3845

NATIONAL LIBRARY

OTTAWA

BIBLIOTHÈQUE NATIONALE

OTTAWA

NAME OF AUTHOR..JOSEPH A. GROVER.....

TITLE OF THESIS..THE REACTIONS OF.....
BENZHYDRYL 2,6-DIMETHYL-
BENZENESULFINATE.....

UNIVERSITY..UNIV. OF ALTA.....

DEGREE..PH.D.....YEAR GRANTED..1969.....

Permission is hereby granted to THE NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

(Signed) Joseph A. Grover

PERMANENT ADDRESS:

c/o Frank Grover
R#2
Alma, Mich U.S.A.

DATED Mar. 11 1969

NL-91

THE UNIVERSITY OF ALBERTA

THE REACTIONS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE

by

© JOSEPH A. GROVER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF CHEMISTRY

EDMONTON, ALBERTA

SPRING, 1969

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Reactions of Benzhydryl 2,6-Dimethylbenzenesulfinate" submitted by Joseph A. Grover in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

David Darwish
Supervisor

Karl R. Kopecky

W. Allen

John Hooz

Cyril M. Kay

Ted Sorensen
External Examiner

Date March 10, 1969

ABSTRACT

The reactions of benzhydryl 2,6-dimethylbenzenesulfinate in a variety of hydroxylic solvents have been examined. In the solvents used the arenesulfinate ester undergoes isomerization to benzhydryl 2,6-dimethylphenyl sulfone as well as giving rise to normal solvolysis products. Isotopic labeling of the sulfonyl oxygen position of the arenesulfinate allowed the determination of rate constants for oxygen scrambling and ionization. The effects of changes in solvent were consistent with an ionization mechanism.

The addition of tetrabutylammonium 2,6-dimethylbenzenesulfinate resulted in no common ion rate depression. Furthermore, this addition did not affect the product distribution observed. There was no increase in the rate constant for formation of sulfone nor was there an increase in the fraction of sulfone formed. No benzhydryl 4-methylphenyl sulfone was formed when the 2,6-dimethylbenzenesulfinate ester was allowed to solvolyze in ethanol in the presence of added tetrabutylammonium 4-methylbenzenesulfinate. The results obtained are consistent with the existence of ion pair species as the important intermediates in the isomerization reaction.

The effects of added tetrabutylammonium azide upon the reactions were also investigated and were compared to the effects of this salt upon the solvolysis of benzhydryl chloride. The data

collected indicate that at least two ion pair species are important in the reactions of the ester in ethanol and aqueous ethanol. It was shown that the solvolysis reaction, as well as the isomerization and scrambling reactions, proceeded through ion pair intermediates.

A mechanism is proposed to account for the reactions of benzhydryl 2,6-dimethylbenzenesulfinate.

To Shima

ACKNOWLEDGEMENTS

The author wishes to express his gratitude and appreciation:

To Dr. D. Darwish without whose constant assistance, guidance and encouragement this work could not have been completed.

To G. Tourigny, L. Green, R. Tomilson, A. Po, M. A. Armour and C. Scott for helpful discussion and occasional supply of gift chemicals.

To Mr. R. N. Swindlehurst and Mr. J. Hoyle for measurement of infrared and nuclear magnetic resonance spectra.

To Mr. J. Olekszyk for measurement of mass spectra.

To the Department of Chemistry and the National Research Council of Canada for generous financial support.

To Canada and Canadians for making his stay in this country a most pleasant one which will always be remembered.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The description of organic chemical reactions which proceed through carbonium ion intermediates has undergone a great deal of change since the early work of Ingold and his collaborators. Originally Scheme I was used for the discussion of ionic intermed-

$$RX \rightleftharpoons R^+ + X^- \xrightarrow[k_s]{SOH} ROS + H^+ + X^-$$

SCHEME I

iates in solvolytic chemical reactions. This scheme describes the reaction of the substrate as a heterolysis to produce a free carbonium ion and a negative ion. The dissociated, or free, carbonium ion is the only species which is shown as being capable of chemical reaction.

It was observed that solvolysis of optically active starting material gave rise in some cases to products of partially inverted configuration rather than to a racemic mixture of products.[9] Hammett suggested[10] that this phenomenon could be interpreted as being due to the intervention of ion pairs as intermediates. It remained, however, for Winstein and co-workers in the early 1950's to provide the first conclusive evidence for the presence of ion pair species as intermediates in solvolysis reactions.[1]

One of the systems studied by Winstein et al. was exo-norbornyl p-bromobenzenesulfonate.[2] Optically active exo-norbornyl

INTRODUCTION

The description of organic chemical reactions which proceed through carbonium ion intermediates has undergone a great deal of change since the early work of Ingold and his collaborators. Originally Scheme I was used for the discussion of ionic intermed-

$$RX \rightleftharpoons R^+ + X^- \xrightarrow[k_s]{SOH} ROS + H^+ + X^-$$

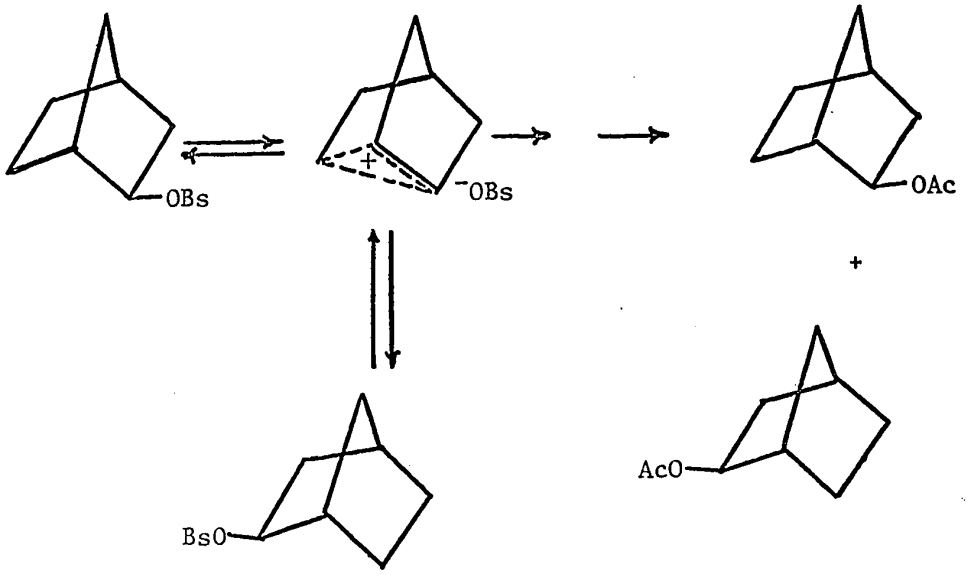
SCHEME I

iates in solvolytic chemical reactions. This scheme describes the reaction of the substrate as a heterolysis to produce a free carbonium ion and a negative ion. The dissociated, or free, carbonium ion is the only species which is shown as being capable of chemical reaction.

It was observed that solvolysis of optically active starting material gave rise in some cases to products of partially inverted configuration rather than to a racemic mixture of products.[9] Hammett suggested[10] that this phenomenon could be interpreted as being due to the intervention of ion pairs as intermediates. It remained, however, for Winstein and co-workers in the early 1950's to provide the first conclusive evidence for the presence of ion pair species as intermediates in solvolysis reactions.[1]

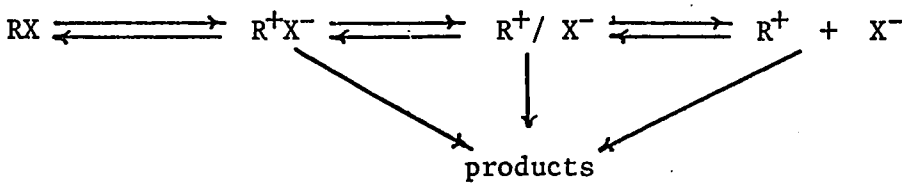
One of the systems studied by Winstein et al. was exo-norbornyl p-bromobenzenesulfonate.[2] Optically active exo-norbornyl

p-bromobenzenesulfonate undergoes acetolysis via a bridged non-classical carbonium ion to give exo-norbornyl acetate which is completely racemic. The fact that the first-order rate constant for loss of optical activity was 3.46 times as great as the titrimetric rate constant for production of solvolysis products was inexplicable using Scheme I. The difference in these rate constants was explained by assuming that ionization of the starting ester produced an ion pair species which could either collapse to give racemic starting material or react with the solvent to give solvolysis products. This reaction sequence is depicted in Scheme II.[6]



SCHEME II

Further studies by Winstein and co-workers led them to propose, for some reactions, an ionization-dissociation scheme which contained two types of ion pair species[3] as shown in Scheme III. In this



SCHEME III

analysis R^+X^- is described as an "intimate ion pair" in which there are no solvent molecules between the ions and the ions are essentially in contact with one another; $R^+/\ X^-$ is an "external or solvent separated ion pair" in which there is one or more than one solvent molecule between the ions, but the ions are still associated; the term, $R^+ + X^-$, represents free ions which are not associated with specific counterions. Products may be represented as arising from either of the ion pair species as well as from free ions.

Justification for postulating the presence of two ion pair species may be described in relation to the acetolysis of threo-3-p-anisyl-2-butyl p-bromobenzenesulfonate.[4] Acetolysis of this compound proceeds by ionization with anchimeric assistance of the p-anisyl group to give a symmetrical bridged carbonium ion. Solvolysis of the optically active threo compound resulted in the formation of completely racemic threo acetate. The rate of loss

of optical activity was 4.07 times greater than the rate of formation of solvolysis products.

The effect of added lithium perchlorate upon the acetolysis reaction was most enlightening. It was found that a modest increase in the rate of loss of optical activity accompanied the addition of lithium perchlorate to the reaction solution. In addition, the magnitude of the increase in the polarimetric rate constant was directly proportional to the amount of lithium perchlorate added. This is the normal salt effect[5] and is shown graphically in Figure I. However, the effect of added lithium perchlorate upon the solvolysis rate constant was very different from its effect upon the polarimetric rate constant; this comparison is made in Figure I. Very low concentrations of added lithium perchlorate resulted in relatively large increases in the solvolysis rate constant. As the concentration of lithium perchlorate was increased this abnormal effect of the salt reached a maximum and the normal salt effect of lithium perchlorate was observed. The abnormal effect of the added lithium perchlorate is termed the "special salt effect"[5] and is explained as being the result of an exchange reaction between the salt and one of the ion pair species, the solvent separated ion pair.

Since the special salt effect is observed only on the solvolysis rate constant, the effect cannot be on the ionization of the starting material, the rate of which is measured by the polarimetric rate constant. The effect must be due, therefore, to interaction of the added salt with an ionized species. Extrapolation

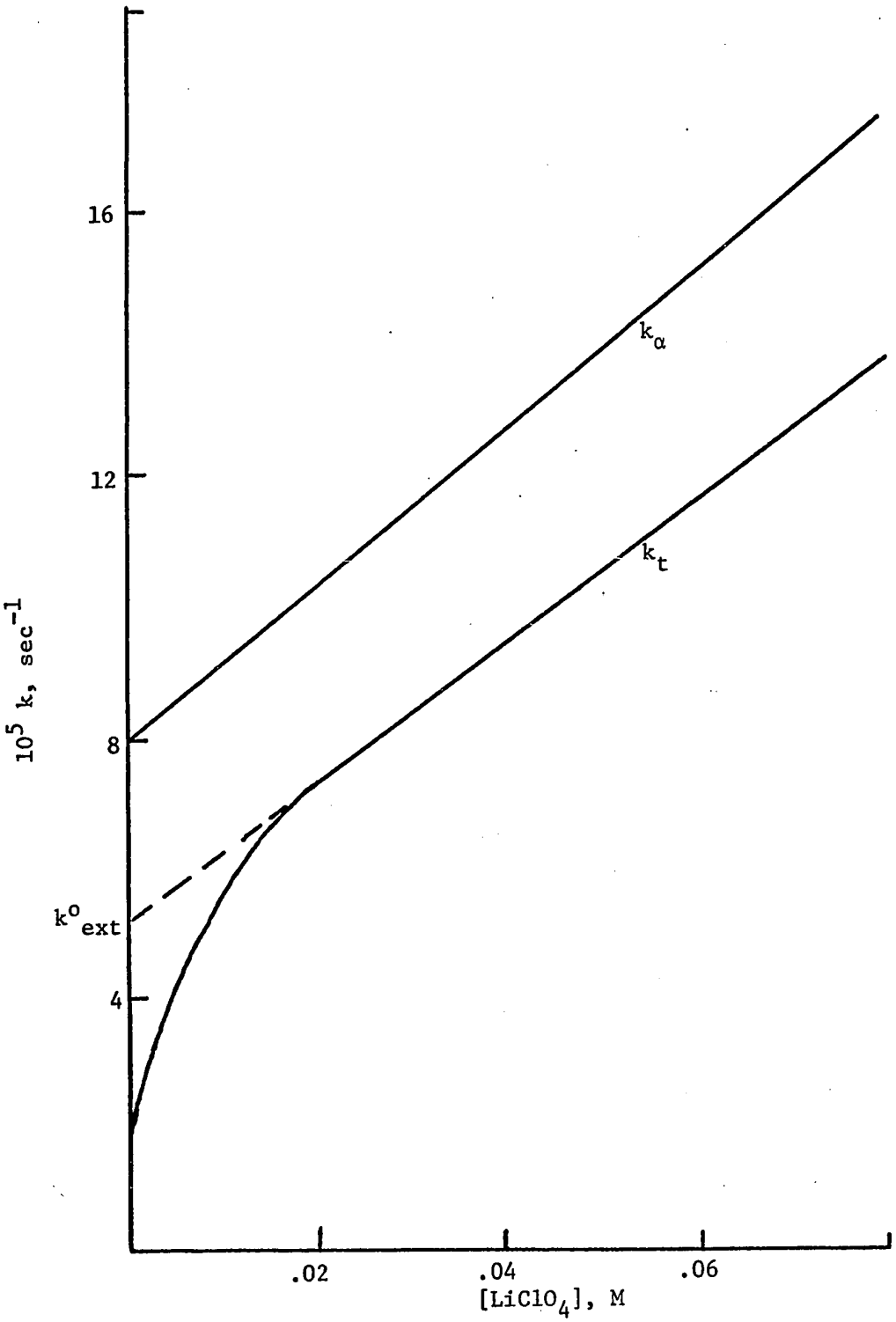
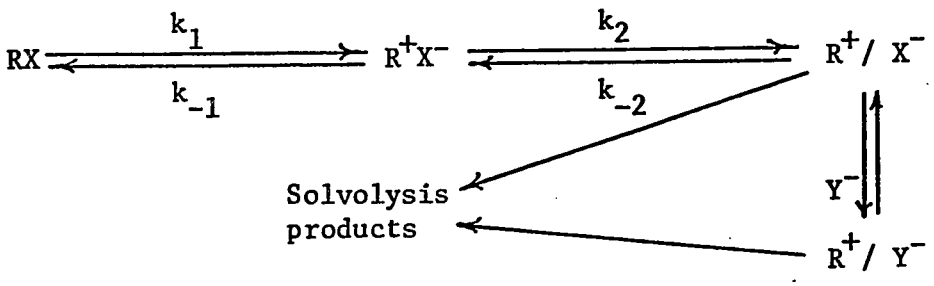


Figure I. Effect of lithium perchlorate on acetolysis of threo-3-p-anisyl-2-butyl p-bromobenzenesulfonate at 25° [taken from S. Winstein and G. C. Robinson, J. Am. Chem. Soc., 80, 169 (1958)].

of the normal salt effect curve for the titrimetric rate constant to zero salt concentration gives the intercept, k^{o}_{ext}, the difference between this value and k^{o}_{t} being the amount of acceleration in rate due to the special salt effect. In the case of threo-3-p-anisyl-2-butyl p-bromobenzenesulfonate, k^{o}_{ext} is 2.6 times greater than k^{o}_{t}.

If no ion pair return existed in the system the polarimetric and titrimetric rate constants would be equal. This is, in fact, never observed; even when the full special salt effect has taken place the polarimetric rate constant is greater than the titrimetric rate constant. Thus the added salt eliminates some, but not all, of the ion pair return. The analysis by these workers was that return from the solvent separated ion pair was eliminated by exchange of the added anion with the anion of the solvent separated ion pair to give a carbonium perchlorate ion pair which solvolyzed rapidly. As the concentration of the added anion is increased the solvent separated ion pair is increasingly diverted to give solvolysis products at the expense of return to the intimate ion pair and to covalent starting material. The suggested mechanism of the special salt effect is shown in Scheme IV.[6] A thorough analysis and review of the role of ion pairs in solvolysis reactions was published in 1964.[6]

Only a limited number of systems may be examined in the manner described above. These methods are applicable only to compounds which on ionization result in rearrangement, bridged ions or non-classical ions. These types of compounds allow the determination

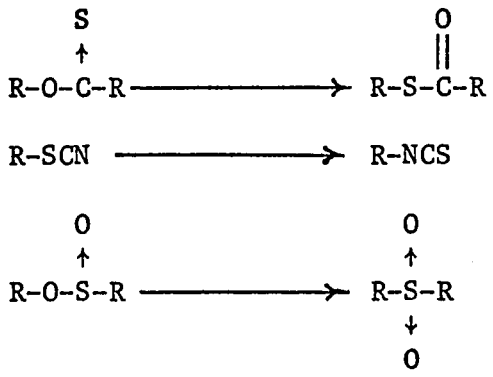


SCHEME IV

of ionization rate constants. The study of open chain systems by these methods is not possible. Even if the incipient cation center is a center of asymmetry there is no guarantee that the rate of ionization is measured by the rate of loss of optical activity. Stereoselective return from an asymmetric ion pair is possible and thus the rate of loss of optical activity is a minimum estimate of the ionization rate constant. Important studies involving open chain compounds which provide evidence for the intermediacy of ion pairs in solvolysis reactions include the solvolysis, racemization and isotopic halide exchange of p-chlorobenzhydryl chloride as reported by Winstein et al.,[7, 33, 34, 35] and Goering and Levy's work on the solvolysis, racemization and ^{18}O scrambling reactions of p-chlorobenzhydryl p-nitrobenzoate-carbonyl-^{18}O in 80% aqueous acetone. Goering and Levy[8] found that addition of sodium azide eliminated racemization but permitted scrambling of the isotopic label to take place on solvolysis of this p-nitrobenzoate. They interpreted these results to indicate that sodium azide must completely eliminate

return from an ionic species which would otherwise return to give scrambled and racemized p-nitrobenzoate but cannot intercept an ionic species (probably an intimate ion pair) which undergoes return to give scrambled but unracemized p-nitrobenzoate.

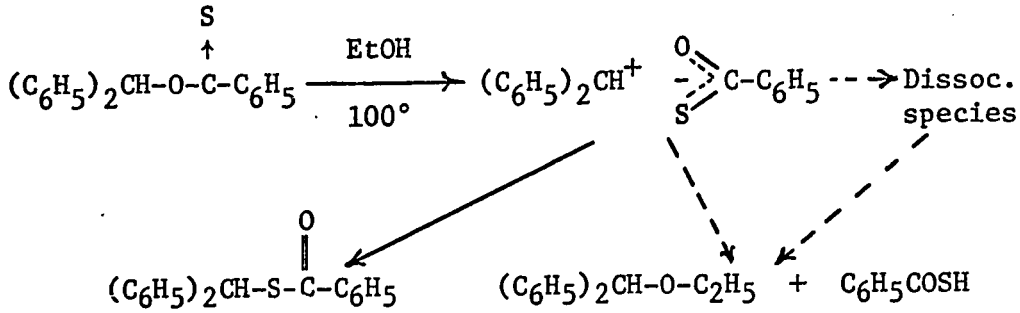
In addition to the use of optically active compounds and isotopic labeling to determine ion and ion pair return in solvolyzing compounds another tool may be used, that of isomerization. There exist various compounds such as thion esters, thiocyanates and sulfinates which can isomerize to give respectively thiol esters, isothiocyanates and sulfones. These isomerization



products are more stable to the reaction conditions employed than are the starting materials and thus provide a ready method of determining the effects of changes in solvent and added nucleophiles upon the solvolysis and rearrangement reactions.

Smith[11] studied the isomerization of benzhydryl thionbenzoate to the corresponding thiolbenzoate. In solvent ethanol the isomerization rates of substituted benzhydryl thionbenzoates are correlated by the $\rho\sigma^+$ relationship. A ρ value of -3.6 was found which is a normal value for an ionization reaction and

would be expected for the solvolysis of benzhydryl compounds in an ionizing solvent. When the reaction is carried out in the presence of added potassium p-methoxythiobenzoate the recovered thiolbenzoate is exclusively the unsubstituted thiolbenzoate, thus showing that no exchange occurs and that thiolbenzoate formation proceeds through an intermediate, probably an ion pair, which cannot be intercepted. The ethanolysis of benzhydryl thionbenzoate results in the production of 83% benzhydryl thiolbenzoate and 17% benzhydryl ethyl ether, so that a minimum of 83% of the reaction is proceeding through ion pairs. No information could be ascertained as to whether more than one ion pair species is involved. Also it cannot be said whether solvolysis products arise directly from the ion pair, from further dissociated species or from both.



$(C_6H_5)_2CH\text{-}O\text{-}C\text{-}C_6H_5$ → $(C_6H_5)_2CH^+$ $C\text{-}C_6H_5$ --→ Dissoc. species

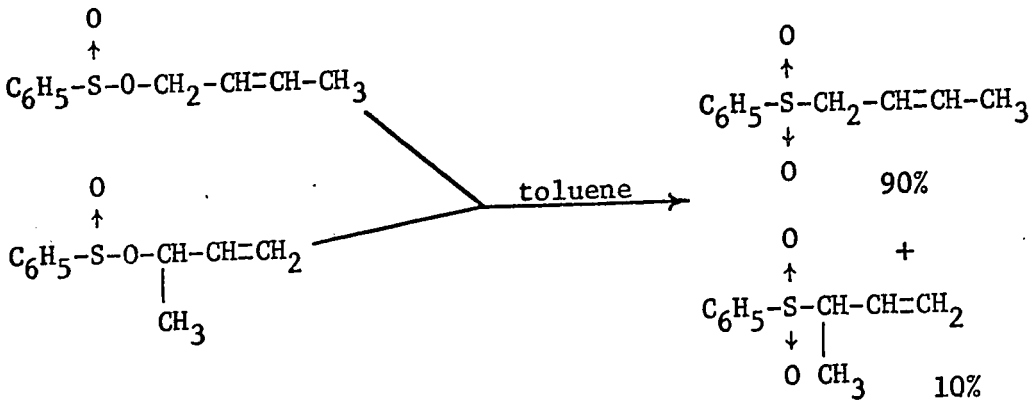
$(C_6H_5)_2CH\text{-}S\text{-}C\text{-}C_6H_5$ $(C_6H_5)_2CH\text{-}O\text{-}C_2H_5$ + C_6H_5COSH

The isomerization of benzhydryl thiocyanate to benzhydryl isothiocyanate was studied by Iliceto *et al.* in the solvents methyl ethyl ketone, acetonitrile and benzene.[12] For substituted benzhydryl compounds a ρ value of -3.4 was found using the $\rho\sigma^+$ relationship. Salt effects were also normal for an ionization reaction. Addition of thiocyanate ion labeled with ^{35}S resulted

in some isotope exchange, but the isomerization rate was substantially faster than the exchange rate. An ion pair was proposed to account for this behavior, but the question of the possibility of more than one type of ion pair species could not be resolved.

