 63, 2056 (1941).
- (79) Wallingford, Homeyer, and Jones, *ibid.*, 63, 2252 (1941).
- (80) Wallingford, Homeyer, and Jones, *ibid.*, 64, 576 (1942).
- (81) Wallingford and Jones, *ibid.*, 64, 578 (1942).
- (82) Wallingford, Thorpe, and Homeyer, *ibid.*, 64, 580 (1942).

- (83) Wegler and Ballauf, Ber., 81, 527 (1948).
- (84) Wheeler and Riemenschneider, Oil and Soap, 16, 207 (1939),
via ref. 62, p. 500.
- (85) Zimmerschied, et. al., J. Am. Chem. Soc., 71, 2947 (1949).
- (86) Zimmerschied, et. al., Ind. Eng. Chem., 42, 1300 (1950).

VITA

Otto Sturzenegger
candidate for the degree of
Doctor of Philosophy

Thesis: EXTENSIONS OF THE PRINS REACTION

Major: Organic Chemistry
Minor: Physical Chemistry, Economics

Biographical and Other Items:

Born: February 27, 1926, at Zurich, Switzerland.
Undergraduate Study: Federal Institute of Technology,
Zurich, Switzerland, 1944-1948; B. S. degree, 1948.
Graduate Study: O.A.M.C., 1948-1952; M. S. degree, 1950.

Scholarship, 1948-1949, Teaching Fellowship in Chemistry
Department, O.A.M.C., 1949-1952; member of the American
Chemical Society, Phi Lambda Upsilon, Phi Kappa Phi,
and associate member of The Society of the Sigma Xi.

Date of Final Examination: September 9, 1952.

THESIS TITLE: EXTENSIONS OF THE PRINS REACTION

AUTHOR: OTTO STURZENEGGER

THESIS ADVISER: DR. H. P. JOHNSTON

The content and form have been checked and approved by the author and thesis adviser. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

TYPIST: Elizabeth J. Kerby
 KERBY TYPING SERVICE