Arenesulfinate esters can conceivably undergo various reactions under solvolytic conditions. These include isomerization to sulfone by a non-ionizing intramolecular pathway,[15] carbon-oxygen bond fission to give solvolysis and/or isomerization to sulfone by an ionic pathway[16,17, 18, 19, 20] and sulfur-oxygen bond fission to give solvolysis. Prior work reported in the literature and discussed briefly below indicated that ion pairs might be important in reactions of arenesulfinate esters.

Cope, Morrison and Field[13] studied the reactions of crotyl and α-methylallyl benzenesulfinates in toluene. Both of these compounds isomerized at elevated temperatures in concentrated solution and were reported to give identical mixtures consisting of about 90% crotyl phenyl sulfone and 10% α-methylallyl phenyl sulfone.



These results were inconclusive with regard to defining a

mechanism. Proposed routes for the reaction were (a) an intramolecular isomerization to sulfone followed by a rearrangement of the allylic side chain, (b) interconversion and equilibration of the esters followed by rearrangement to sulfone, (c) an ionic route giving an identical resonance stabilized cation from both esters which would yield identical mixtures or (d) a combination of these proposed routes.

Kenyon and co-workers[22, 23, 24] reported on the reactions of optically active α-phenylethyl p-toluenesulfinate. If-(-) α-phenylethyl p-toluenesulfinate is left at room temperature for several days some racemic α-phenylethyl p-tolyl sulfone is formed.[22] Acetolysis of the optically active ester gives rise to the formation of racemic α-phenylethyl acetate and racemic α-phenylethyl p-tolyl sulfone.[23] Ethanolysis, however, resulted in somewhat different behavior. Solvolysis of the (-) ester in ethyl alcohol gave the ethyl ether with some partial inversion of configuration. However, in alcohol containing potassium carbonate the corresponding alcohol was obtained with complete retention of configuration. This evidence indicated that with no added potassium carbonate solvolysis resulted in carbon-oxygen bond fission, while in the presence of the added base sulfur-oxygen bond fission took place to give alcohol of completely retained configuration. This behavior is also observed in the ethanolysis of the optically active p-toluenesulfinate ester of 3-hydroxy-3-phenyl propionate.[25]

Kenyon and co-workers subsequently reported[24] that formolysis of (-)- α-phenylethyl p-toluenesulfinate resulted in the formation

of α-phenylethyl p-tolyl sulfone which was racemic. This sulfone accounted for 60% of the starting ester. Formolysis of the ester in the presence of sodium formate resulted in the formation of sulfone which was 63% of retained configuration. This sulfone accounted for 10% of the starting material. It was proposed that d,l-sulfone was formed by an ionic mechanism while retained sulfone was formed by a non-ionic rearrangement. Streitwieser later suggested[26] that the results could be interpreted as arising via an ion pair intermediate, sulfone of retained configuration arising by return from an asymmetric ion pair.

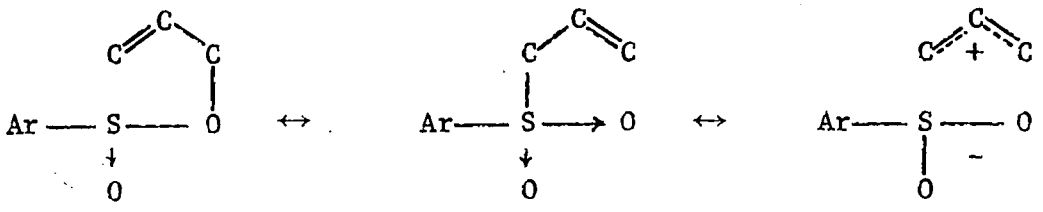
Wragg, McFadyen and Stevens[27] studied the reactions of various arenesulfinates in solvents which included acetic acid-hydrochloric acid, nitromethane and acetonitrile. The relative reactivities of the esters were consistent with an ionization mechanism. Further evidence that the reactions were ionic in nature was provided by the production of some benzhydryl p-chlorophenyl sulfone from the solvolysis of benzhydryl p-toluenesulfinate in acetic acid-hydrochloric acid with added p-chlorosulfinic acid. It should be noted that since these reactions were carried out in acidic media the product determinations given may not be the result of kinetic control in the reaction. Since the formation of some of the products (sulfone formed would be stable) may be reversible under these conditions the thermodynamically most stable product mixture may be obtained.

Recently a study of a series of alkyl arenesulfinates in these laboratories has resulted in the expansion of information available

concerning the solvolysis and isomerization of arenesulfinate esters. This thesis is a continuation of those studies.

Darwish and Noreyko[21] studied the solvolysis of a series of p-methoxyneophyl arenesulfinates in ethanol and aqueous ethanol. These arenesulfinate esters were all esters of a primary alcohol. In all cases extensive sulfur-oxygen bond fission was found which resulted in the formation of p-methoxyneophyl alcohol and ethyl arenesulfinate. The strength of the base used in the reaction affected the rate of reaction. As would be expected the rates followed the order ethoxide > acetate > 2,6-lutidine.

Braverman[15] examined the isomerization of allyl, crotyl, α-methylallyl, α,γ-dimethylallyl, cinnamyl and α-phenylallyl 2,6-dimethylbenzenesulfinates in acetic acid and in 60% ethanol. Sulfur-oxygen bond fission did not take place with these compounds. It was found that simultaneous allylic and sulfinate to sulfone rearrangements took place. The transition state for the reaction was pictured in terms of the resonance structures below.



A B C

The importance of resonance structure C, it was suggested, would depend upon the substituents attached to the allyl moiety. Alkyl or aryl substituents in the place of hydrogen atoms would

increase the importance of this resonance structure. Better ionizing solvents would also enhance the importance of this resonance structure. With the unsubstituted and α and γ methyl substituted allyl compounds studied, the contribution of resonance structure C was proposed to be low.

McLaren[17] studied the solvolysis and isomerization of α-phenylethyl and α-(p-methoxyphenyl)ethyl 2,6-dimethylbenzenesulfinates in ethanol and 60% ethanol. In 60% ethanol optically active α-phenylethyl 2,6-dimethylbenzenesulfinate gave 12% of optically active α-phenylethyl 2,6-dimethylphenyl sulfone which was 95% of retained configuration. Goering and Levy[8] had shown that in the solvolysis of p-chlorobenzhydryl p-nitrobenzoate-carbonyl-^{18}O in 80% acetone an intimate ion pair species gave rise to return without loss of optical activity while return from further dissociated species resulted in racemization. McLaren's results by analogy to this work by Goering suggest that an intimate ion pair is the important intermediate for the production of sulfone from α-phenylethyl 2,6-dimethylbenzenesulfinate.

The solvolysis of α-(p-methoxyphenyl)ethyl 2,6-dimethylbenzenesulfinate with added sodium azide showed that the solvolysis reaction was more sensitive to the addition of azide ion than was the isomerization reaction. A greater proportion of solvolysis than of rearrangement products was diverted to give α-(p-methoxyphenyl)ethyl azide on addition of azide ion.

Mermelstein[18] studied a variety of phenyl substituted 2-phenyl-2-propyl 2,6-dimethylbenzenesulfinates. These compounds underwent

solvolysis and isomerization in solvents acetic acid, ethanol and aqueous ethanol at relative rates which were consistent with an ionic process for both solvolysis and isomerization reactions. In addition the effects of added salts upon the reaction rates were consistent with an ionization mechanism. Addition of 2,6-dimethylbenzenesulfinate anion resulted in neither common ion rate depression nor in a change in the fraction of the reaction which produced sulfone, indicating that sulfone was produced from an ion pair species.

Darwish and Preston reported[20] that trityl 2-methylbenzenesulfinate undergoes reaction in carbon tetrachloride, chloroform, acetonitrile, nitrobenzene and dimethylsulfoxide to give entirely the corresponding sulfone. The effects of these solvents upon the rearrangement rate of the ester were consistent with an ionic reaction. The effect of added azide ion gave dramatic evidence for the existence of two ionic species, one trappable (dissociated ions, a solvent separated ion pair or both) and one non-trappable (an intimate ion pair). The effect of added azide is shown in Table I.

The relative insensitivity of the amount of trityl azide formed to the concentration of tetrabutylammonium azide in solution suggests that approximately 55% of the rearrangement in the absence of tetrabutylammonium azide takes place through an intimate ion pair and that about 45% takes place through a further dissociated species.

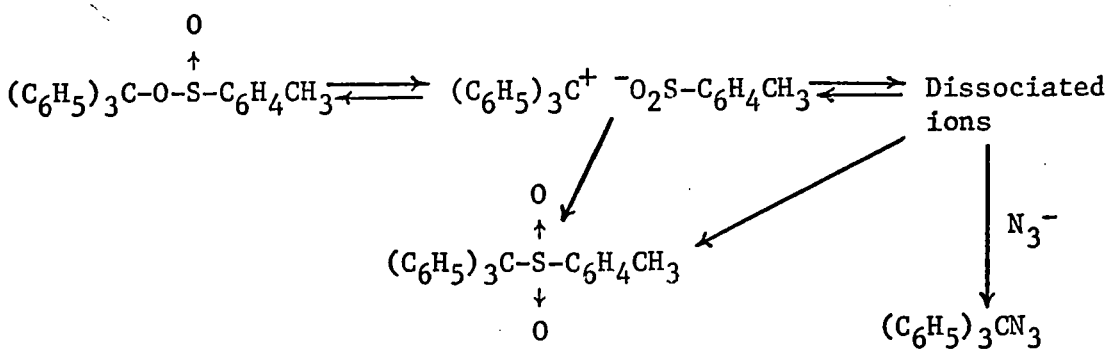
Persad[19] examined further the rearrangement of trityl 2-methylbenzenesulfinate and utilized, as a model compound, trityl

TABLE I[20]

EFFECT OF TETRABUTYLAMMONIUM AZIDE ON THE REARRANGEMENT OF TRITYL 2-METHYLBENZENESULFINATE IN ACETONITRILE AT ROOM TEMPERATURE.

[Ester], molar	$[Bu_4NN_3]$, molar	10^3 k; sec^{-1}	Fraction azide
0.0260	0.010	1.1 ± 0.1	0.33
0.0260	0.026	1.1 ± 0.1	0.36
0.0260	0.051	0.91 ± 0.05	0.42
0.0264	0.230	ca. 1.0	ca. 0.45

2,6-dimethylbenzenesulfinate. The isomerization of this ester to sulfone does not take place. Apparently steric considerations make this reaction impossible. Persad showed that the reaction of trityl 2,6-dimethylbenzenesulfinate with added tetrabutylammonium azide in acetonitrile was subject to common ion rate depression and concluded, assuming the 2-substituted and the 2,6-disubstituted esters undergo similar ionization and dissociation patterns, that the trappable species in the reaction of trityl 2-methylbenzenesulfinate in acetonitrile is the free trityl cation. The proposed mechanism for the isomerization of trityl 2-methylbenzenesulfinate was as follows.



The research covered in this thesis was prompted by the results of Darwish and McLaren[16]. These authors reported on the reactions of several 2,6-dimethylbenzenesulfinate esters including benzhydryl 2,6-dimethylbenzenesulfinate. Solvolysis of this compound in aqueous dioxane, aqueous acetone, ethanol, aqueous ethanol and acetic acid (all with added base to neutralize the acid produced on solvolysis) showed that the isomerization and solvolysis reactions of this compound were ionic in nature. In addition the fraction of sulfone formed remained constant throughout a run and the addition of lutidinium 2,6-dimethylbenzenesulfinate had no significant effect on the amount of sulfone formed. This was taken to indicate that sulfone was not produced from free ions.

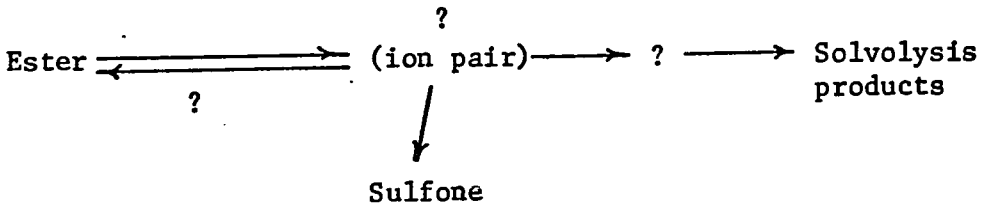
Several points of interest arose from this study. It was not demonstrated whether or not more than one type of ion pair was precursor to sulfone. It was not shown whether solvolysis products arose directly from the ion pair species or whether dissociated ions were important in the solvolysis reaction. Since it was not known whether return from ionic species to regenerate the starting material took place, neither the fraction of ion pairs returning to give sulfone nor the ionization rate for the reaction could be calculated. It was with these questions in mind that a detailed determination of the mechanism of the solvolysis and isomerization of benzhydryl 2,6-dimethylbenzenesulfinate was undertaken.

CHAPTER I

Ionization and Ion Pair Return in the Solvolysis of Benzhydryl 2,6-Dimethylbenzenesulfinate

INTRODUCTION

On solvolysis in ionizing solvents certain arenesulfinate esters have been shown to undergo isomerization to sulfone by an ionization-recombination process.[16, 18, 17, 39] Benzhydryl 2,6-dimethylbenzenesulfinate undergoes isomerization and solvolysis in ethanol to benzhydryl 2,6-dimethylphenyl sulfone and benzhydryl ethyl ether by a process which involves ionization.[16] The isomerization was shown not to involve free ions. It must therefore proceed through some ion pair intermediate or intermediates. This intermediate must in addition give rise to solvolysis products either directly or through dissociation to a species which is more readily capturable by the solvent. The following scheme describes graphically the questions which existed concerning the reactions of benzhydryl 2,6-dimethylbenzenesulfinate. It was not known



whether return from the ion pair to give starting ester takes place. It was not known whether solvolysis products arise directly from the ion pair species or whether dissociation to another ionic

intermediate which is captured by the solvent takes place. In addition the identity of the ion pair species was not known; it could either be an intimate ion pair or a solvent separated ion pair or both of these species could be important intermediates. The research reported here was undertaken to determine what intermediates are formed and the roles of these intermediates with respect to solvolysis, isomerization and return to ester.

Although it might be assumed that return to oxygen takes place after ionization of benzhydryl 2,6-dimethylbenzenesulfinate, this recombination had not been experimentally demonstrated. If this reaction did take place it should be detectable by either of two methods. The arenesulfinate ester has an asymmetric sulfur atom and could be resolved; alternatively the ester might be labeled at one oxygen position with oxygen isotope eighteen. After partial reaction the remaining ester could be examined. Loss of optical activity or scrambling of the isotopic label would indicate that return to oxygen does take place.

At the time this work was initiated no facile method of resolution of arenesulfinate esters had been demonstrated. It was therefore thought that isotopic labeling would provide the most convenient method of determining whether return to oxygen from an ionic species does take place. Accordingly this method was investigated during the course of this work and the results are reported here.

RESULTS

Preparation of reagents.

2,6-Dimethylbenzenesulfinic acid was prepared according to the procedure of Hanke[14] involving the diazotization of 2,6-dimethylaniline and reaction of the diazonium salt with sulfur dioxide in the presence of finely divided copper.

The sulfinic acid, when treated with thionyl chloride, yielded the acid chloride. The acid chloride was not characterized but was treated with benzhydryl alcohol in pyridine which resulted in the formation of benzhydryl 2,6-dimethylbenzensulfinate.

Tetrabutylammonium salts were prepared by the addition of the appropriate acid to an aqueous solution of tetrabutylammonium hydroxide which was prepared from tetrabutylammonium bromide. With the exception of the perchlorate and bromide salts, these compounds were very hygroscopic.

Preparation of reaction products.

Benzhydryl 2,6-dimethylphenyl sulfone was prepared in good yield by the treatment of 2,6-dimethylbenzenesulfinic acid in formic acid containing sodium formate with benzhydryl alcohol. Benzhydryl phenyl sulfone and benzhydryl 4-methylphenyl sulfone were prepared in analogous manner.[49]

Benzhydryl chloride was treated with excess tetrabutylammonium azide in dry acetone to afford benzhydryl azide.

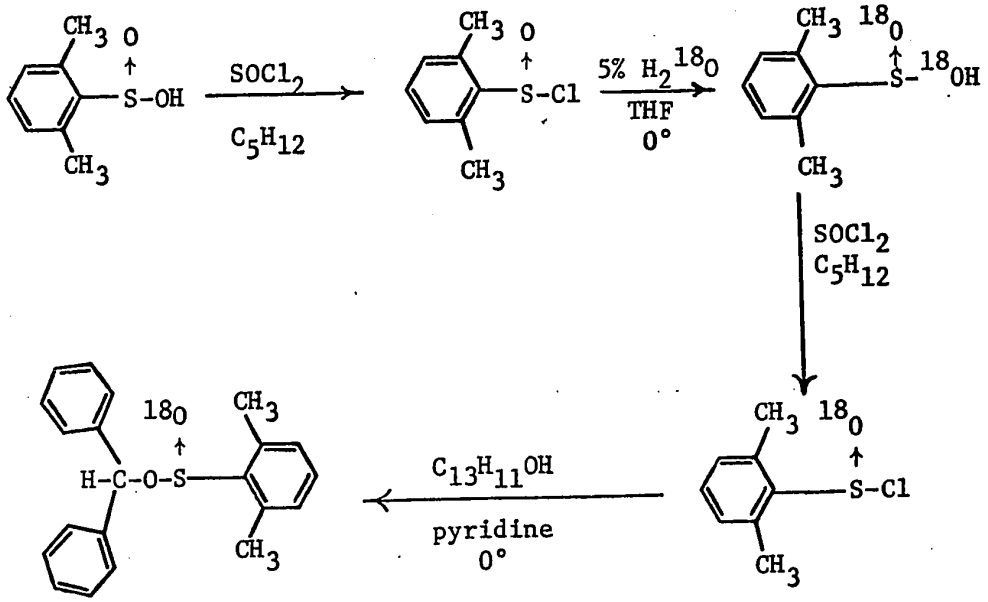
Benzhydryl ethyl ether was prepared by the reaction between benzhydryl alcohol and ethyl alcohol in the presence of hydro-

chloric acid.

Benzhydryl acetate was obtained in good yield from the reaction of benzhydryl alcohol with acetic anhydride in pyridine.

Preparation of Benzhydryl 2,6-Dimethylbenzenesulfinate-Sulfonyl-^{18}O.

The labeled ester was synthesized by preparation of the acid chloride from 2,6-dimethylbenzenesulfinic acid, treatment of the acid chloride with water containing five atom percent excess oxygen isotope eighteen to reform the acid, conversion of the labeled acid to the acid chloride and reaction of the acid chloride with benzhydryl alcohol in pyridine. This synthesis is outlined in Scheme V. Preparations of the labeled ester contained from 1.88 to 2.23 atom percent excess ^{18}O at the sulfonyl oxygen.



SCHEME V

Analysis of ^{18}O-containing Compounds.

A modified Unterzaucher apparatus for the determination of oxygen in organic compounds as described by Oita and Conway[21] was constructed with further modifications as suggested by Denney and Greenbaum.[39] A detailed description of the construction of this apparatus is contained in the Experimental section. The atom percent excess oxygen isotope eighteen present in a compound was determined using this apparatus. The combustion train was continually swept with a stream of purified nitrogen containing 1% hydrogen. A sample of the compound being analyzed was pyrolyzed and the resulting gas and vapors were passed through a platinized carbon packing at 900°C. This resulted in the conversion of all oxygen in the compound into carbon monoxide. The carbon monoxide was oxidized in the gas phase in a heated combustion tube which contained iodine pentoxide. The resulting carbon dioxide was collected and submitted for mass spectrometric analysis.

Combustion of samples for analysis was carried out in triplicate. The atom percent excess oxygen isotope eighteen was calculated using the formulae of Goering.[42]

$$\text{atom \% excess } ^{18}O \text{ in sample} = 100\ (X - 0.00204)$$

$$X = R' / (1 + R')$$

$$R' = [(R_s/R_t)\ 0.00409] - 0.00204$$

where R_s = intensity of mass 46 peak in sample CO_2/ intensity of mass 44 peak in sample CO_2

R_t = intensity of mass 46 peak in tank CO_2/ intensity of mass 44 peak in tank CO_2

The use of these formulae results in the determination of the total atom percent excess oxygen isotope eighteen in the sample molecule. Since benzhydryl 2,6-dimethylbenzenesulfinate-sulfonyl-^{18}O is specifically labeled in the sulfonyl position the value obtained for total atom percent excess oxygen isotope eighteen in a sample of the ester must be multiplied by a factor of 2, the number of oxygen atoms in the molecule, to obtain the value for the atom percent excess oxygen isotope eighteen in the sulfonyl oxygen position.

Methods Used for Kinetic Measurements in the Study of the Reaction of Benzhydryl 2,6-Dimethylbenzenesulfinate in Ethanol and 80% Aqueous Ethanol.

Studies on the solvolysis and isomerization reactions of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol and aqueous ethanol were carried out at 90.0° in the presence of 2,6-lutidine. The lutidinium 2,6-dimethylbenzenesulfinate formed was titrated with standard sodium methoxide solution, and the rate constant for the disappearance of starting ester was calculated from the titers using the equation

$$k = \frac{2.303}{t} \log \frac{(T_\infty - T_o)}{(T_\infty - T_t)}$$

where T_t is the titer at time = t.

The rate constants obtained are determined from observed infinity titers. The total rate of reaction is therefore given

by the rate constants reported. Rates were generally followed to about 80% reaction and first-order kinetics were observed.

In the presence of large amounts of tetrabutylammonium azide it was difficult to obtain good rate constants. Error ranges with greater than 0.1 M added tetrabutylammonium azide were as high as ±10%. Even in the absence of added salts it was difficult to obtain rate constants with an error range less than ±5%. A reasonable explanation for the high error range in the case of runs with added tetrabutylammonium azide is that a buffered solution of hydrazoic acid is being titrated. End points of the titrations were extremely difficult to see.

Rate constants were also determined by an infrared spectrometric method. Each sample was submitted to a standard extraction procedure. The percentage transmittance of the organic products of the reaction in a standard amount of carbon tetrachloride was determined at 1305 cm^{-1} and the absorbance due to benzhydryl 2,6-dimethylphenyl sulfone was calculated. The fist-order rate constant was calculated using the equation

$$k = \frac{2.303}{t} \log \frac{(D_\infty - D_o)}{(D_\infty - D_t)}$$

where D_t is the absorbance at time = t.

When added tetrabutylammonium azide was present in the reaction, the rate constant of the reaction could be determined by following the increase in benzhydryl azide concentration. The amount of benzhydryl azide was determined spectrometrically.

After the standard extraction procedure the transmittance of the solution of the organic products of the reaction in carbon tetrachloride was determined at 2100 cm^{-1}. Rate constants were determined using the same equation as was used in calculating rate constants from the amount of sulfone formed except when the concentration of benzhydryl azide produced reached an ultimate value of 0.9 mg/ml of ethanol or greater. In these cases the absorbance values were converted to concentration values and the rate constant was calculated using the equation

$$k = \frac{2.303}{t} \log \frac{(C_\infty - C_o)}{(C_\infty - C_t)}$$

where C_t is the concentration of benzhydryl azide at time = t.

Controls were carried out to determine whether the Lambert-Beer Law was obeyed for these compounds and to account for any loss of material during the extraction procedure. A series of solutions of the sulfone was prepared. This series corresponded to the concentration range expected for the solvolysis reaction. Aliquots of these solutions were carried through the same extraction procedure as was used for the kinetic points. The transmittance of the carbon tetrachloride solution of the sulfone isolated was determined in the infrared from 1370 to 1265 cm^{-1}. The results of these controls are shown in Table II and Figure II. A linear relationship between sulfone concentration and absorbance was found in the concentration range used.

In a similar manner a control was carried out on benzhydryl

TABLE II

RELATIONSHIP BETWEEN OPTICAL DENSITY AND CONCENTRATION FOR BENZHYDRYL 2,6-DIMETHYLPHENYL SULFONE AS MEASURED IN CARBON TETRACHLORIDE AT 1305 CM^{-1}.

Solution[a]	Sulfone, mg/ml ethanol	I_o/I	log I_o/I
2-133-100	3.351	4.302	.63367
2-133-80	2.682	3.140	.49693
2-133-66	2.234	2.729	.43600
2-133-60	2.011	2.461	.39111
2-133-50	1.675	2.171	.33666
2-133-40	1.341	1.906	.28012
2-133-33	1.117	1.719	.23528
2-133-20	0.670	1.407	.14829

[a]In this and all tables these numbers refer to the notebook numbers, e.g., 2-133-100 is on p. 133 of the second notebook.

TABLE III

RELATIONSHIP BETWEEN OPTICAL DENSITY AND CONCENTRATION FOR BENZHYDRYL AZIDE AS MEASURED IN CARBON TETRACHLORIDE AT 2100 CM^{-1}.

Solution	Azide, mg/ml ethanol	I_o/I	log I_o/I
2-212-100	1.417	3.292	.51746
2-212-90	1.275	3.044	.48344
2-212-75	1.063	2.547	.40603
2-212-60	0.850	2.230	.34830
2-212-50	0.708	1.977	.29601
2-212-40	0.567	1.730	.23805
2-212-30	0.425	1.526	.18355
2-212-20	0.283	1.341	.12743

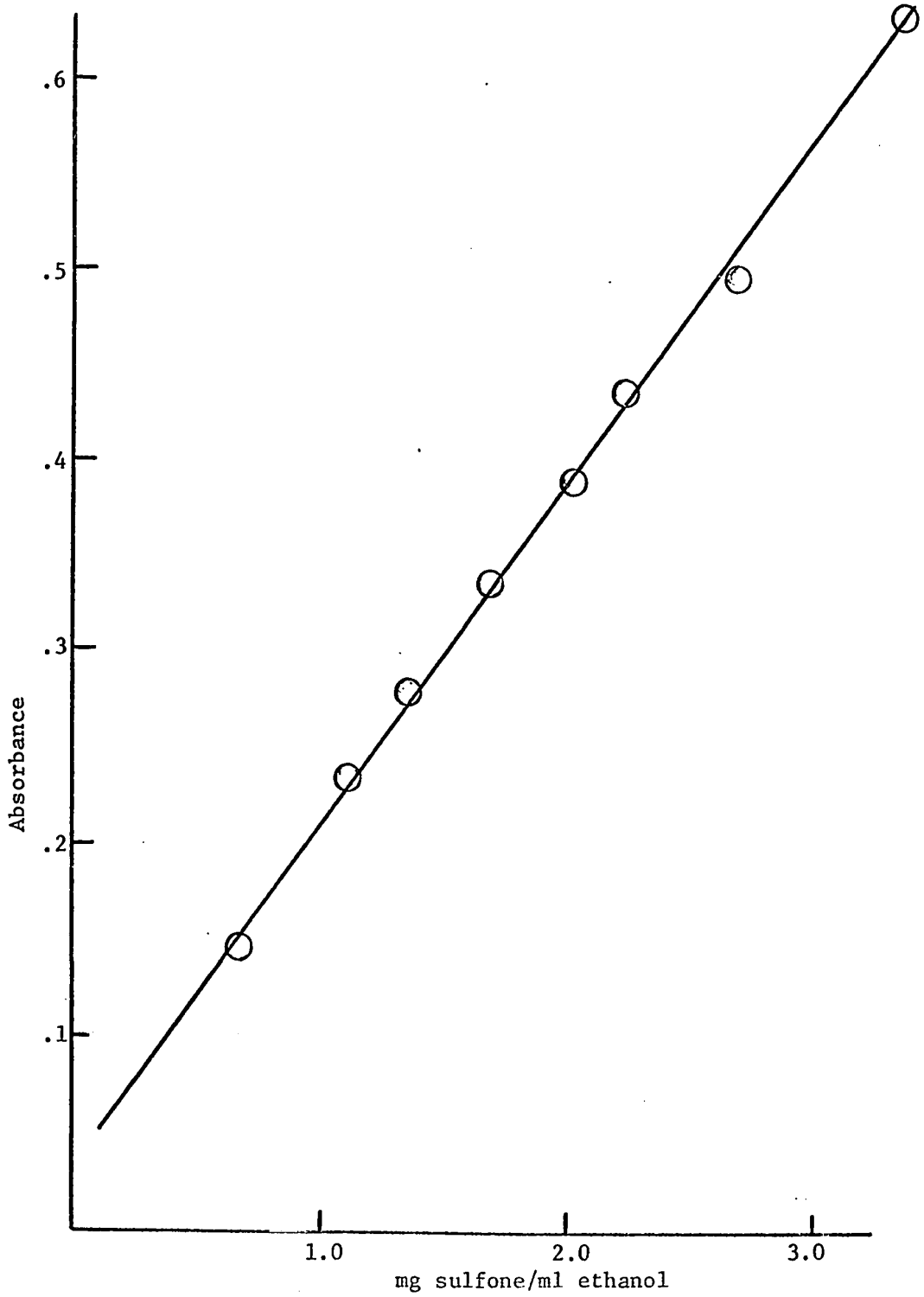


Figure II. Relationship between concentration and absorbance for benzhydryl 2,6-dimethylphenyl sulfone in 1.000 ml of carbon tetrachloride after isolation from ethanol.

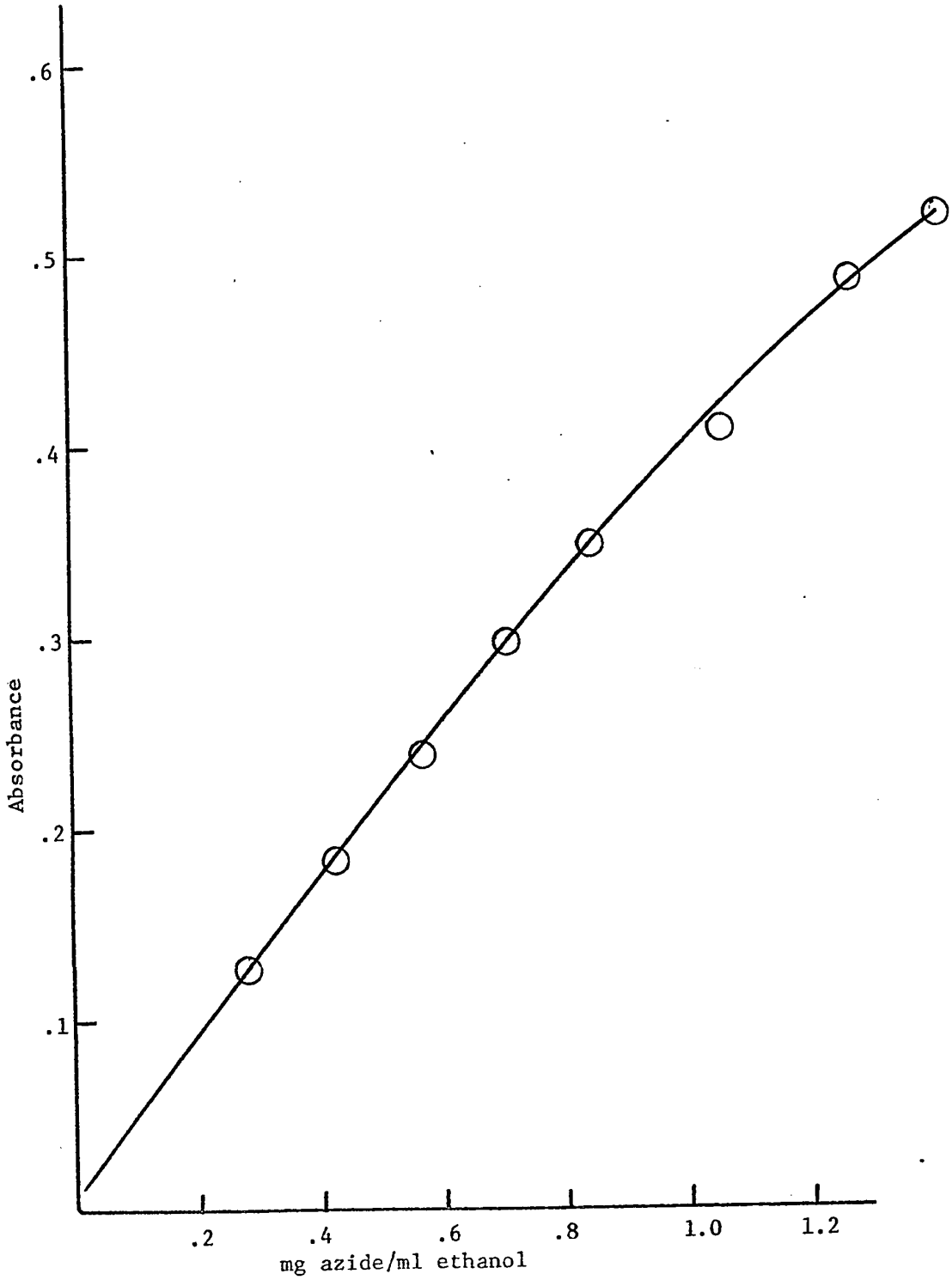


Figure III. Relationship between concentration and absorbance for benzhydryl azide in 1.000 ml of carbon tetrachloride after isolation from ethanol.

azide measuring the absorbance between 2270 and 2000 cm^{-1}. The relationship between optical density and concentration is given in Table III and Figure III. In the case of this compound a linear relationship between concentration and absorbance was found at concentrations of less than 0.9 mg/ ml of ethanol.

In addition to following the rate of reaction titrimetrically and spectrometrically, rate constants for scrambling of the oxygen atoms of benzhydryl 2,6-dimethylbenzenesulfinate specifically labeled in the sulfonyl position with ^{18}O were determined. These rate constants were obtained for the reaction of the ester in anhydrous ethanol.

Solutions of benzhydryl 2,6-dimethylbenzenesulfinate-sulfonyl-^{18}O were prepared and the reaction was allowed to proceed at 90.0° for the desired length of time. After cooling the solutions were subjected to a standard extraction procedure. The organic products of the reaction were then treated with sodium hydroxide in dioxane-water solution. This treatment results in hydrolysis of the ester by sulfur-oxygen bond fission. The alcohol produced contained the oxygen atom which corresponds to the ether oxygen atom in the arenesulfinate ester. The sulfonyl oxygen atom then is present in the sulfinate ion. Thus any incorporation of ^{18}O into the originally unlabeled ether oxygen position would result in the formation of labeled benzhydryl alcohol. The benzhydryl alcohol was separated from the other compounds by solid-liquid chromatography on alumina. The alcohol was pyrolyzed using the modified Ünterzaucher apparatus and carbon dioxide obtained was

analyzed by mass spectrometry. The atom % excess ^{18}O in the carbon dioxide from pyrolysis of the alcohol corresponds to the atom % excess ^{18}O in the ether oxygen position of the arenesulfinate ester. The rate constant was calculated from the data obtained as is detailed for an individual sample below.

CALCULATION OF THE RATE OF OXYGEN SCRAMBLING IN THE ETHANOLYSIS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ETHANOL AT 90.0° WITH ADDED 0.04757 M 2,6-LUTIDINE. RUN 2-85-4.

C_o = initial concentration of ester = 0.02831 M.

C_t = ester concentration after 22920 sec.

C_{net} = concentration of unscrambled ester after 22920 sec.

$$F_{scr} = \frac{\text{(atom \% excess } ^{18}O \text{ in alcohol from hydrolysis) x 2}}{\text{atom \% excess } ^{18}O \text{ originally in sulfonyl position}}$$

k = rate constant for ethanolysis and isomerization of the ester = 2.30×10^{-5} sec^{-1}.

k_{total} = rate constant for the sum of oxygen scrambling and disappearance of the ester.

k_{scr} = rate constant for oxygen scrambling.

$$\ln C_t = \ln C_o - kt$$

$$2.303 \log C_t = (2.303 \times \log 0.02831) - (2.30 \times 10^{-5} \times 22920)$$

$$\log C_t = 8.22301 - 10$$

$$C_t = 0.01671$$

$$C_{net} = C_t - (F_{scr} \times C_t) = .01671 - (.141 \times .01671) = .01435$$

F_{scr} for this sample = .141

$$k_{total} = \frac{2.303 \log C_o/C_{net}}{t} = \frac{2.303 \times .29508}{22920 \text{ sec}} = \underline{2.97 \times 10^{-5} \text{ sec}^{-1}}$$

$$k_{scr} = k_{total} - k = 0.67 \times 10^{-5} \text{ sec}^{-1}.$$

It was shown by appropriate controls that the ester was specifically labeled in the sulfonyl position. It was further shown that the extraction, hydrolysis and isolation procedures permitted no loss or introduction of labeled oxygen at the ether oxygen position.

Kinetics of the Reactions of Benzhydryl 2,6-Dimethylbenzenesulfinate in Ethanol and 80% Aqueous Ethanol.

It had been reported that the rate of solvolysis and isomerization of benzhydryl 2,6-dimethylbenzenesulfinate in anhydrous ethanol in the presence of potassium acetate was 2.38×10^{-5} sec^{-1}.[16] In the work to be carried out the effects of various added salts upon the solvolysis and isomerizations were to be studied. It was decided that an amine base be used rather than potassium acetate in order to avoid any complications which might arise from cation exchange between the added salt and the added base. Noreyko[21] had shown that 2,6-lutidine was a very poor nucleophile in the reactions between various bases and arenesulfinate esters. For these reasons 2,6-lutidine was the choice as added base.

The reaction of benzhydryl 2,6-dimethylbenzenesulfinate in anhydrous ethanol and 80% aqueous ethanol gave rise to first-order kinetics. Titrimetric rate constants in the absence of added salts were usually ± 3-5% and rate constants determined by spectrometric analysis under the same conditions were normally ± 2-4%. In some cases a drift in the rate constant was observed as the reaction proceeded. An example of such a case is shown in Table IV.

TABLE IV

RATE OF REACTION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE (.02503 M) IN ANHYDROUS ETHANOL AT 90.0° WITH ADDED 2,6-LUTIDINE (.04945 M).

Base: Sodium methoxide (.03611 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 3.466 ml

Time (sec)	Titer (ml)	sulfone $\log I_o/I$	$10^5 k_t$, sec^{-1}	$10^5 k_{ir}$, sec^{-1}
Blank	.036	.01452	-----	-----
0	.050	.01536		
6900	.366	-----	2.07	-----
10200	.518	.11826	2.15	2.41
13800	.671	.14706	2.19	2.37
17700	.822	.17667	2.22	2.36
21600	.982	.20249	2.30	2.34
26160	1.128	.23045	2.31	2.33
30300	1.268	.25696	2.37	2.37
37200	1.460	.29203	2.42	2.37
43800	1.620	.31639	2.47	2.32
51600	1.742	.34223	2.41	2.29
61200	1.943	.36736	2.60	2.24
67500	2.051	.40054	2.48	2.28
10 $t_{1/2}$	2.408	.49402		
10 $t_{1/2}$	2.446	.48052		
		Averages	2.33 ± .13	2.33 ± .04

Titer at infinity was 70% of theoretical. Sulfone produced was 30.1% of theoretical.

TABLE V

RATE OF REACTION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE (.02495 M) IN 80% AQUEOUS ETHANOL AT 90.0° WITH ADDED 2,6-LUTIDINE (.05296 M).

Base: Sodium methoxide (.0474 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 2.632 ml

Time (sec)	Titer (ml)	$10^4 k_t$, sec^{-1}
0	.050	-----
450	.200	2.07
960	.324	1.84
1260	.414	1.93
1560	.471	1.84
2280	.642	1.89
2640	.722	1.92
3000	.788	1.92
4200	.959	1.84
4810	1.073	1.94
5400	1.118	1.85
7200	1.287	1.83
10560	1.481	1.78
19 $t_{1/2}$	1.726	Average 1.89 ± .06
22 $t_{1/2}$	1.718	
30 $t_{1/2}$	1.762	
42 $t_{1/2}$	1.746	

Average titer at infinity was 1.738 ml, 65% of theoretical. Sulfone produced was 35% by difference.

The rate constants as measured by titrimetry and infrared spectrometry usually agreed within experimental error. Sample kinetic runs for solvolysis and rearrangement of benzhydryl 2,6-dimethylbenzenesulfinate in these solvents are shown in Tables IV and V.

The effects of added tetrabutylammonium perchlorate and some tetrabutylammonium arenesulfinate salts on the kinetics and product distribution of the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol are shown in Table VI. Added tetrabutylammonium perchlorate and tetrabutylammonium 2,6-dimethylbenzenesulfinate had no effect upon the rate constants of solvolysis and isomerization and the product distribution is identical with the values obtained in the absence of any added salt. In addition the effects of these salts upon the ionization and scrambling rate constants were investigated and the results obtained are given in Tables VII - IX. The rate constants for the ionization and and scrambling were also unaffected by the addition of the added salts.

The effect of added tetrabutylammonium benzenesulfinate and 4-methylbenzenesulfinate on the solvolysis and rearrangement reactions of the ester are also shown in Table VI. With these added salts there is a small decrease in the amount of sulfone formed. However, there was no evidence for formation of any benzhydryl phenyl sulfone or benzhydryl 4-methylphenyl sulfone. Examination of the product mixture by infrared spectrometry and nuclear magnetic resonance spectrometry gave no evidence for the formation of either of these sulfones. It is estimated that if

TABLE VI

THE SOLVOLYSIS AND REARRANGEMENT OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ETHANOL AT 90.0°.

Run	[Ester]	Salt	[Salt]	F_{acid}	$F_{sulfone}$	$10^5 k_t$, sec^{-1}	$10^5 k_{ir}$, sec^{-1}
1-24	.02638	----		.68	----	2.20 ± .08	----
1-31	.02503	----	----	.74	----	2.42 ± .16	----
3-40	.02492	----	----	.70	.30	2.30 ± .09	2.32 ± .04
3-42	.02503	----	----	.70	.30	2.33 ± .13	2.33 ± .04
2-132	.02479	$Bu_4NO_2SC_6H_3(CH_3)_2$[b]	.1224	---	.30	----[c]	2.37 ± .07
2-150	.02498	Bu_4NClO_4	.1200	.78	---	2.36 ± .04	----
2-264	.02485	Bu_4NClO_4	.1173	.77	.30	----	----
2-286	.02541	$Bu_4NO_2SC_6H_4CH_3$[d]	.1301	---	.26[e]	----	----
2-287	.02484	$Bu_4NO_2SC_6H_5$[f]	.1353	---	.27[e]	----	----
3-27	.02982	$Bu_4NO_2SC_6H_4CH_3$[d]	.1262	---	---[e]	----	----

[a] 2,6-Lutidine approximately .05 M in all runs.
[b] Tetrabutylammonium 2,6-dimethylbenzenesulfinate.
[c] Development of acid continued after ester solvolysis and rearrangement was complete.
[d] Tetrabutylammonium 4-methylbenzenesulfinate.
[e] Infrared and nuclear magnetic resonance spectra showed no trace of sulfone other than benzhydryl 2,6-dimethylphenyl sulfone.
[f] Tetrabutylammonium benzenesulfinate.

TABLE VII

THE RATE OF SCRAMBLING OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE-SULFONYL-^{18}O IN ANHYDROUS ETHANOL AT 90.0° WITH ADDED .05 M 2,6-LUTIDINE.

Run[a]	time, sec	F_{scr}	$10^5 k_{ioniz}$, sec^{-1}	$10^5 k_{scr}$, sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
2-85-1	4680	.033	(3.32)[c]	(1.02)[c]	1.61[a]	0.69[a]
2-180	9900	.056	2.88	0.58		
2-181	9900	.057	2.90	0.60		
2-171	9900	.057	2.89	0.59		
2-85-2	10140	.061	2.92	0.62		
2-85-3	15540	.106	3.02	0.72		
2-182	16200	.092	2.90	0.60		
2-172	17100	.098	2.90	0.60		
2-85-4	22920	.141	2.97	0.67		
2-173	24300	.164	3.04	0.74		
2-74	29100	.200	3.06	0.76		
2-174	36000	.232	3.03	0.73		
2-184	39600	.231	2.96	0.66		
2-91-1	40800	.255	3.02	0.72		
2-175	56700	.315	2.97	0.67		
2-91-2	60780	.353	3.03	0.73		
	Averages		2.97 ± .05	0.67 ± .05		

[a] All runs contain approximately 0.028 molar ester.
[b] Average of rate constants from four runs.
[c] Not included in calculation of average rate constant.

TABLE VIII

THE RATE OF SCRAMBLING OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE-SULFONYL-^{18}O IN ANHYDROUS ETHANOL AT 90.0° WITH ADDED .05 M 2,6-LUTIDINE AND 0.12 M TETRABUTYLAMMONIUM AZIDE.

Run[a]	time, sec	F_{scr}	$10^5 k_{ioniz}$, sec^{-1}	$10^5 k_{scr}$, sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
2-156	10800	.065	2.98	0.62	1.65[b]	0.71[b]
2-163	10800	.063	2.96	0.60		
2-157	18000	.106	2.98	0.62		
2-164	18000	.108	3.00	0.64		
2-155	25200	.172	3.11	0.75		
2-165	25200	.154	3.02	0.66		
2-158	36900	.217	3.02	0.66		
2-166	36900	.203	2.97	0.61		
2-159	55200	.307	3.02	0.66		
	Averages		3.01 ± .03	0.65 ± .03		

a All runs contain approximately 0.028 M ester.
b Taken from Table VI Runs 2-150 and 2-164.

as much as 2% of the reaction of the ester proceeded to give p-tolyl sulfone that this compound would have been detected. Detection limits for benzhydryl phenyl sulfone would have been much higher. This sulfone has no characteristic absorption in the infrared or nuclear magnetic resonance spectra which would not be obscured if a large amount of benzhydryl 2,6-dimethylphenyl sulfone were present. However, since no exchange was observed with the 4-methylbenzenesulfinate salt, it was considered unlikely that any took place with the benzenesulfinate salt.

The effects of added tetrabutylammonium azide upon the

TABLE IX

THE RATE OF SCRAMBLING OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE-SULFONYL-^{18}O IN ANHYDROUS ETHANOL AT 90.0° WITH ADDED .05 M 2,6-LUTIDINE AND 0.12 M TETRABUTYLAMMONIUM 2,6-DIMETHYLBENZENESULFINATE.

Run[a]	time, sec	F_{scr}	$10^5 k_{ioniz}$, sec^{-1}	$10^5 k_{scr}$ sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
2-142-1	10140	.054	2.92	0.55	1.66[b]	0.71[b]
2-142-2	16200	.083	2.91	0.54		
2-137-1	23880	.130	2.95	0.58		
2-137-2	31860	.167	2.94	0.57		
2-136	70620	.302	2.88	0.55		
	Averages		2.92 ± .02	0.55 ± .02		

[a] All runs contain approximately 0.028 M ester.
[b] Taken from Table VI, Run 2-132.

reactions of the ester in both ethanol and 80% ethanol were investigated. Sample kinetic runs are given in Tables X and XI. The effects of added tetrabutylammonium azide upon the rate constants for solvolysis, isomerization and scrambling of the ester in ethanol and the solvolysis and isomerization of the ester in 80% aqueous ethanol are shown in Tables XII, XIII and XIV. In solvent ethanol it was found that the rate constants for reaction of the arenesulfinate ester determined spectrometrically from the amount of benzhydryl azide produced were much larger than the titrimetric rate constants when low concentrations of tetrabutylammonium azide were present. In addition the values for the rate constants were subject to large experimental error. An explanation for these

TABLE X

RATE OF REACTION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE (.02458 M) IN ANHYDROUS ETHANOL AT 90.0° WITH ADDED 2,6-LUTIDINE (.05012 M) AND TETRABUTYLAMMONIUM AZIDE (.1129 M).

Base: Sodium methoxide (.0474 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein. Calculated infinity: 2.593 ml

Time (sec)	Titer (ml)	azide log I_o/I	10^5 k_t, sec^{-1}	10^5 k_{ir}, sec^{-1}
Blank	.031	0	-----	-----
0	.039	0	-----	-----
3300	.141	.03423	2.88	2.09
7500	.253	.07463	2.81	2.25
9600	.305	.09794	2.81	2.46
12000	.349	.12131	2.69	2.58
14100	.392	.14087	2.67	2.76
16800	.458	.15864	2.77	2.62
19500	.496	.17724	2.67	2.63
22500	.554	.19740	2.72	2.66
30720	.635	.22953	2.46	2.59
40260	.738	.26800	2.41	2.59
83040	1.023	.34684	2.50	2.36
$10\ t_{1/2}$ avg. 1.164		.20808 (sample dissolved in 2 ml of CCl_4; kinetic points dissolved in 1 ml of CCl_4.)		
$20\ t_{1/2}$				
		Averages:	2.64 ± .15	2.49 ± .16

Titer at infinity was 43.7% of theoretical. Azide produced was 14.1% of theoretical.

TABLE XI

RATE OF REACTION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE (.02527 M) IN 80% ETHANOL AT 90.0° WITH ADDED 2,6-LUTIDINE (.05043 M) AND TETRA-BUTYLAMMONIUM AZIDE (.1140 M).

Base: Sodium methoxide (.04740 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 2.665 ml

Time (sec)	Titer (ml)	Azide log I_o/I	10^4 k_t, sec^{-1}	10^4 k_{ir}, sec^{-1}
Blank	0.039	0	-----	-----
0	.103	.02274	-----	-----
420	.192	.06793	1.87	(1.93)
960	.329	.12223	2.21	2.22
1260	.394	.14987	2.25	2.24
1560	.431	.17157	2.09	2.23
2280	.576	.22155	2.24	2.30
2640	.652	.23259	2.37	2.18
3000	.688	.26483	2.28	2.37
4200	.829	-----	2.27	-----
4800	.884	.33164	2.26	2.28
5400	.961	.34845	2.40	2.23
7200	1.092	.38652	2.52	2.25
4 $t_{1/2}$	1.298	.44869		
		Averages	2.25 ± .11	2.24 ± .05
25 $t_{1/2}$	1.247	.45478		
25 $t_{1/2}$	1.273	-----		
108 $t_{1/2}$	1.318	-----		
108 $t_{1/2}$	1.282	-----		

Titer at infinity was 46.7% of theoretical. Azide produced was 16.5% of theoretical.

TABLE XII

KINETICS OF THE SOLVOLYSIS AND ISOMERIZATION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ANHYDROUS ETHANOL AT 90.0° IN THE PRESENCE OF ADDED TETRABUTYLAMMONIUM AZIDE.

Run	[Ester]	[2,6-lut]	$[Bu_4NN_3]$	F_{isom}	$10^5 k_t$, sec^{-1}	$10^5 k_{ir}$[a] sec^{-1}
1-198	.02471	.05012	.02352	.27	1.79 ± .09	-----
1-45	.02502	.05012	.02576	---	1.82 ± .15	2.79 ± .22
1-58	.02533	.05012	.03999	---	2.27 ± .10	2.64 ± .14
2-200	.02384	.05000	.05380	.27	2.35 ± .06	2.69 ± .09
1-200	.02464	.05012	.05402	.26	2.17 ± .09	-----
1-206	.02462	.05012	.1012	.24	2.59 ± .10	-----
2-214	.02510	.05000	.1064	.24	2.86 ± .08	3.08 ± .06
1-56	.02458	.05012	.1129	---	2.64 ± .15	2.49 ± .16
2-204	.02381	.05000	.1573	---	3.34 ± .04	3.15 ± .10
1-50	.02670	.05012	.2059	---	3.53 ± .10	3.40 ± .21
2-216	.02511	.05000	.2091	.20	3.89 ± .15	3.28 ± .06

[a] Followed by azide production using infrared spectrometric method.

observations may be that as the solvolysis reaction proceeds the 2,6-dimethylbenzenesulfinic acid which is formed reacts with the added tetrabutylammonium azide to generate hydrazoic acid. If 2,6-lutidine does not effectively neutralize the hydrazoic acid, a considerable amount of hydrazoic acid might exist in undissociated form since it is a weak acid. This would effectively reduce the concentration of azide ion in solution. As a result of this behavior less benzhydryl azide would be formed as the reaction proceeds and the fraction of benzhydryl azide would not be constant

TABLE XIII

KINETICS OF THE SOLVOLYSIS AND ISOMERIZATION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN 80% AQUEOUS ETHANOL AT 90.0° IN THE PRESENCE OF ADDED TETRABUTYLAMMONIUM AZIDE.

Run	[Ester]	[2,6-lut]	$[Bu_4NN_3]$	F_{isom}[a]	$10^4 k_t$, sec^{-1}	$10^4 k_{ir}$[b] sec^{-1}
1-54	.02495	.05296	-----	(.35)	1.89 ± .06	------
1-68	.02493	.05043	.02824	----	2.04 ± .04	2.17 ± .08
1-66	.02567	.05043	.05505	(.36)	2.15 ± .06	2.10 ± .10
1-64	.02527	.05043	.1140	(.34)	2.25 ± .11	2.24 ± .05
1-62	.02409	.05043	.2102	(.30)	2.15 ± .15	2.02 ± .06

[a] Taken from later runs; see Chapter II, p. 87 , Table XXVII.
[b] Followed by azide production using infrared spectrometric method.

TABLE XIV

THE RATE OF SCRAMBLING OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE-SULFONYL-^{18}O IN ANHYDROUS ETHANOL AT 90.0° WITH ADDED .05 M 2,6-LUTIDINE AND 0.12 M TETRABUTYLAMMONIUM AZIDE.

Run[a]	time, sec	F_{scr}	$10^5 k_{ioniz}$, sec^{-1}	$10^5 k_{scr}$, sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
2-103-1	10800	.065	3.45	0.63	2.15[b]	0.68[b]
2-100	15300	.089	3.44	0.62		
2-103-IV	22380	.115	3.38	0.56		
2-103-II	30300	.167	3.43	0.61		
2-116-2	40380	.216	3.43	0.61		
2-116-1	54360	.245	3.35	0.53		
	Averages		3.41 ± .03	0.59 ± .03		

[a] All runs contain approximately 0.028 M ester.
[b] Obtained from plot of $[Bu_4NN_3]$ against k_t for ester, Figure IV, and data in Table XII.

throughout the reaction. Pseudo first-order kinetics would not be observed and calculation of the rate constant as a first-order rate constant would result in a value with a large error range. At higher tetrabutylammonium azide concentrations this behavior would have a much smaller effect on the determination of the rate constant for the reaction as a much smaller fraction of the total available azide ion would be tied up as hydrazoic acid.

The yields of both solvolysis and isomerization products are decreased by the addition of tetrabutylammonium azide and benzhydryl azide is produced. A quantitative treatment of the effects of tetrabutylammonium azide on the product distribution will be presented and discussed thoroughly in Chapter II. The addition of large amounts of tetrabutylammonium azide increases the rate of reaction in ethanol but has practically no effect upon the overall rate of reaction in 80% ethanol. In both solvents the rates of isomerization are unchanged within experimental error. The scrambling rate constant for the ester in ethanol is also unchanged within experimental error.

Winstein has suggested[31] the use of the following equation to correlate the effect of added salts upon the rate constant of a reaction. In this equation k_o is the rate constant in the

$$k = k_o \{ 1 + b[\text{salt}] \}$$

absence of the salt and k is the rate constant in the presence of the salt; b is the percentage increase in the rate constant per 0.01 molar increase in salt concentration.

In aqueous ethanol this equation is obviously not applicable. As the concentration of tetrabutylammonium azide is increased in this solvent there is no steady increase in the rate constant.

The application of this equation is questionable in the case of the solvolysis of the ester in ethanol. In ethanol with low concentrations of tetrabutylammonium azide an apparent decrease in the rate constant is observed. This would not be expected if the above equation were followed. In addition this equation is normally applied in the region of 0.08 molar salt concentration or less. In this range there is no obvious increase in the rate constant for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate. The relationship between the rate constant for the disappearance of the ester and the concentration of tetrabutylammonium azide is given graphically in Figure IV. Using an extrapolated k_o of 1.79×10^{-5} sec^{-1} rather than the observed value of 2.30×10^{-5} sec^{-1} a b value of 4.86 is determined.

Product Analysis by Gas Chromatography.

Preliminary kinetic runs resulted in the determination that only about 94% of the starting ester was accounted for by acid titer and sulfone formation for the reaction in ethanol. Later runs (see Table VI) accounted for all of the starting material. In the presence of added tetrabutylammonium azide only about 70% of the starting material was accounted for. As a result of this it was desired to check for formation of unexpected products by gas chromatography.

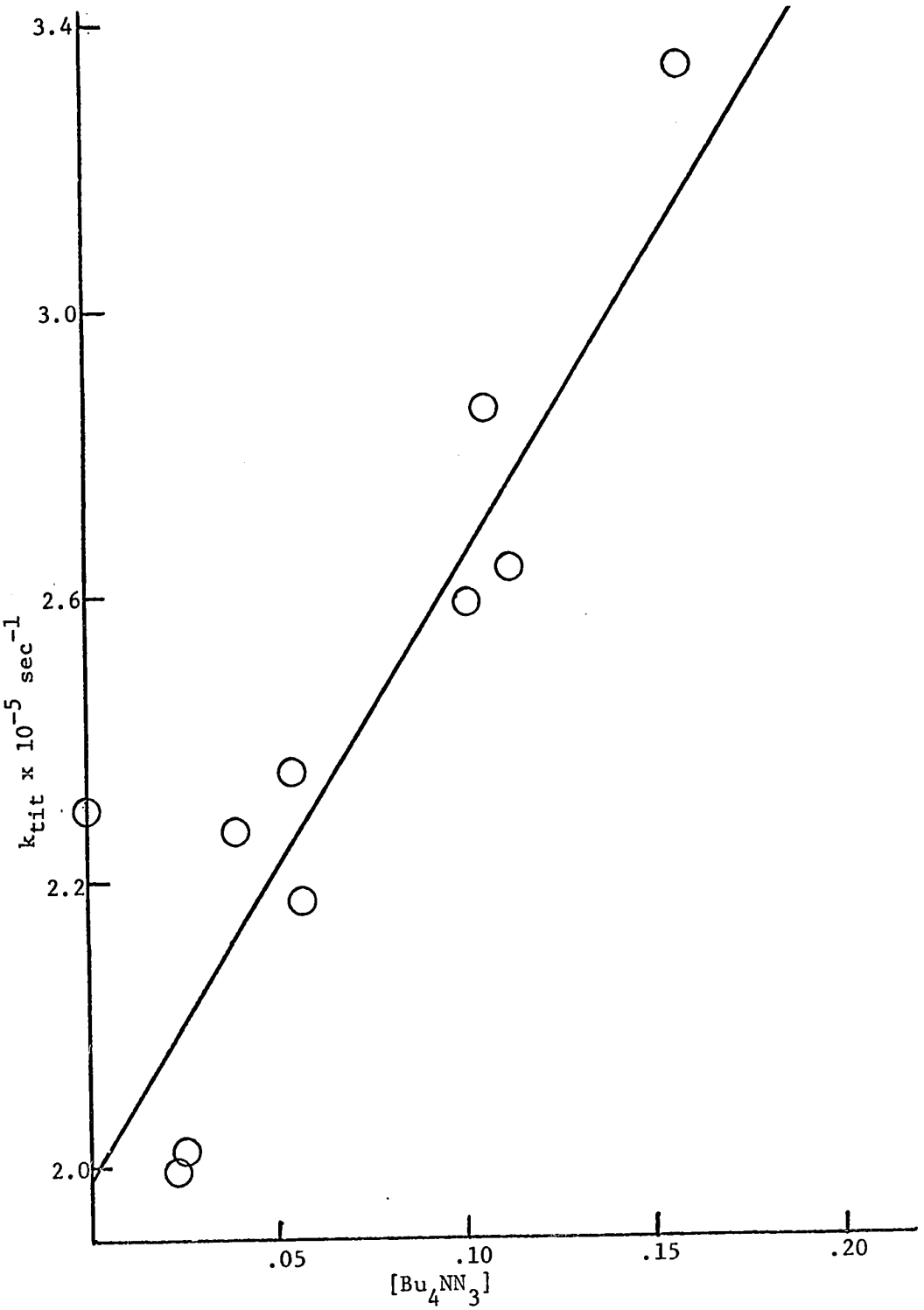


Figure IV. The effect of added tetrabutylammonium azide on the rate of reaction of benzhydryl 2,6-dimethylbenzenesulfinate in anhydrous ethanol at 90.0° with added 2,6-lutidine.

A control was carried out to determine the relative thermal conductivities of the expected products and the internal standard, phenyl ether. Standard solutions of benzhydryl azide and benzhydryl ethyl ether in ethanol were prepared. Aliquots of these solutions were subjected to a standard extraction procedure and the isolated compounds were dissolved in known amounts of phenyl ether in chloroform. Samples of these solutions were analyzed by gas chromatography. The relationships between the area ratios of the peaks obtained and the weight ratios of the compounds to phenyl ether are shown in Tables XV and XVI and in Figures V and VI.

The results of product analyses for the products of ethanolysis of the ester in the presence and absence of tetrabutylammonium azide are shown in Table XVII. These results were obtained by a combination of infrared and gas chromatographic techniques.

TABLE XVII

PRODUCT ANALYSES FOR THE ETHANOLYSIS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE WITH ADDED 2,6-LUTIDINE AT 90.0°.

Run[a]	[Ester]	$[Bu_4NN_3]$	F_{ether}	F_{azide}	$F_{sulfone}$	F_{ROH}	Total
3-42	.02503	-----	0.70	-----	0.30	----	1.00
2-200	.02384	.05380	0.65	0.067	0.26	.06	1.04
2-214	.02510	.1064	0.62	0.11	0.24	.07	1.04
2-204	.02381	.1573	0.57	0.14	0.22	.09	1.02
2-216	.02511	.2091	0.54	0.18	0.20	.11	1.03

[a] All runs contained approximately 0.050 M 2,6-lutidine.

TABLE XV

STANDARDIZATION OF GAS-LIQUID CHROMATOGRAPHIC ANALYSIS PROCEDURE FOR BENZHYDRYL ETHYL ETHER USING PHENYL ETHER AS THE INTERNAL STANDARD.

Solution	$\frac{\text{mg } (C_6H_5)_2CHOEt}{\text{mg } (C_6H_5)_2O}$	$\frac{\text{peak area } (C_6H_5)_2CHOEt}{\text{peak area } (C_6H_5)_2O}$
2-190-100	0.3863	1.747
2-190-90	0.3477	1.579
2-190-80	0.3091	1.374
2-190-66	0.2575	1.120
2-190-50	0.1932	0.887
2-190-40	0.1545	0.671
2-190-33	0.1288	0.569
2-190-20	0.0773	0.331

TABLE XVI

STANDARDIZATION OF GAS-LIQUID CHROMATOGRAPHIC ANALYSIS PROCEDURE FOR BENZHYDRYL AZIDE USING PHENYL ETHER AS INTERNAL STANDARD.

Solution	$\frac{\text{mg } (C_6H_5)_2CHN_3}{\text{mg } (C_6H_5)_2O}$	$\frac{\text{peak area } (C_6H_5)_2CHN_3}{\text{peak area } (C_6H_5)_2O}$
2-190-100	0.1219	0.541
2-190-90	0.1097	0.488
2-190-80	0.0975	0.406
2-190-66	0.0813	0.322
2-190-50	0.0609	0.257
2-190-40	0.0488	0.191
2-190-33	0.0406	0.173
2-190-20	0.0244	0.092

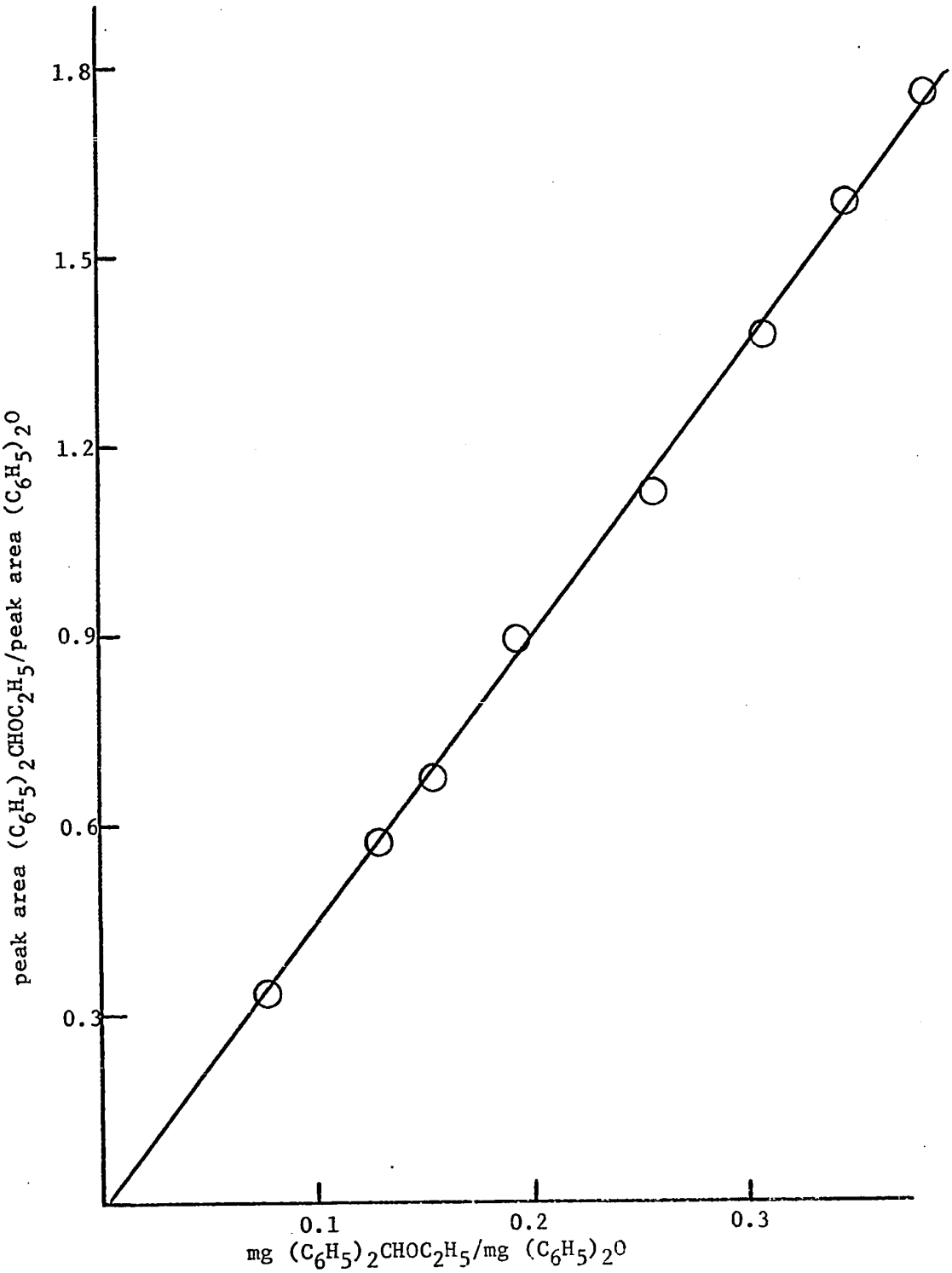


Figure V. Curve for gas-liquid chromatography of benzhydryl ethyl ether upon isolation from ethanol. Phenyl ether was used as internal standard.

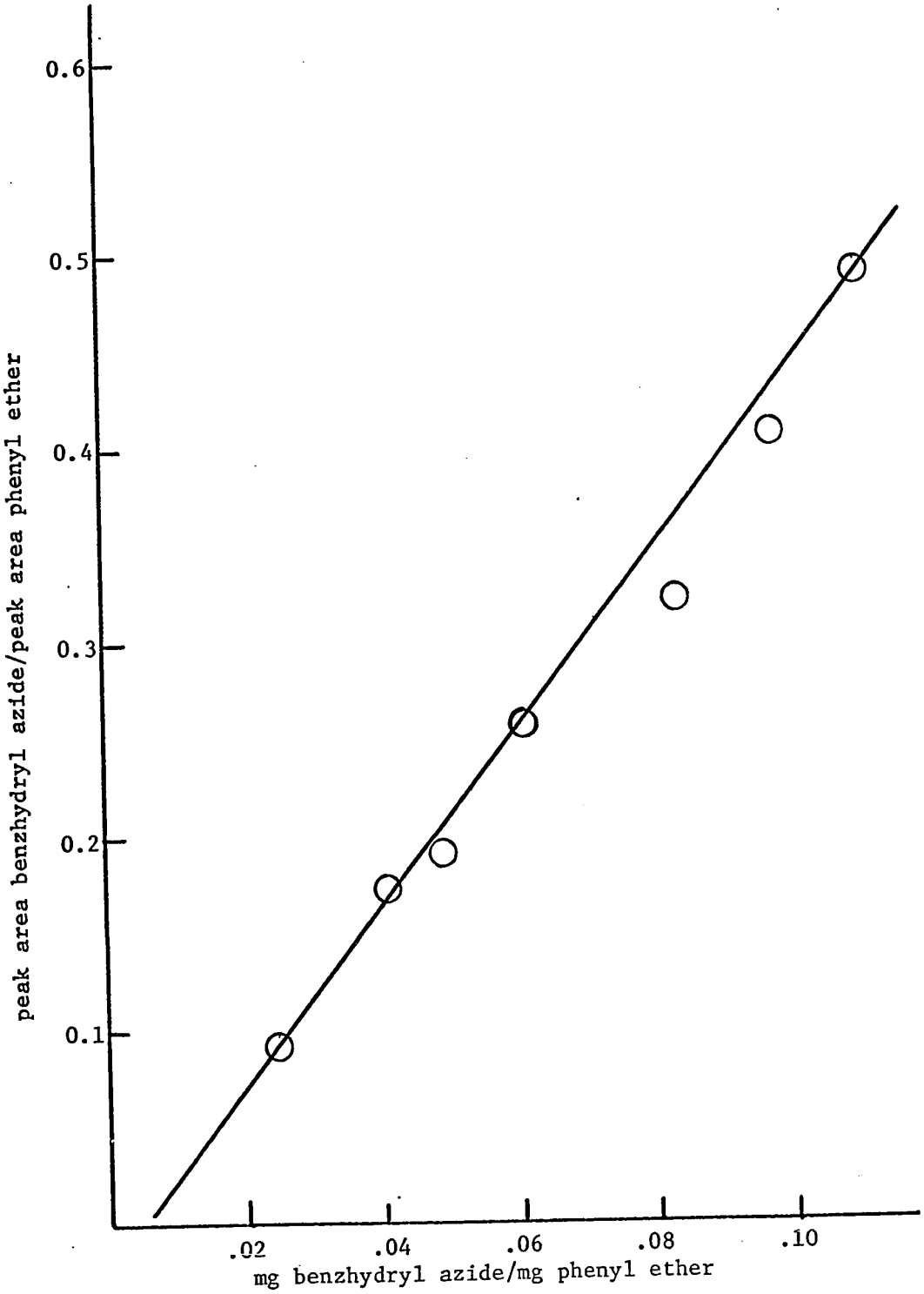


Figure VI. Curve for gas-liquid chromatography of benzhydryl azide upon isolation from ethanol. Phenyl ether was used as internal standard.

The amount of alcohol formed was difficult to determine quantitatively as the peak due to this compound on gas chromatography overlapped the benzhydryl ethyl ether peak. The analysis was accomplished using a DuPont Model 310 Curve Resolver. The assistance of Mrs. R. B. Jordan in the resolution of these curve mixtures is gratefully acknowledged.

The production of small amounts of benzhydryl alcohol is consistent with the existence of some sulfur-oxygen bond fission. This sulfur-oxygen bond fission was attributed to the action of the nucleophilic azide ion. This suggestion was substantiated by the use of 0.046 molar potassium acetate as the added base rather than 2,6-lutidine. This change resulted in approximately 15% sulfur-oxygen bond fission. Gas chromatography also revealed that benzhydryl alcohol formation was accompanied by the production of a similar amount of ethyl 2,6-dimethylbenzenesulfinate. This would be expected if sulfur-oxygen bond fission were the source of the alcohol.

The Reaction of Benzhydryl 2,6-Dimethylbenzenesulfinate in Acetic Acid.

It was not possible to follow the solvolysis reaction of the arenesulfinate ester in acetic acid titrimetrically. 2,6-Dimethylbenzenesulfinic acid is a weak acid in acetic acid solvent and cannot be titrated. In addition the 2,6-dimethylbenzenesulfinic acid produced is consumed to give 2,6-dimethylphenyl 2,6-dimethylbenzenethiolsulfonate and 2,6-dimethylbenzenesulfonic acid.[45, 47]

$$ArSOOH + {}^{-}OAc \rightleftharpoons HOAc + ArSO_2^{-}$$

$$3\ ArSOOH \longrightarrow Ar\text{-}\overset{\overset{O}{\uparrow}}{S}\text{-}\overset{\overset{O}{\downarrow}}{S}\text{-}Ar + ArSO_3H + H_2O$$

$$ArSO_3H + {}^{-}OAc \rightleftharpoons HOAc + ArSO_3^{-}$$

The kinetics of the reaction of the ester were determined by following the production of benzhydryl 2,6-dimethylphenyl sulfone and benzhydryl acetate spectrometrically. This method of following the reaction also sufficed to give an analysis for the products formed since the sum of acetate and sulfone formation accounted for the total amount of starting material. Suitable controls were carried out on the analyses for sulfone and acetate. The control runs showed that a linear relationship exists for both of these compounds between concentration and absorbance in the infrared. The results of these controls are shown in Tables XVIII and XIX and in Figures VII and VIII.

Kinetics of the reaction were determined by a sealed ampoule method. The optical densities due to benzhydryl 2,6-dimethylphenyl sulfone and benzhydryl acetate formed were calculated. The first-order rate constants for the reactions were calculated using the equation

$$k = \frac{2.303}{t} \log \frac{(D_\infty - D_o)}{(D_\infty - D_t)}$$

where D_t is the absorbance at time = t. Reasonably good first-

TABLE XVIII

RELATIONSHIP BETWEEN OPTICAL DENSITY AND CONCENTRATION OF BENZHYDRYL 2,6-DIMETHYLPHENYL SULFONE AS MEASURED IN CARBON TETRACHLORIDE AFTER EXTRACTION FROM ACETIC ACID. ABSORBANCE MEASURED AT 1305 CM^{-1}.

Solution	Sulfone, mg/ml acetic acid	I_o/I	log I_o/I
2-210-100	5.599	3.421	.53415
2-210-90	5.039	3.166	.50037
2-210-75	3.799	2.653	.42374
2-210-60	3.359	2.148	.33203
2-210-50	2.799	1.959	.29203
2-210-40	2.240	1.758	.24502
2-210-30	1.680	1.542	.18808
2-210-20	1.120	1.336	.12581

TABLE XIX

RELATIOSHIP BETWEEN OPTICAL DENSITY AND CONCENTRATION OF BENZHYDRYL ACETATE AS MEASURED IN CARBON TETRACHLORIDE AFTER EXTRACTION FROM ACETIC ACID. ABSORBANCE MEASURED AT 1747 CM^{-1}.

Solution	Acetate, mg/ml acetic acid	I_o/I	log I_o/I
2-229-100	2.817	2.347	.37051
2-229-90	2.535	2.158	.33405
2-229-75	2.113	1.950	.29003
2-229-60	1.690	1.724	.23654
2-229-50	1.403	1.576	.19756
2-229-40	1.127	1.430	.15534
2-229-30	0.845	1.304	.11528
2-229-20	0.563	1.203	.08027

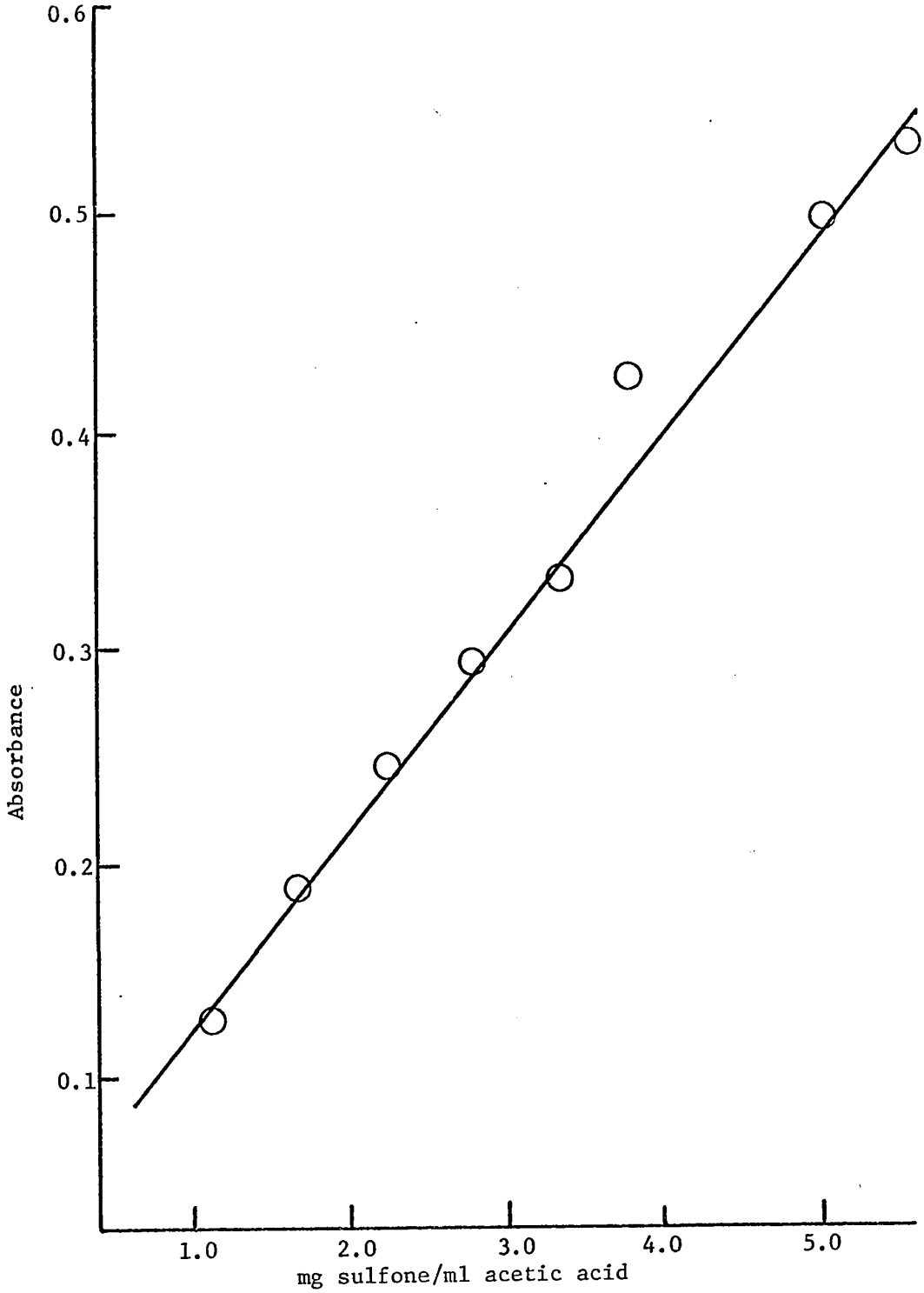


Figure VII. Relationship between concentration and absorbance for benzhydryl 2,6-dimethylphenyl sulfone in 3.844 ml of carbon tetrachloride after isolation from acetic acid.

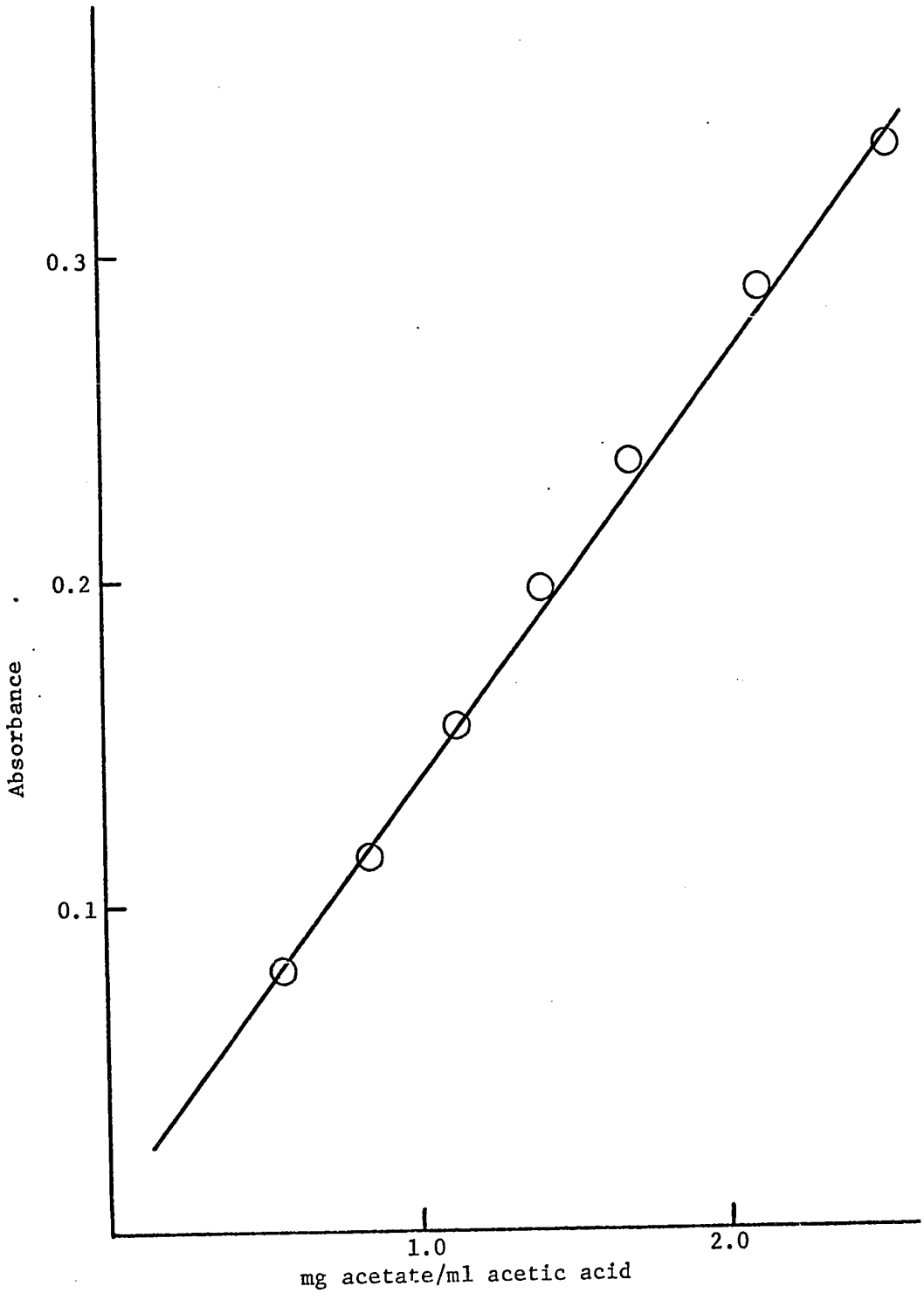


Figure VIII. Relationship between concentration and absorbance for benzhydryl acetate in 3.844 ml of carbon tetrachloride after isolation from acetic acid.

order rate constants were obtained. A sample rate run is shown in Table XX. The results of kinetic runs measuring rate constants for solvolysis and isomerization are shown in Table XXI. This table also includes product analysis data.

TABLE XXI

KINETICS AND PRODUCTS OF THE SOLVOLYSIS AND REARRANGEMENT OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ACETIC ACID WITH ADDED SODIUM ACETATE.

Run	[Ester]	[NaOAc]	[$LiClO_4$]	T,°C	10^5 k, sec^{-1}	F_{isom}	$F_{acetate}$
2-220	.02499	.09987	-----	70	16.7 ± .6	.58	.40
2-232	.02499	.09983	-----	50	1.53 ± .26	.63	.35
2-233	.02497	.1001	-----	50	1.70 ± .06	.63	.35
2-237	.02978	.09987	-----	50	1.63 ± .03	.63	---
2-236-1	.02511	.0598	-----	50	-----	.64	.34
2-236-2	.02482	.1184	-----	50	-----	.63	.36
2-236-3	.02470	.1801	-----	50	-----	.61	.37
2-250	.02500	.09972	.05386	50	3.72 ± .05	.48	.56
2-255	.02495	.1002	.1065	50	7.16 ± .10	.37	.60

The possibility of any significant amount of sulfur-oxygen bond fission was considered. The expected product of this reaction would be benzhydryl alcohol. A control on the stability of benzhydryl alcohol in this solvent under the reaction conditions showed a rate constant for esterification of approximately 6×10^{-7} sec^{-1}. After 10 half-lives for the solvolysis and isomerization reactions

TABLE XX

RATE OF REACTION OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE (.02499 M) IN ANHYDROUS ACETIC ACID AT 70.0° WITH ADDED SODIUM ACETATE (.9987 M)

Aliquot: 5.00 ml

Calculated infinities: 8.409 mg sulfone/ml
5.650 mg acetate/ml

Time, sec	sulfone log I_o/I	acetate log I_o/I		10^4 k, sec^{-1} from sulfone	10^4 k, sec^{-1} from acetate
0	.01703	.02816		-----	-----
780	.07225	.06333		1.63	1.72
1200	.09621	.07518		1.56	1.54
1680	.13545	.09552		1.76	1.65
2220	.15685	.10992		1.62	1.57
2940	.19976	.13001		1.71	1.55
3660	.23350	.15290		1.73	1.62
4680	.26998	.17348		1.69	1.58
5880	.31112	.20085		1.72	1.65
7620	.34163	.21165		1.59	1.41
25 $t_{1/2}$	.47914	.31154	Averages	1.67 ± .06	1.59 ± .06
25 $t_{1/2}$	.48700	.30750			
60 $t_{1/2}$	.47276	.30103			
60 $t_{1/2}$	.47712	.30664			
Averages	.47900	.30668			

Sulfone produced was 57.5% of theoretical. Acetate produced was 40.4% of theoretical.

of the ester (approximately 90 hours) any alcohol produced would have esterified only to the extent of approximately 20%. Examination of a sample of a solvolysis mixture after 10 half-lives showed that no benzhydryl alcohol was present. This sample was analyzed by gas chromatography and if as much as 0.5% of the alcohol were produced from the solvolysis it would have been detected.

Oxygen Scrambling in the Acetolysis of Benzhydryl 2,6-Dimethylbenzenesulfinate-Sulfonyl-^{18}O.

In addition to the study of the solvolysis and isomerization reactions an analysis of the effect of added lithium perchlorate on the rate of scrambling of labeled ester in acetic acid was carried out. The procedure used was similar to that used in the ethanolysis of the ester with one exception. Since benzhydryl acetate is formed in the acetolysis a correction factor must be applied to the value for the atom percent excess ^{18}O obtained for the alcohol resulting from basic hydrolysis of the ester. The hydrolysis of unreacted arenesulfinate ester by reaction with sodium hydroxide results in alcohol production by hydrolysis of benzhydryl acetate as well. The alcohol from the acetate would be free of excess ^{18}O.

A determination of the amount of benzhydryl acetate present in each kinetic point was carried out using the standard infrared spectrometric method. The amount of sulfone was also determined. This allowed the calculation of the amount of ester remaining. The results of the scrambling runs are shown in Table XXII.

TABLE XXII

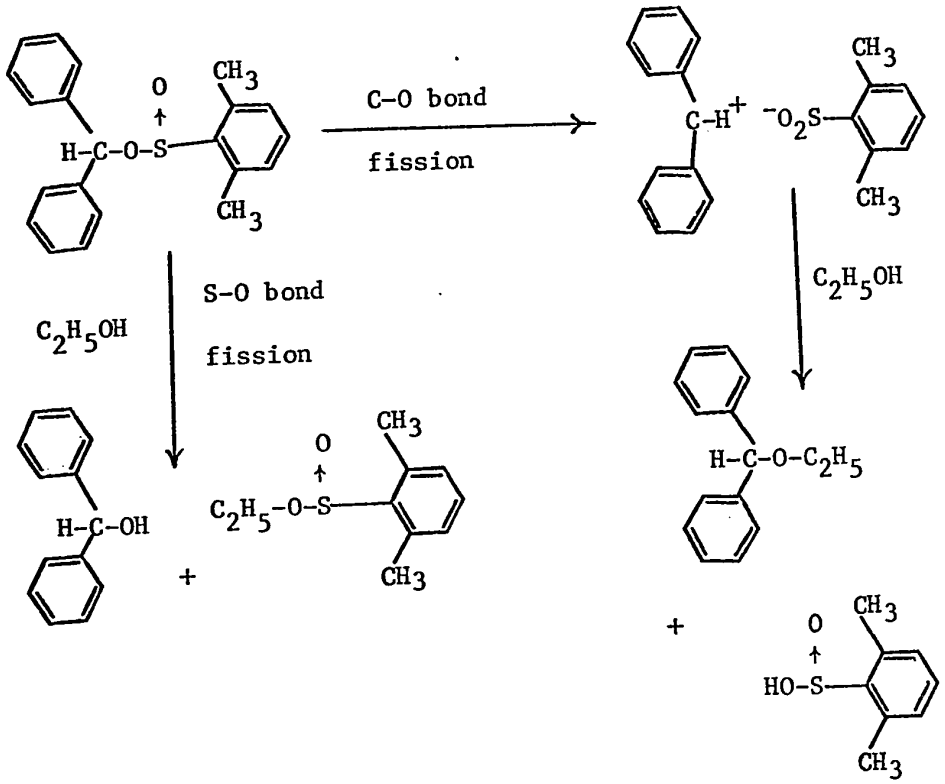
THE RATE OF SCRAMBLING OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE-SULFONYL-^{18}O IN ANHYDROUS ACETIC ACID AT 50.0° WITH 0.1 M SODIUM ACETATE AND 0.1 M ACETIC ANHYDRIDE.

Run	time, sec	F_{scr}	$10^5 k_{ioniz}$, sec^{-1}	$10^5 k_{scr}$, sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
2-237-1	12600	.161	3.06	1.39	0.69	0.98
2-237-2	21600	.256	3.09	1.47	0.63	0.99
2-237-3	34100	.380	3.07	1.40	0.62	1.05
2-237-4	50640	.520	3.08	1.45	0.60	1.03
2-237-5	73200	.649	3.03	1.44	0.59	1.01
	Averages		3.07 ± .02	1.43 ± .03	0.63 ± .03	1.01 ± .02
2-256-1[a]	7020	.124	5.67	1.89	2.22	1.56
2-256-2[a]	11700	.181	5.35	1.70	2.04	1.61
2-256-3[a]	17280	.259	5.38	1.74	1.96	1.68
2-256-4[a]	24900	.360	5.33	1.79	1.93	1.61
2-256-5[a]	37320	.474	5.13	1.76	1.85	1.52
	Averages		5.37 ± .12	1.78 ± .05	2.00 ± .10	1.60 ± .04

[a] Contains 0.05386 M lithium perchlorate.

DISCUSSION

The possibility exists in the reaction of benzhydryl 2,6-dimethylbenzenesulfinate that either sulfur-oxygen or carbon-oxygen bond fission may occur to give solvolysis products. The possible reactions are shown below.



Noreyko and Darwish[21] studied the reactions of several p-methoxyneophyl arenesulfinates and showed that these primary arenesulfinates react via sulfur-oxygen bond fission. The observed first-order rate constant for the reaction of p-methoxyneophyl 2,6-dimethylbenzenesulfinate in the presence of 0.0505 molar 2,6-lutidine in ethanol was 6×10^{-9} sec^{-1} at 90.0°. While benzhydryl

2,6-dimethylbenzenesulfinate might undergo this reaction with more facility than the p-methoxyneophyl ester, a rate enhancement by a factor of about 400 would be necessary to make sulfur-oxygen bond fission responsible for 10% of the reaction of the benzhydryl ester. The observed rate constant for disappearance of benzhydryl 2,6-dimethylbenzenesulfinate is 2.30×10^{-5} sec^{-1}. A rate enhancement of the value described would not be anticipated.

The use of a stronger base, e.g. potassium acetate, causes a large rate enhancement in the reaction of the p-methoxyneophyl ester, $k_{obs} = 7.5 \times 10^{-6}$ sec^{-1} in ethanol at 90° with 0.048 molar potassium acetate present. When 0.05 molar potassium acetate was used as the added base in the solvolysis of the benzhydryl ester approximately 15% of the reaction of the ester proceeded by sulfur-oxygen bond fission. This would be equivalent to a first-order rate constant of approximately 3×10^{-6} sec^{-1} for the acetate catalyzed sulfur-oxygen bond fission of benzhydryl 2,6-dimethylbenzenesulfinate. If the effect of changing from potassium acetate base to 2,6-lutidine base is similar for benzhydryl and p-methoxyneophyl 2,6-dimethylbenzenesulfinates, then the benzhydryl ester may be estimated to undergo sulfur-oxygen bond fission in ethanol with added 0.05 molar 2,6-lutidine at 90.0° with a rate constant of *ca.* 3×10^{-9} sec^{-1}. This value is smaller than the observed solvolysis rate constant by a factor of 10^4.

Noreyko and Darwish also observed that the rate of sulfur-oxygen bond fission of p-methoxyneophyl 2,6-dimethylbenzenesulfinate in the presence of 2,6-lutidine undergoes a rate enhance-

ment by a factor of 10 on changing to 60% aqueous ethanol from anhydrous ethanol. The observed rate constant for the reaction in 60% aqueous ethanol in the presence of 0.05 molar 2,6-lutidine is 7×10^{-8} sec^{-1} at 90° (compared to 6×10^{-9} sec^{-1} in anhydrous ethanol). If the estimated value for sulfur-oxygen bond fission in benzhydryl 2,6-dimethylbenzenesulfinate, 3×10^{-9} sec^{-1} at 90°, is increased by a factor of 10 on changing to 80% ethanol, the rate constant for this reaction would be estimated to be 3×10^{-8} sec^{-1}. This is slower than the observed rate constant for solvolysis of the benzhydryl ester in 80% ethanol ($k = 1.94 \times 10^{-4}$ sec^{-1} at 90°) by more than a factor of 6000.

Even allowing for a considerable error in these estimates it appears highly unlikely that appreciable sulfur-oxygen bond fission occurs in the solvolysis of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol and 80% aqueous ethanol.

Product analysis by gas chromatography as shown in Table XVI indicated that ethanolysis of benzhydryl 2,6-dimethylbenzenesulfinate in the presence of 2,6-lutidine occurred entirely by carbon-oxygen bond fission. The only products in the absence of any added salt were shown to be the corresponding benzhydryl ethyl ether and benzhydryl 2,6-dimethylphenyl sulfone. In the presence of added tetrabutylammonium azide some sulfur-oxygen bond fission was indicated by the presence of small peaks in the gas chromatogram indicating the presence of ethyl 2,6-dimethylbenzenesulfinate and benzhydryl alcohol in addition to the expected products of carbon-oxygen bond fission. The amount of sulfur-oxygen bond

fission varied with the concentration of the added azide salt. At concentrations of .05, .10, .16 and .21 molar tetrabutylammonium azide sulfur-oxygen bond fission was detected to the extent of 6%, 7%, 9% and 11% respectively.

The existence of sulfur-oxygen bond fission in the case of the solvolysis of the ester in 80% aqueous ethanol would not be detectable if it did take place with added tetrabutylammonium azide. Benzhydryl alcohol is an expected product of carbon-oxygen bond fission and any ethyl 2,6-dimethylbenzenesulfinate which might be formed would solvolyze in this medium to give ethyl alcohol and the arenesulfinic acid. The existence of appreciable sulfur-oxygen bond fission may be ruled out on consideration of the kinetics of sulfur-oxygen bond fission reported by Darwish and Noreyko.[21] These authors observed that on changing from anhydrous ethanol to 60% ethanol that the rate constant for sulfur-oxygen bond fission in p-methoxyneophyl 2,6-dimethylbenzenesulfinate in the presence of 2,6-lutidine was enhanced by a factor of 10, while in the presence of potassium acetate the rate constant was retarded by a factor of 10. The behavior of azide ion in promoting sulfur-oxygen bond fission would be expected to parallel that of acetate ion since both of these are charged species while 2,6-lutidine is a neutral species. The observed rate of solvolysis of benzhydryl 2,6-dimethylbenzenesulfinate in 80% ethanol is larger by a factor of 10 than the rate constant for the reaction of the ester in anhydrous ethanol. The combination of an increase in the rate constant by a factor of 10 and a retardation in the

rate of azide assisted sulfur-oxygen bond fission by a factor of 10 on changing solvents would suggest that only 1/100 as much sulfur-oxygen bond fission would be observed in the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in 80% aqueous ethanol as in anhydrous ethanol.

Controls were carried out to determine whether sulfur-oxygen bond fission took place in the acetolysis of benzhydryl 2,6-dimethylbenzenesulfinate in acetic acid with added sodium acetate and acetic anhydride. A three-fold increase in the concentration of sodium acetate decreased the fraction of reaction proceeding to give benzhydryl 2,6-dimethylphenyl sulfone from 0.64 to 0.61 as may be seen from the date in Table XX. If acetate ion were promoting appreciable sulfur-oxygen bond fission in acetic acid, a larger effect upon the distribution of solvolysis and rearrangement products would be expected by this change in concentration of sodium acetate. In all cases the sum of acetate and sulfone production accounted for 97% or more of the starting material. In addition the fractions of solvolysis and isomerization products were constant throughout a kinetic run.

The expected product of sulfur-oxygen bond fission in acetic acid would be benzhydryl alcohol. The possibility existed that benzhydryl alcohol might be formed and react with acetic acid solvent to give the acetate. However, when benzhydryl alcohol was submitted to the reaction conditions the observed rate of benzhydryl acetate formation, $k = 6 \times 10^{-7}$ sec^{-1}, was found to be non-competitive with the total reaction rate of 1.66×10^{-5} sec^{-1}

for the ester. Any alcohol formed would not have had the opportunity to react with the solvent before the product concentrations were determined. Gas chromatographic analysis of an infinity point from a solvolysis reaction after 96 hours (10 half-lives for solvolysis) showed that no benzhydryl alcohol was present. If any were formed, less than 20% of the alcohol would have undergone esterification during this time.

Ionization of Benzhydryl 2,6-Dimethylbenzenesulfinate to Give Solvolysis, Isomerization and Scrambling.

Preliminary studies of the solvolysis and isomerization of benzhydryl 2,6-dimethylbenzenesulfinate were reported by Darwish and McLaren[16] for a variety of solvents. Their results are shown in Table XXIII. For the solvents listed in the table there is a

TABLE XXIII[16]

SOLVOLYSIS AND REARRANGEMENT OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN A VARIETY OF SOLVENTS AT 90.0°.

Solvent	10^5 k, sec^{-1}	$F_{sulfone}$
90% Dioxane[a]	0.0912	0.68
90% Acetone[a]	0.241	0.50
Ethanol[b]	2.38 (2.30)[a, d]	0.35 (0.30)[d]
80% Ethanol[a]	23.0 (19.4)[a, d]	0.37 (0.36)[d]
Acetic Acid[c]	79.4	0.57

[a] 2,6-Lutidine present.
[b] Potassium acetate present.
[c] Sodium acetate present
[d] Data from research reported in this thesis

variation in the rate constant for the reaction of the ester by a factor of nearly 1000. This factor is of the magnitude which would be expected for an ionization reaction. Since the isomerization reaction and the solvolysis reaction both show solvent sensitivity of the same magnitude it was suggested that the reactions are ionic in character.

Further evidence that the reactions of benzhydryl 2,6-dimethylbenzenesulfinate are ionic was obtained by comparison with the solvolysis reactions of benzhydryl chloride. This compound should be a good model for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate since benzhydryl chloride would yield the same cation as would the ester. It is known that benzhydryl chloride undergoes solvolysis by ionization in these solvents. If similar intermediates are important in the reactions of both of these compounds, the compounds would be expected to exhibit similar sensitivity to changes in the reaction medium. The relationships between the logs of the rate constants for the solvolysis and isomerization of benzhydryl 2,6-dimethylbenzenesulfinate and the logs of the solvolysis rate constants for benzhydryl chloride are shown in Figure IX.

A linear relationship between the logs of the rate constants for ester solvolysis and the logs of the rate constants for benzhydryl chloride solvolysis was found with a slope of 0.82, with the exception of the reactions in acetic acid. A similar relationship with a slope of 0.67, also with the exception of the reactions is acetic acid, was found between the logs of the isomerization rate

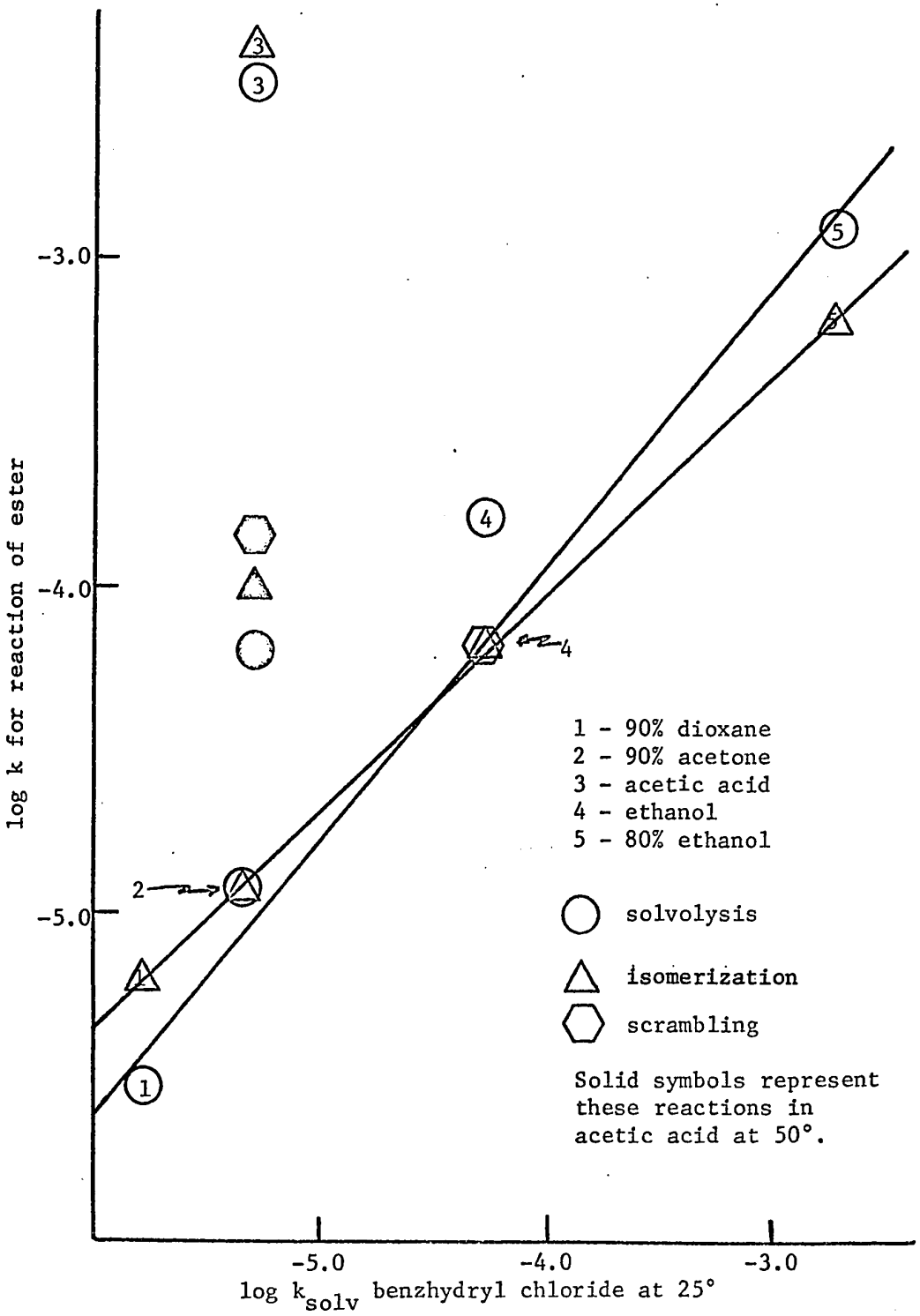


Figure IX. Relationship between log k's for solvolysis, isomerization, and oxygen scrambling of benzhydryl 2,6-dimethylbenzenesulfinate (90°) and log k for solvolysis of benzhydryl chloride.

constants for the ester and the logs of the rate constants for the solvolysis of the chloride. The linear relationships between the logs of the rate constants for the solvolysis and isomerization reactions of the ester and the logs of the solvolysis rate constants of benzhydryl chloride indicate that the reactions of the ester are ionic in character.

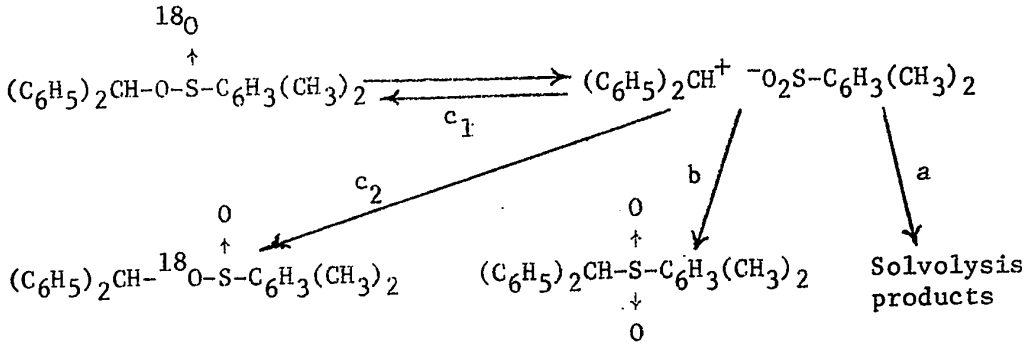
The values for the logs of the solvolysis and isomerization reactions of the ester in acetic acid are much greater than would be anticipated from the corresponding rate of solvolysis of the chloride. The values for the rate constants of the solvolysis and isomerization reactions are approximately 500 times larger than would be predicted. Part of this factor may be due to extensive ion pair return in the case of benzhydryl chloride in acetic acid. p-Chlorobenzhydryl chloride in acetic acid has been demonstrated to undergo **return** after ionization 38 times as fast as it solvolyzes while in 80% acetone the corresponding rate ratio is 3.[34] Thus the ionization rate of benzhydryl chloride in acetic acid is seriously underestimated. An additional factor to account for the enhancement of the reactions of benzhydryl 2,6-dimethylbenzenesulfinate in acetic acid was suggested by Darwish and McLaren[16] who proposed that specific solvation of the leaving group may be responsible for a portion of the increased rate of reaction. It has been proposed[30, 65] that the solvolyses of certain alkyl fluorides are enhanced by hydrogen bonding between the fluoride and a proton donor. Strong acids have been shown to accelerate the solvolyses of arenesulfinates as well.[66] A combination of the underestimation

of the ionization rate for benzhydryl chloride in acetic acid and acceleration of the reaction of the arenesulfinate due to hydrogen bonding with the solvent could account for the total rate deviation of the logs of the rate constants for reactions of the ester in acetic acid. However, whatever the detailed description for the mode of the rate enhancement observed in the solvolysis of benzhydryl 2,6-dimethylbenzenesulfinate in acetic acid, the same effect is observed upon both the solvolysis and isomerization rate constants. The fact that this very large rate enhancement in acetic acid is found for both the solvolysis and isomerization rate constants strongly indicates that the same transition state is important for both the solvolysis and isomerization reactions.

Also included in Figure IX are the logs of the rate constants for ^{18}O scrambling of labeled benzhydryl 2,6-dimethylbenzenesulfinate in ethanol at 90° and in acetic acid at 50°. The behavior of these rate constants parallels that of the solvolysis and isomerization rate constants. Just as the solvolysis and isomerization reactions are enormously speeded up in acetic acid, the rate constant for scrambling in acetic acid is much larger than would be expected on comparison to the solvolysis rate constant for benzhydryl chloride. Thus the same transition state may be postulated for the scrambling reaction as is suggested for the solvolysis and isomerization reactions.

The values for ionization rate constants given in the results of this chapter represent lower limits to the rate constants for

ionization of benzhydryl 2,6-dimethylbenzenesulfinate. Upon ionization the arenesulfinate ester has been shown to undergo three different reactions. These reactions are (a) reaction of the



benzhydryl cation with the solvent to give solvolysis products, (b) recombination of the ions to generate sulfone and (c) recombination of the ions to regenerate the arenesulfinate ester. If the rate constants for all of these reactions are determined, the sum of the values will be equal to the ionization rate constant. The rate constants for the solvolysis and isomerization reactions may be determined without ambiguity. However, the possibility exists that return to the arenesulfinate ester may take place with preferential attack at the oxygen atom originally bonded to the benzhydryl moiety, i.e. $c_1 > c_2$. If any preference exists for return to this oxygen atom then the ionization rate constant would be greater than the sum of the observed rate constants for solvolysis, isomerization and scrambling. The sum of these rate constants therefore represents a minimum estimate of the ionization rate constant.

The Ionic Intermediates Involved in the Reactions of Benzhydryl 2,6-Dimethylbenzenesulfinate in Ethanol and 80% Aqueous Ethanol.

The effects of added salts upon solvolysis reactions often provide a great deal of insight into the course of the reactions. The effects of various added salts upon the solvolysis, isomerization and oxygen scrambling rate constants for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol at 90° are summarized in Table XXIV. The error range for the rate constants reported in this table is ± 5%.

TABLE XXIV

SOLVOLYSIS, SCRAMBLING AND ISOMERIZATION IN THE ETHANOLYSIS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE.

Added salt	[Salt]	$10^5 k_{ion}$, sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{scr}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
None	----	2.97	1.61	0.67	0.69
Bu_4NN_3	.12	3.41[a]	2.15[a]	0.59	0.68
		(3.18)	(1.92)		
Bu_4NClO_4	.12	3.01	1.65	0.65	0.71
$Bu_4NO_2SC_6H_3(CH_3)_2$[b]	.12	2.92	1.66	0.55	0.71

[a] These values include contribution to reaction of the ester by sulfur-oxygen bond fission with k_{s-o} estimated at 0.23×10^{-5} sec^{-1}. Values in parentheses are after subtraction of k_{s-o}.
[b] Tetrabutylammonium 2,6-dimethylbenzenesulfinate.

The addition of 0.12 molar concentration of tetrabutylammonium perchlorate and tetrabutylammonium 2,6-dimethylbenzenesulfinate resulted in essentially no change in the rate constants for solvolysis,

isomerization and oxygen scrambling. The lack of any positive salt effect by tetrabutylammonium perchlorate suggests that no common ion rate depression is taking place in the presence of added 2,6-dimethylbenzenesulfinate anion. The possibility existed that any decrease in the rate constant due to common ion rate depression could have been obscured by a combination of an increase in the reaction rate constant due to a positive salt effect and the decrease due to common ion rate depression. The lack of any positive salt effect in the presence of tetrabutylammonium perchlorate renders this possibility very unlikely.

The lack of any change in the rate constant for sulfone formation or in the fraction sulfone formed in the reaction with added 2,6-dimethylbenzenesulfinate salt shows that sulfone must arise from an ion pair species. Free ions cannot be involved to any significant extent because a greater amount of sulfone would be formed if they were.

Further evidence for the lack of involvement of free ions in sulfone formation was given in Table VI. Added tetrabutylammonium benzenesulfinate and 4-methylbenzenesulfinate did not result in formation of benzhydryl phenyl and 4-methylphenyl sulfones respectively. If any return from dissociated ions to give sulfone were taking place, added 0.12 molar concentrations of these added salts should compete effectively with the maximum approximately 0.02 molar concentration of 2,6-dimethylbenzenesulfinate anion produced in the reaction.

In the case of ethanolysis runs containing added tetrabutylammonium azide, the values of the rate constants for ionization and solvolysis are more difficult to analyze. The values reported for the ionization and solvolysis rate constants in the presence of this added salt include the rate constant for sulfur-oxygen bond fission in the presence of azide ion. From the data obtained in the product analysis (Table XVII) the contribution of this reaction may be determined. The calculated rate constant for sulfur-oxygen bond fission at 0.12 molar tetrabutylammonium azide concentration is 0.23×10^{-5} sec^{-1}. After subtraction of this value from the rate constants for solvolysis and ionization, these rate constants overlap the values of the rate constants of solvolysis and ionization in the absence of any added salt within the experimental error.

If these rate constants are indeed different in the presence and absence of tetrabutylammonium azide, the difference could be explained by a second-order displacement reaction by azide ion upon the ester to give benzhydryl azide. Such a reaction would be expected to be relatively insensitive to solvent effects on changing from ethanol to aqueous ethanol. If any effect were observed, it would be expected that the second-order reaction would decrease in rate. Since the rate constant for disappearance of benzhydryl 2,6-dimethylbenzenesulfinate in 80% ethanol is almost 10 times the value in anhydrous ethanol, very little benzhydryl azide would be expected from the reaction in 80% ethanol if a second-order reaction with the ester were giving rise to benzhydryl azide. However, a

similar amount of benzhydryl azide is formed in aqueous ethanol. This suggests that a second-order reaction between the ester and azide ion to yield benzhydryl azide is not taking place. The determination of the rate constants for solvolysis and isomerization in the presence of tetrabutylammonium azide (see Table XII) have inherent in their measurement a large experimental error. This is accounted for by the difficulty in determining the end points of the titrations since the weak acid, hydrazoic acid, is being titrated in the presence of an azide salt. In view of the large error it is difficult to say whether the rate constants in the absence and in the presence of 0.12 molar tetrabutylammonium azide are significantly different.

With larger concentrations of added tetrabutylammonium azide it is obvious that sulfur-oxygen bond fission cannot account for the total increase in the reaction rate of benzhydryl 2,6-dimethylbenzenesulfinate. It is possible that the remaining amount of the increase is due to the existence of a positive salt effect.

In both ethanol and 80% ethanol the presence of tetrabutylammonium azide results in the formation of benzhydryl azide in the reaction of benzhydryl 2,6-dimethylbenzenesulfinate. It is seen from Tables XII and XIII that the fraction of isomerization is decreased by the added azide salt. It is shown in Table XVII that solvolysis and isomerization products are decreased by approximately the same relative amounts on addition of the azide salt. The conclusion reached therefore is that in ethanol and in

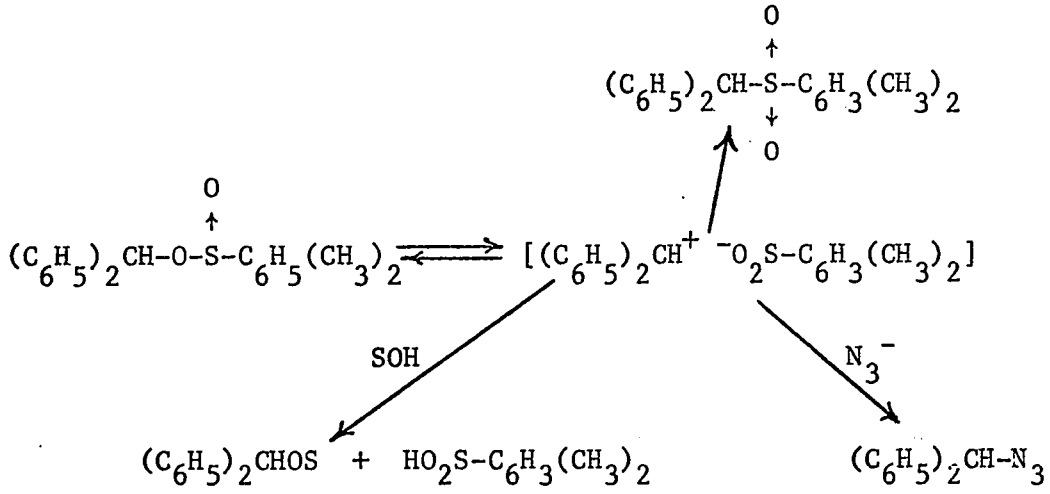
80% ethanol a precursor of both solvolysis products and sulfone is diverted to benzhydryl azide by the azide ion.

It has been shown that sulfone does not arise from free ions. Added tetrabutylammonium 2,6-dimethylbenzenesulfinate does not change the fraction of sulfone formed and added 4-methylbenzenesulfinate and benzenesulfinate anions do not lead to the production of the benzhydryl sulfones which would arise from exchange with these anions. In addition return to give ester cannot take place from free ions since, if this were the case, added unlabeled tetrabutylammonium 2,6-dimethylbenzenesulfinate at 0.12 molar concentration would virtually eliminate all scrambling. Instead, the rate constant for scrambling is essentially unchanged. Both isomerization and scrambling must therefore involve an ion pair species and not free ions. It is not possible to rule out the formation of solvolysis products through free ions. If free ions are formed, however, they must react entirely to give solvolysis products.

On the basis of evidence presented so far concerning the reactions of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol and aqueous ethanol it may be said that at least one ion pair species is an important intermediate in the solvolysis, isomerization and oxygen scrambling reactions of the ester. Free ions are proposed to be of negligible importance in the isomerization and oxygen scrambling reactions. The existence of more than one ion pair species cannot be proved or disproved by the data presented.

The conclusions reached thus far suggest the following

reaction scheme. In this scheme the intermediate is an ion pair. Whether it is an intimate or solvent-separated ion pair cannot as yet be defined.



The Reactions of Benzhydryl 2,6-Dimethylbenzenesulfinate in Acetic Acid.

The reaction of benzhydryl 2,6-dimethylbenzenesulfinate in acetic acid is similar to the corresponding reaction in ethanol. The roles of isomerization and solvolysis are quantitatively reversed, with the formation of 63% sulfone and 37% solvolysis products at 50°. The nucleophilicity of acetic acid is considerably less than that of ethanol. This could result in a decrease in the formation of products of nucleophilic attack by solvent as compared to recombination of the arenesulfinate anion with the benzhydryl cation.

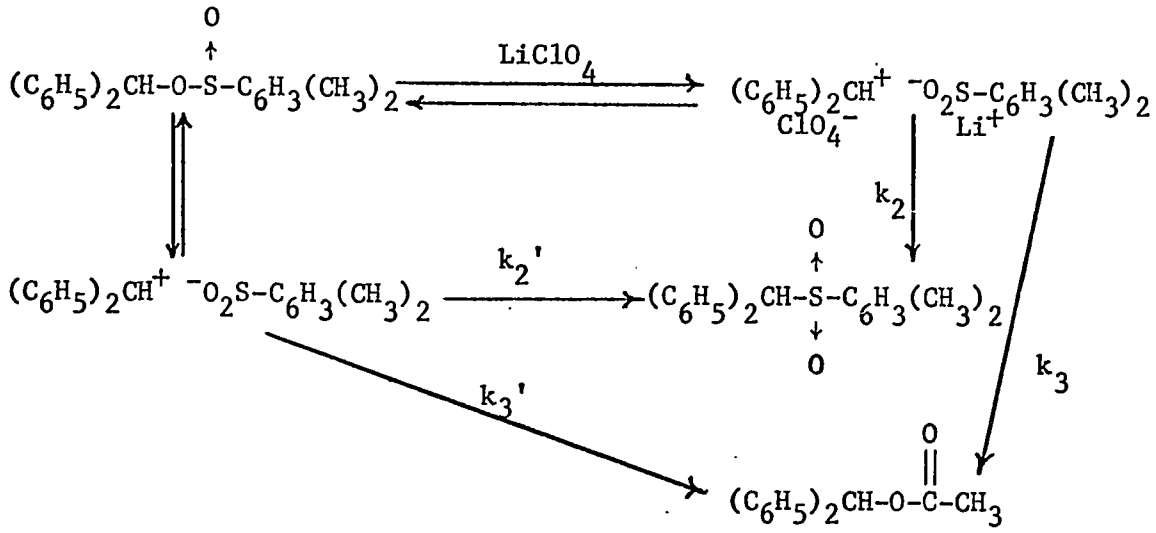
A considerable enhancement in the rate of disappearance of the ester in acetic acid is observed on the addition of lithium perchlorate. This rate enhancement would correspond to a b value of approximately 25. In addition the effect upon the product distribution and upon the relative rates of solvolysis, isomerization to benzhydryl 2,6-dimethylphenyl sulfone and oxygen scrambling is pronounced. These changes may be explained in two ways.

The observations are consistent with the intervention of two ionic species. Examination of the rates of ionization, scrambling, solvolysis and rearrangement as given in Table XXII shows that the addition of 0.053 molar lithium perchlorate results in a 75% increase in the ionization rate constant, a 24% increase in the scrambling rate constant, a 58% increase in the isomerization rate constant and a 217% increase in the solvolysis rate constant. Since the increases in rates of scrambling and isomerization are less than the increase in the ionization rate a net decrease in the fraction of reaction proceeding to give these products is observed. These figures would be consistent with the action of lithium perchlorate on an ion pair to promote dissociation to a second ionic species further along the ionization-dissociation sequence. This dissociation could take place at the expense of ion pair recombination which would result in isomerization or scrambling. This data is qualitatively in accord with the results obtained by Goering and Fickes[46] in the study of the solvolysis of endo-bicyclo [3.2.1] octan-2-yl (equatorial) p-toluenesulfonate. These

workers showed that in the acetolysis of this arenesulfonate that lithium perchlorate affected the polarimetric and titrimetric rate constants differently. They observed a much larger increase in the titrimetric (solvolysis) rate constant than in the polarimetric (ionization) rate constant. These authors concluded that racemization resulted from internal return and that solvolysis products resulted from a species which was less associated and which was incapable of return to ester.

An alternate explanation of the effect of lithium perchlorate on the behavior of the arenesulfinate ester in acetic acid may be suggested. Addition of lithium perchlorate could result in the direct assistance of the ionization reaction by this salt. This might be pictured as salt promoted ionization of the ester to give an ionic aggregate composed of benzhydryl and lithium cations and perchlorate and 2,6-dimethylbenzenesulfinate anions. Thus in the presence of lithium perchlorate reaction would be viewed as proceeding by the normal ionization-dissociation process and by a lithium perchlorate assisted ionization process. This type of scheme is shown on the following page.

In this scheme the reactions k_3 and k_3' do not necessarily represent direct conversion of the respective intermediates to benzhydryl acetate. These reactions may take place directly from the species suggested or from an ionic species which is further along the ionization dissociation sequence.



If it is assumed that there is no change in the rate constants for the normal reactions when lithium perchlorate is added, it is possible to calculate the fractions of the assisted reaction which proceed to give solvolysis, isomerization and scrambling.

The rate constants for ionization, oxygen scrambling, solvolysis and isomerization of benzhydryl 2,6-dimethylbenzesulfinate in the presence and in the absence of added lithium perchlorate are presented in Tables XXI and XXII. They are summarized in Table XXV.

Calculation of the percentages of the ionization rate constant due to the scrambling, solvolysis and isomerization rate constants in the absence of lithium perchlorate gives 47%, 20% and 33% respectively. This then is how the product of ionization distributes itself among the possible reactions in the absence of lithium perchlorate.

In the presence of 0.05386 molar lithium perchlorate all rate

TABLE XXV

RATE CONSTANTS FOR THE REACTIONS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ANHYDROUS ACETIC ACID WITH ADDED (0.1 M) SODIUM ACETATE AND (0.1 M) ACETIC ANHYDRIDE.

$[LiClO_4]$		$10^5 k_{ioniz}$ sec^{-1}	$10^5 k_{scr}$, sec^{-1}	$10^5 k_{solv}$, sec^{-1}	$10^5 k_{isom}$, sec^{-1}
-----		3.07 ± .02	1.43 ± .03	0.63 ± .03	1.01 ± .02
.05386		5.37 ± .12	1.78 ± .05	2.00 ± .10	1.60 ± .04
	Δk[a]	2.30	0.35	1.37	0.59
.1002		----	----	4.40 ± .06	2.76 ± .04
	Δk[a]	----	----	3.77	1.75

[a] Difference between the rate constant with the added salt and the rate constant in the absence of the added salt.

constants are increased and the amounts of the increases in the rate constants are given by the Δk values. If it is assumed that the increases in the rate constants are due wholly to salt assisted ionization to give an ion aggregate, and that the unassisted reactions proceed with the same rate constants as were observed in the absence of lithium perchlorate, the percentage distributions of the ion aggregate for each reaction may be calculated from the Δk values. The percentages of the assisted ionization rate constant which are due to the scrambling, solvolysis and isomerization rate constants are 15%, 60% and 26% respectively. The relative rates of solvolysis, scrambling and isomerization in the absence of added lithium perchlorate are 1 : 2.27 : 1.60; these numbers are equivalent to the rate ratios for the unassisted

reaction. For the assisted reaction, as determined from the Δk values, the relative rates of solvolysis, scrambling and isomerization are 1 : 0.26 : 0.43. This change in the relative rates for the various reactions would be consistent with the proposal that an ion aggregate is formed. It would be expected that very different proportions of products would be formed from the ion aggregate than from the ion pair.

If the rate constants for solvolysis and isomerization of benzhydryl 2,6-dimethylbenzenesulfinate with added lithium perchlorate are examined it is seen that the ratio for the increases in these rate constants are nearly the same. With 0.05386 molar lithium perchlorate the ratio of Δk_{solv} to Δk_{isom} is 2.32, while with 0.1002 molar lithium perchlorate this ratio is 2.15. The fact that this ratio remains nearly constant on changing the concentration of the lithium perchlorate suggests that this treatment of the action of added lithium perchlorate may be valid.

During the period covered by this research Fava and coworkers reported on the synthesis and reaction of optically active benzhydryl p-toluenesulfinate in acetic acid.[40, 41] These authors found that this optically active arenesulfinate ester lost its optical activity in acetic acid at 51° with a rate constant of $k_{\alpha} = 2.1 \times 10^{-4}$ sec^{-1}. Isomerization to sulfone proceeded with a rate constant of $k_{isom} = 0.8 \times 10^{-4}$ sec^{-1}. The racemization rate was equal to $k_{\alpha} - k_{isom}$ and was 1.6 times as great as the isomerization rate constant. These authors considered the possibility that the loss of optical activity could be

due to pyramidal inversion at sulfur but concluded that this was an unlikely explanation for the racemization of the ester, although this process could not be unequivocally ruled out.

The results obtained and described in this chapter support the conclusions of these workers. In acetic acid at 50° benzhydryl 2,6-dimethylbenzenesulfinate has been shown to undergo ionization to give at least one ion pair species. Return from the ionic species formed results in return to oxygen at a rate 1.4 times as large as the rate of return to sulfur. This closely parallels the equivalent rate ratio of 1.6 observed by Fava et al. for the racemization reaction to the isomerization reaction of benzhydryl p-toluenesulfinate. In addition the work reported here unequivocally shows that return to oxygen takes place rather than pyramidal inversion.

CHAPTER II

The Intermediates Involved in the Reactions of Benzhydryl 2,6-Dimethylbenzenesulfinate

INTRODUCTION

It was shown in Chapter I that the reactions of benzhydryl 2,6-dimethylbenzenesulfinate involve at least one ion pair species. It was impossible to tell, however, if a second ion pair species was involved in the reaction. In addition the role of free ions, if they are involved in the reactions, is not clear.

The effect of added tetrabutylammonium azide may resolve some of these questions. If there is more than one species which is important in the reaction the different intermediates would be expected to demonstrate dissimilar behavior toward the trapping agent. This type of behavior was observed by Darwish and Preston.[17] They observed that trityl 2-methylbenzenesulfinate underwent incomplete trapping by tetrabutylammonium azide in chloroform. It was reasoned that two ionic intermediates were involved in the reaction of this compound. One intermediate was capable of being trapped by added tetrabutylammonium azide while the other was not.

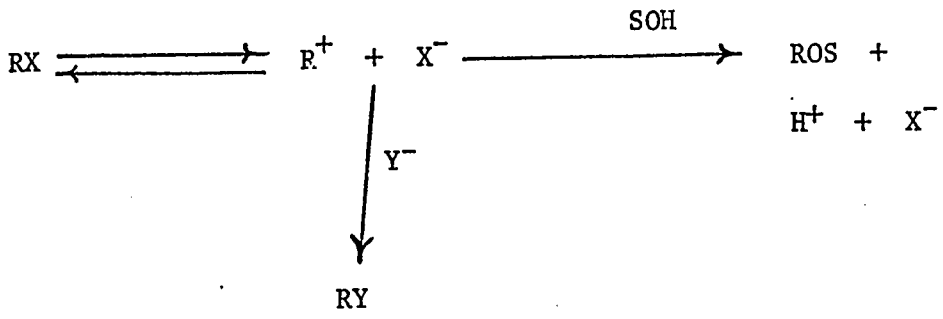
To determine if similar behavior is observed with benzhydryl 2,6-dimethylbenzenesulfinate the work described in this chapter was begun. It was desired to examine a model compound which would solvolyze to give products through ionic species which would be

trappable by an added nucleophile. In this way the behavior of the arenesulfinate ester could be compared with that of the model compound.

The solvolyses of benzhydryl chloride and substituted benzhydryl chlorides in a variety of solvents has been studied by several workers including Winstein and co-workers and Ingold and his research group.

The early studies of Bateman, Hughes and Ingold[28, 32] provided evidence that the solvolyses of benzhydryl chloride and bromide were ionic reactions. Most of the efforts of these workers were concentrated on the reactions of these compounds in aqueous acetone. The effects of added salts upon the reactions were investigated. It was found that these compounds were subject to common ion rate depression. In addition the effect of sodium azide upon the course of the reactions was investigated. Conversion of the substrates into the corresponding benzhydryl azides by the addition of sodium azide to the solvolysis medium was effected in high yield. p, p'-Dimethylbenzhydryl chloride gave essentially complete conversion to the azide in 50% aqueous acetone at 0.44 molar sodium azide concentration. The reactions of these compounds were conveniently explained by the assumption that the reaction proceeded by the way of dissociated ions. This is shown in Scheme VI.

Winstein and co-workers[7, 33, 34, 36, 37] examined the solvolysis and radiochloride exchange reactions of p-chlorobenzhydryl chloride as well as the racemization of optically active



SCHEME VI

p-chlorobenzhydryl chloride. It was apparent that ion pairs were important in the reaction of p-chlorobenzhydryl chloride in 80% aqueous acetone. The rate of loss of optical activity was about three times as large as the rate of solvolysis.[33] In acetic acid, a less nucleophilic solvent, the ratio of the polarimetric rate constant to the solvolysis rate constant increased to a value of 38.[34] The original Ingold scheme was modified by the inclusion of ion pairs which lose optical integrity and return to give racemic starting material.

Benzhydryl chloride was therefore viewed as a good model for the solvolysis of benzhydryl 2,6-dimethylbenzenesulfinate. It undergoes reaction in relatively nucleophilic solvents such as aqueous acetone *via* dissociated ions. Ion pairs are important as well in explaining the solvolytic behavior of this compound. If the capturable species is the free benzhydryl cation, complete conversion of the chloride to benzhydryl azide would be expected if the concentration of added azide ion were raised to a sufficiently high level.

RESULTS

The Effect of Added Tetrabutylammonium Azide upon the Solvolysis and Rearrangement of Benzhydryl 2,6-Dimethylbenzenesulfinate.

In addition to the kinetic runs described in Chapter I, product analysis runs were carried out to determine the effect of added tetrabutylammonium azide upon the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol and 80% ethanol. In all cases the fraction of benzhydryl azide formed was determined by infrared spectrometry using the standard procedure which has been described. The value for the fraction of benzhydryl azide formed in anhydrous ethanol is reported both as a fraction of total reaction and as a fraction of the total reaction less the contribution of sulfur-oxygen bond fission. The results of the runs in ethanol and in 80% aqueous ethanol are reported in Tables XXVI and XXVII respectively.

After carrying out the initial runs it was considered that 2,6-lutidine might not be a strong enough base to efficiently neutralize the acid formed. If this were the case the concentration of azide ion at low levels of added azide salt would be appreciably affected as the reaction proceeded and more acid was produced. To avoid this possibility triethylamine was used as the added base in a series of runs.

The use of sodium azide as the source of added azide ion for the reaction in 80% aqueous ethanol was examined. Only very

TABLE XXVI

PRODUCTS FROM THE SOLVOLYSIS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ANHYDROUS ETHANOL AT 90° WITH ADDED TETRABUTYLAMMONIUM AZIDE.

Run	[Ester]	[2,6-lut]	$[Bu_4NN_3]$	F_{azide}	$^{b}F_{azide}^{corr}$	$F_{sulfone}$
2-21	.02510	.05003	.04832	.052	.055	-----
2-28	.02492	.05003	.05286	.057	.061	-----
2-277	.02513	.05000	.05064	.055	.059	.292
2-146-1	.02516	.05003	.05487	.056	.060	.260
2-20	.02503	.05003	.06609	.068	.072	-----
2-3	.02402	.05003	.08366	.085	.091	.240
2-276	.02511	.05000	.1013	.107	.115	.261
2-146-2	.02500	.05003	.1097	.110	.118	.241
2-4	.02495	.05003	.1466	.125	.137	.213
2-275	.02517	.05000	.1519	.147	.162	.241
2-146-3	.02513	.05003	.1574	.139	.153	.224
2-274	.02510	.05000	.2026	.179	.201	.225
2-146-4	.02516	.05003	.2054	.164	.184	.206
2-273	.02527	.05000	.2532	.221	.251	.209
2-294	.02527	.05000	.4475	.276	-----	.149
3-23-5[a]	.02400	.05001	.04628	.055	.059	-----
3-23-6[a]	.02404	.05001	.07713	.083	.089	-----
3-23-4[a]	.02387	.05001	.09256	.097	.104	-----
3-23-3[a]	.02414	.05001	.1388	.131	.142	-----
3-23-2[a]	.02386	.05001	.1851	.156	.173	-----
3-23-1[a]	.02477	.05001	.2314	.179	.201	----

[a] Indicates the base was triethylamine rather than 2,6-lutidine.
[b] Fraction azide produced as a fraction of the sum of solvolysis, isomerization and azide formation reactions.

TABLE XXVII

PRODUCTS FROM THE SOLVOLYSIS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN 80% AQUEOUS ETHANOL AT 90.0° IN THE PRESENCE OF 2,6-LUTIDINE AND ADDED TETRABUTYLAMMONIUM AZIDE.

Run	[ester]	[2,6-lut]	$[Bu_4NN_3]$	F_{azide}	$F_{sulfone}$
2-29	.01236	.05002	.05001	.065	----
2-23	.01337	.05002	.05211	.066	----
2-293	.01784	.0500	.05216	.066	.361
2-22	.01281	.05002	.07528	.095	----
2-5	.01150	.05002	.09201	.111	.321
2-292	.01792	.0500	.1043	.120	.339
2-6	.01222	.05002	.1482	.158	.321
2-291	.01821	.0500	.1565	.161	.321
2-290	.01824	.0500	.2086	.200	.298
2-289	.01789	.0500	.2608	.229	.300
2-295	.01758	.05002	.4968	.330	.254
3-25-5[a]	.01803	.05068	.05346	.060	----
3-25-6[a]	.01815	.05068	.08910	.092	----
3-25-4[a]	.01828	.05068	.1069	.106	----
3-25-3[a]	.01808	.05068	.1604	.145	----
3-25-2[a]	.01809	.05068	.2138	.173	----
3-25-1[a]	.01803	.05068	.2673	.199	----
3-36-5[a,b]	.01478	.05091	.05016	.068	----
3-36-6[a,b]	.01460	.05091	.08360	.105	----
3-36-4[a,b]	.01525	.05091	.1003	.120	----
3-36-3[a,b]	.01553	.05091	.1505	.155	----
3-36-2[a,b]	.01466	.05091	.2006	.182	----

continued . . .

Run	[Ester]	[2,6-lut]	[Bu_4NN_3]	F_{azide}	$F_{sulfone}$
3-36-1[a,b]	.01519	.05091	.2508	.206	----

[a] The base is triethylamine rather than 2,6-lutidine.
[b] The azide salt is sodium azide rather than tetrabutylammonium azide.

slight changes in the amount of benzhydryl azide formed are noted in comparison to runs containing tetrabutylammonium azide.

The Solvolysis of Benzhydryl Chloride in Ethanol and 80% Aqueous Ethanol.

Benzhydryl chloride commercially available from the Aldrich Chemical Company was found to be sufficiently pure for kinetic runs after it had been distilled at reduced pressure. The kinetics of the solvolysis reaction were followed titrimetrically by the formation of acid in most cases. In a few runs in aqueous ethanol the reactions were followed by titration of chloride ion. The procedure used was the adaptation by Fainberg and Winstein[43] of a modified Volhard method described by Caldwell and Moyer.[42]

The reaction was studied at 25° in the presence and the absence of added salts and base. Care must be taken to have the solvent pre-equilibrated at 25° when the reaction is run in 80% aqueous ethanol since the reaction is very rapid ($t_{1/2}$ = 6 min). It was important in runs in which an added salt was present that the benzhydryl chloride be added to a solution of the salt in the solvent employed. Direct weighing of benzhydryl chloride onto the salt used resulted in reaction between the chloride and the

salt prior to addition of the solvent.

Aliquots of the reaction solution were withdrawn and the reaction was quenched by delivery into acetone. This solution was titrated for developing acid. The rate constant for production of acid was determined using the equation

$$k = \frac{2.303}{t} \log \frac{(T_\infty - T_o)}{(T_\infty - T_t)}$$

where T_t is the titer at time = t.

Good first-order kinetics were observed under all conditions investigated. Rate constants were free from drift and sample calculations for the solvolysis in ethanol and 80% aqueous ethanol in the presence and the absence of tetrabutylammonium, sodium and lithium azide salts are given in Tables XXVIII - XXXIV. Error ranges for rate constants are usually less than ± 2%.

In all kinetic runs in the presence of azide salts the amount of benzhydryl azide was determined by the difference between the theoretical and the observed acid titers. In product analysis runs the amount of benzhydryl azide was determined directly by infrared spectrometry. The standard extraction procedure described in Chapter I for the determination of the concentration of benzhydryl azide in alcohol solution was used. The results of kinetic and product analysis experiments for the solvolysis of benzhydryl chloride are given in Tables XXXV - XL. The effects of changes in solvent and the addition of tetrabutylammonium, sodium and lithium azides are shown in these tables.

The relationships between the concentration of the added azide salts and the observed solvolysis rate constants of benzhydryl chloride in the presence of these salts are shown graphically in Figures X - XIV. The calculations of b values using the equation

$$k = k_o \{1 + b[salt]\}$$

were carried out and these results are given on the figures.

TABLE XXVIII

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02414 M) IN ANHYDROUS ETHANOL AT 25.0°.

Base: Sodium methoxide (.02803 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 4.312 ml

Time (sec)	Titer (ml)	10^5 k_t, sec^{-1}
0	.413	----
1920	.777	5.25
3603	1.051	5.11
4919	1.281	5.28
6295	1.459	5.12
7677	1.663	5.20
9358	1.920	5.40
11045	2.117	5.40
12833	2.273	5.25
15246	2.273	5.25
14 $t_{1/2}$	4.207	Average 5.24 ± .08
14 $t_{1/2}$	4.208	Reported[30] 5.49
17 $t_{1/2}$	4.213	

Titer was 97.6% of theoretical.

TABLE XXIX

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02730 M) IN ANHYDROUS ETHANOL AT 25.0° WITH ADDED TETRABUTYLAMMONIUM AZIDE (.05273 M).

Base: Sodium methoxide (.02803 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 4.869 ml

Time (sec)	Titer (ml)	$10^5 k_t$, sec^{-1}
0	0.193	----
1803	0.649	(6.29)
3754	1.059	6.07
5197	1.336	6.02
6247	1.538	6.09
7352	1.711	6.01
8845	1.956	6.05
10550	2.183	5.98
12589	2.432	5.94
14455	2.653	5.98
16775	2.880	5.96
19270	3.099	5.97
21206	3.248	5.98
16 $t_{1/2}$	4.454	
		Average 6.00 ± .04
16 $t_{1/2}$	4.447	
24 $t_{1/2}$	4.438	

Average infinity titer was 91.3% of theoretical. Normalizing to 100% reaction from 97.6% indicates 93.5% of theoretical acid and 6.5% of theoretical azide formed.

TABLE XXX

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02450 M) IN ANHYDROUS ETHANOL AT 25.0° WITH ADDED LITHIUM AZIDE (.2068 M).

Base: Sodium methoxide (.02803 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 4.376 ml

Time (sec)	Titer (ml)	$10^5 k_t$, sec^{-1}
0	.262	----
1496	.594	8.40
3213	.938	(7.84)
4175	1.087	8.32
5077	1.237	8.38
6159	1.406	8.48
7307	1.551	8.39
10324	1.906	8.51
11960	2.058	8.51
13252	2.165	8.52
15039	2.300	8.57
17446	2.430	8.44
19975	2.548	8.39
23988	2.693	8.32
12 $t_{1/2}$	3.078	Average 8.44 ± .07
12 $t_{1/2}$	3.080	
27 $t_{1/2}$	3.070	
27 $t_{1/2}$	3.072	

Average infinity titer was 70.3% of theoretical. Normalizing to 100% reaction from 97.6% indicates 72.0% of theoretical acid and 28.0% of theoretical azide formed.

TABLE XXXI

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02364 M) IN 80% AQUEOUS ETHANOL AT 25.0°.

Titrants: Potassium thiocyanate (.03047 M) Aliquot: 5.00 ml
Silver nitrate (.03029 M)

Indicator: Ferric alum Calculated infinity: 3.908 net ml of silver nitrate.

Time (sec)		Titer (ml)	10^3 k_t, sec^{-1}
0		0.957	----
60		1.279	1.96
116		1.487	1.74
173		1.724	1.95
228		1.936	1.80
293		2.177	1.78
359		2.520	1.94
439		2.520	1.77
497		2.706	1.86
567		2.906	1.97
632		2.992	1.91
717		3.116	1.90
809		3.274	1.98
10 $t_{1/2}$			
10 $t_{1/2}$	Average	3.856	1.88 ± .08
50 $t_{1/2}$			

Titer was 98.7% of theoretical.

TABLE XXXII

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02520 M) IN 80% AQUEOUS ETHANOL AT 25.0° WITH ADDED TETRABUTYLAMMONIUM AZIDE (.1192 M).

Base: Sodium methoxide (.02803 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 4.501 ml

Time (sec)	Titer (ml)	$10^3 k_t$, sec^{-1}
0	0.642	----
41	0.866	1.83
81	1.071	1.84
120	1.271	1.89
157	1.422	1.85
198	1.604	1.88
236	1.748	1.87
300	1.971	1.86
358	2.153	1.87
419	2.322	1.86
479	2.487	1.89
566	2.716	1.95
658	2.852	1.89
748	2.992	1.89
840	3.114	1.90
20 $t_{1/2}$	3.745	
20 $t_{1/2}$	3.741	Average 1.88 ± .02
30 $t_{1/2}$	3.746	

Average titer was 83.2% of theoretical. Normalizing to 100% reaction from 98.7% gives 84.3% of theoretical acid and 15.7% of theoretical azide.

TABLE XXXIII

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02439 M) IN 80% AQUEOUS ETHANOL AT 25.0° WITH ADDED LITHIUM AZIDE (.1051 M).

Base: Sodium methoxide (.02803 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 4.356 ml

Time (sec)	Titer (ml)	$10^3 k_t$, sec^{-1}
0	1.251	-----
39	1.454	(2.36)
79	1.657	2.45
115	1.826	2.49
155	2.008	2.57
195	2.160	2.57
259	2.364	2.55
319	2.528	2.53
380	2.677	2.54
442	2.823	2.59
536	2.960	2.52
626	3.089	2.55
719	3.189	2.55
805	3.256	2.53
24 $t_{1/2}$	3.555	Average 2.54 ± .03
34 $t_{1/2}$	3.553	
34 $t_{1/2}$	3.563	

Average titer was 81.6% of theory. Normalizing to 100% reaction from 98% gives 82.7% of theoretical acid and 17.3% of theoretical azide.

TABLE XXXIV

RATE OF REACTION OF BENZHYDRYL CHLORIDE (.02393 M) IN 80% AQUEOUS ETHANOL AT 25.0° WITH ADDED SODIUM AZIDE (.09840 M).

Base: Sodium methoxide (.02803 M) Aliquot: 5.00 ml

Indicator: Phenolphthalein Calculated infinity: 4.274 ml

Time (sec)	Titer (ml)	$10^3 k_t$, sec^{-1}
0	0.839	----
37	1.054	2.25
77	1.277	2.31
118	1.485	2.33
154	1.649	2.33
193	1.802	2.30
231	1.971	2.37
273	2.115	2.36
331	2.305	2.38
393	2.479	2.40
454	2.617	2.39
513	2.716	2.34
604	2.882	2.36
695	3.002	2.35
785	3.086	2.30
15 $t_{1/2}$	3.530	Average 2.34 ± .03
15 $t_{1/2}$	3.538	
180 $t_{1/2}$	3.523	
180 $t_{1/2}$	3.519	

Average titer was 82.5% of theoretical. Normalizing to 100% reaction from 98.0% gave 83.6% of theoretical acid and 16.4% of theoretical azide.

TABLE XXXV

THE SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN ANHYDROUS ETHANOL AT 25.0° IN THE ABSENCE OF BASE.

Run	[Chloride]	Salt	[Salt]	F_{solv} [a]	F_{azide} [b]	$10^5 k_t$, sec^{-1}
1-181	.02414	-----	-----	1.0	-----	5.24 ± .08
2-25	.03120	Bu_4NN_3	.05004	.930	.070	----
1-232	.02730	"	.05273	.935	.065	6.00 ± .04
2-24	.03124	"	.06316	.908	.092	----
2-11	.02650	"	.07355	.901	.099	6.00 ± .12
2-1	.02600	"	.09855	.855	.145	6.24 ± .02
1-260-.1	.03092	"	.09876	.852	.148	----
1-233	.02529	"	.1035	.868	.132	6.48 ± .09
2-2	.02270	"	.1548	.783	.217	6.68 ± .03
1-260-.2	.02998	"	.2069	.720	.280	----
1-247	.02762	"	.4496	.528	.472	7.38 ± .05
1-190	.02064	LiN_3	.02289	.969	.031	5.55 ± .07
1-187	.02568	"	.05093	.918	.082	6.10 ± .04
2-7	.02534	"	.07426	.882	.118	6.47 ± .11
1-186	.02644	"	.09907	.839	.161	6.94 ± .04
1-191	.02450	"	.2068	.720	.280	8.44 ± .07
1-192	.02586	"	.4093	.562	.438	11.4 ± .10

[a] Actual acid titer in the absence of any azide salt is 97.6% of theory. The tabulated values for the fraction of reaction giving solvolysis are normalized by dividing the observed fraction by 0.976.

[b] Obtained by difference ($1.000 - F_{solv}$).

TABLE XXXVI

THE SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN ANHYDROUS ETHANOL AT 25.0° IN THE PRESENCE OF TETRABUTYLAMMONIUM AZIDE AND 0.05056 M TRIETHYLAMINE.

Run	[Chloride]	$[Bu_4NN_3]$	F_{azide} [a]
3-19-1	.02198	.2575	.333
3-19-2	.02240	.2060	.281
3-19-3	.02129	.1545	.230
3-19-4	.02364	.1030	.166
3-19-6	.02396	.08583	.150
3-19-5	.02273	.05150	.100

[a] The chloride used gave 98.5% of the theoretical acid titer in the absence of any added salt. The amount of azide formed was determined by infrared spectroscopy and was divided by .985 to normalize to 100% reaction.

TABLE XXXVII

THE SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN ANHYDROUS ETHANOL AT 25.0° IN THE PRESENCE OF LITHIUM AZIDE AND 0.02899 M LITHIUM ETHOXIDE.

Run	[Chloride]	$[LiN_3]$	F_{azide} [a]
3-13-1	.02467	.2548	.387
3-13-2	.02617	.2038	.331
3-13-3	.02648	.1529	.260
3-13-4	.02421	.1019	.189
3-13-6	.02105	.08493	.166
3-13-5	.02666	.05096	.110

[a] The chloride used gave 98.5% of the theoretical acid titer in the absence of any added salt. The amount of azide formed was determined by infrared spectroscopy and was divided by .985 to normalize to 100% reaction.

TABLE XXXVIII

SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN 80% AQUEOUS ETHANOL AT 25.0° IN THE ABSENCE OF ADDED SALTS AND IN THE PRESENCE OF ADDED TETRABUTYLAMMONIUM AZIDE.

Run	[Chloride]	$[Bu_4NN_3]$	Base	[Base]	F_{azide}[b]	$10^3 k_t$, sec^{-1}
1-132[a]	.02023	----	----	----	----	2.10 ± .1
1-133[a]	.02362	----	----	----	----	1.94 ± .03
1-134[a]	.02285	----	----	----	----	1.96 ± .03
1-145[a]	.02364	----	----	----	----	1.88 ± .08
1-156-I	.02553	.03873	-----	----	.069	----
1-136	.02242	.03301	----	----	.050	1.92 ± .04
2-27	.02810	.04288	----	----	.048	----
2-26	.02397	.06872	----	----	.096	----
2-8	.02626	.06986	----	----	.088	----
1-152	.02520	.1192	----	----	.157	1.88 ± .02
1-156-II	.02767	.1884	----	----	.227	----
1-287	.02769	.1971	----	----	.272	----
1-149	.02341	.4177	----	----	.348	1.50 ± .04
1-182	.02653	.4340	----	----	.383	1.46 ± .02
3-18-5[d]	.02410	.04146	TEA[c]	.05037	.070	----
3-18-6[d]	.02705	.06910	TEA	.05037	.106	----
3-18-4[d]	.02252	.08292	TEA	.05037	.126	----
3-18-3[d]	.02003	.1244	TEA	.05037	.173	----
3-18-2[d]	.02252	.1658	TEA	.05037	.206	----
3-18-1[d]	.01825	.2073	TEA	.05037	.241	----
3-31-3[d]	.02092	.05346	TEA	.05070	.072	----
3-34-5[d]	.02761	.05030	TEA	.05171	.074	----

continued . . .

Run	[Chloride]	[Bu_4NN_3]	Base	[Base]	F_{azide}[b]
3-34-6[d]	.02398	.08383	TEA	.05171	.113
3-34-4[d]	.02137	.1006	TEA	.05171	.130
3-34-3[d]	.01786	.1509	TEA	.05171	.178
3-34-2[d]	.02242	.2012	TEA	.05171	.214
3-34-1[d]	.02297	.2515	TEA	.05171	.250
3-31-1[d]	.01930	.4303	TEA	.05070	.351
3-38-5[d]	.02416	.05448	Bu_4NOH[e]	.05840	.073
3-38-6[d]	.02123	.09080	"	.05840	.115
3-38-4[d]	.02447	.1090	"	.05840	.131
3-38-3[d]	.02443	.1634	"	.05840	.179
3-38-2[d]	.02169	.2179	"	.05840	.220
3-38-1[d]	.02013	.2724	"	.05840	.256

[a] These runs followed by production of chloride ion; all others followed by acid production.
[b] Determined by difference between theoretical normalized titer and observed acid titer.
[c] Triethylamine.
[d] Benzhydryl azide determined by infrared spectrometry.
[e] Tetrabutylammonium hydroxide.

TABLE XXXIX

SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN 80% AQUEOUS ETHANOL AT 25.0° IN THE PRESENCE OF SODIUM AZIDE.

Run	[Chloride]	[NaN_3]	[NaOEt][a]	F_{azide}[b]	$10^3 k_t$, sec^{-1}
1-148	.02337	.02587	----	.037	2.05 ± .03
2-19-1	.02540	.04989	----	.078	----
2-9	.02496	.05109	----	.070	----
2-19-2	.02397	.06718	----	.109	----
1-150	.02393	.09840	----	.164	2.34 ± .03
2-10	.02679	.1516	----	.224	2.55 ± .03
1-151	.02570	.2010	----	.297	2.79 ± .05
1-154	.02336	.4007	----	.469	3.31 ± .06
3-2-5[c]	.02506	.05068	.02361	.100	----
3-7-2[c]	.02667	.07240	.02361	.133	----
3-2-4[c]	.02406	.1014	.02361	.176	----
3-2-3[c]	.02104	.1520	.02361	.238	----
3-2-2[c]	.02313	.2027	.02361	.295	----
3-2-1[c]	.02510	.2534	.02361	.352	----

[a] Sodium ethoxide.
[b] Determined by difference between theoretical normalized acid titer and observed acid titer.
[c] Benzhydryl azide determined by infrared spectrometry.

TABLE XXXX

SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN 80% AQUEOUS ETHANOL AT 25.0° IN THE PRESENCE OF ADDED LITHIUM AZIDE.

Run	[Chloride]	[LiN_3]	[LiOEt][a]	F_{azide}	10^3 k, sec^{-1}
1-173	.02442	.02732	----	.044	2.11 ± .03
1-174	.02599	.05524	----	.092	2.21 ± .03
1-176	.02439	.1051	----	.173	2.54 ± .03
1-177	.02426	.2009	----	.282	2.91 ± .05
1-178	.02510	.4160	----	.466	3.38 ± .14
3-10-5[c]	.02502	.05094	.03069	.091	----
3-10-6[c]	.02541	.08490	.03069	.158	----
3-10-4[c]	.02820	.1019	.03069	.165	----
3-10-3[c]	.02520	.1528	.03069	.230	----
3-10-2[c]	.02491	.2038	.03069	.284	----
3-10-1[c]	.02704	.2547	.03069	.335	----

[a] Lithium ethoxide.
[b] Determined by difference between the theoretical normalized acid titer and the observed acid titer.
[c] Benzhydryl azide determined by infrared spectrometry.

TABLE XXXX

SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN 80% AQUEOUS ETHANOL AT 25.0° IN THE PRESENCE OF ADDED LITHIUM AZIDE.

Run	[Chloride]	[LiN_3]	[LiOEt][a]	F_{azide}	10^3 k, sec^{-1}
1-173	.02442	.02732	----	.044	2.11 ± .03
1-174	.02599	.05524	----	.092	2.21 ± .03
1-176	.02439	.1051	----	.173	2.54 ± .03
1-177	.02426	.2009	----	.282	2.91 ± .05
1-178	.02510	.4160	----	.466	3.38 ± .14
3-10-5[c]	.02502	.05094	.03069	.091	----
3-10-6[c]	.02541	.08490	.03069	.158	----
3-10-4[c]	.02820	.1019	.03069	.165	----
3-10-3[c]	.02520	.1528	.03069	.230	----
3-10-2[c]	.02491	.2038	.03069	.284	----
3-10-1[c]	.02704	.2547	.03069	.335	----

[a] Lithium ethoxide.
[b] Determined by difference between the theoretical normalized acid titer and the observed acid titer.
[c] Benzhydryl azide determined by infrared spectrometry.

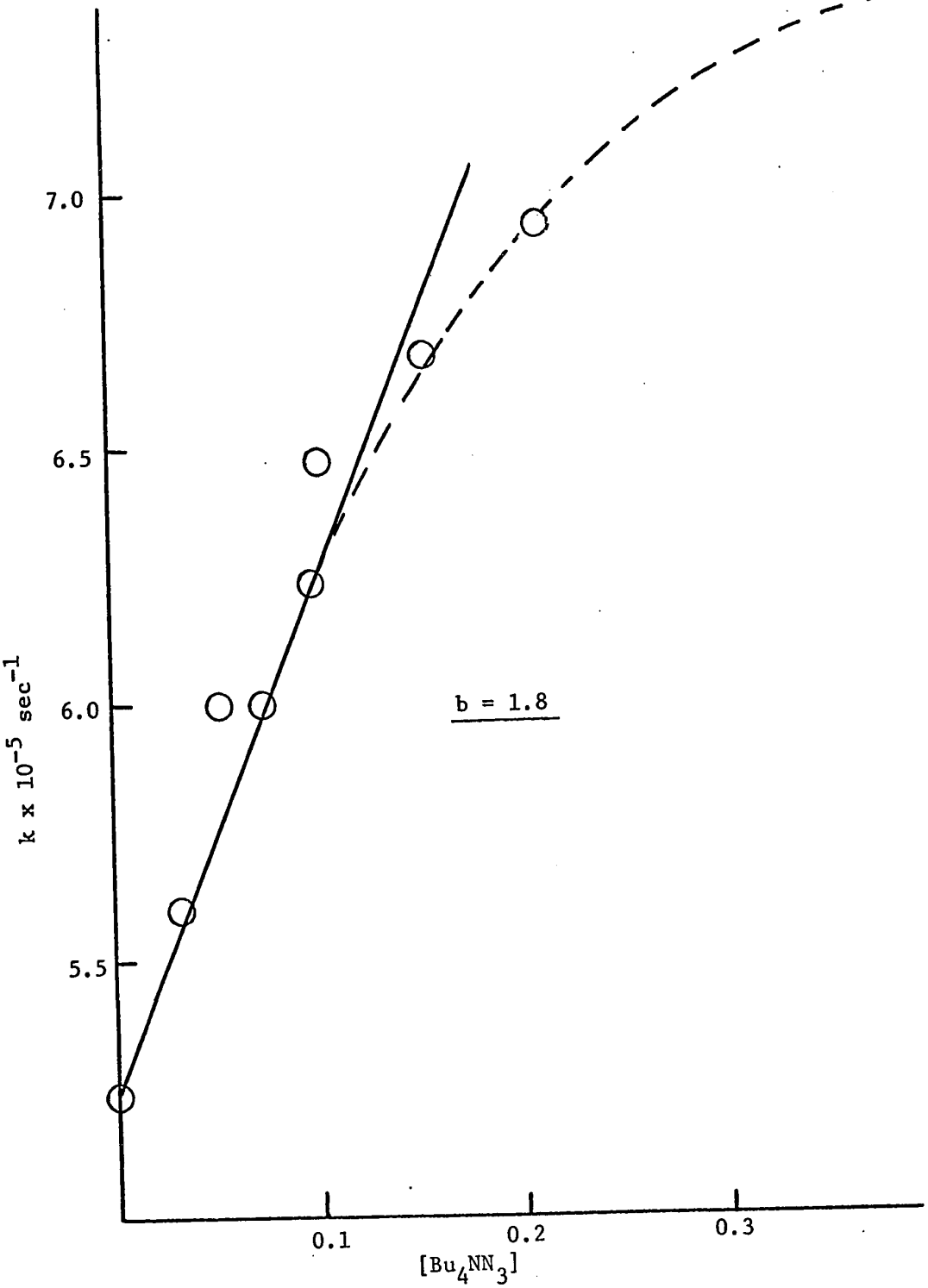


Figure X. The effect of added tetrabutylammonium azide on the rate of reaction of benzhydryl chloride in anhydrous ethanol at 25°.

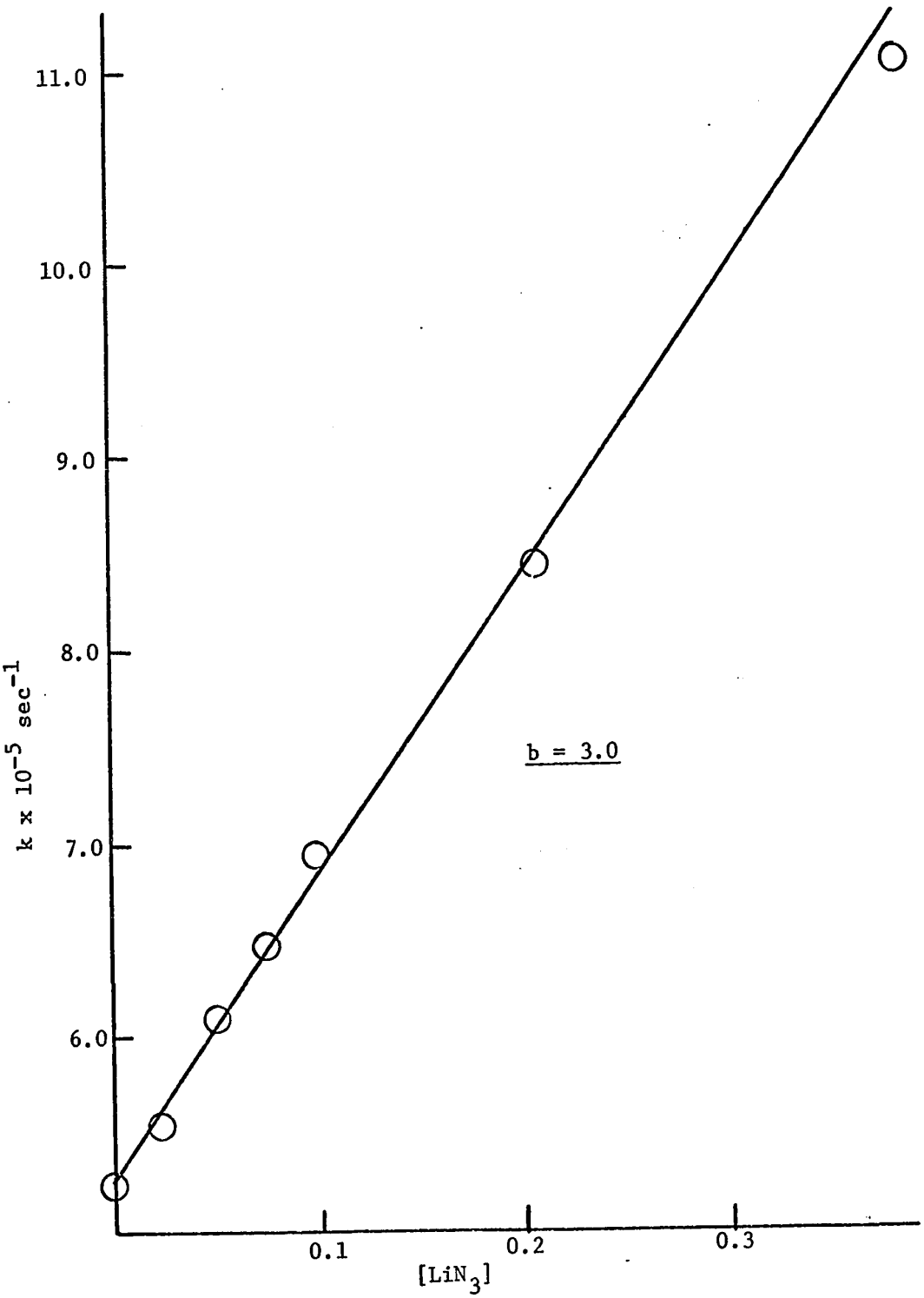


Figure XI. The effect of added lithium azide on the rate of reaction of benzhydryl chloride in anhydrous ethanol at 25°.

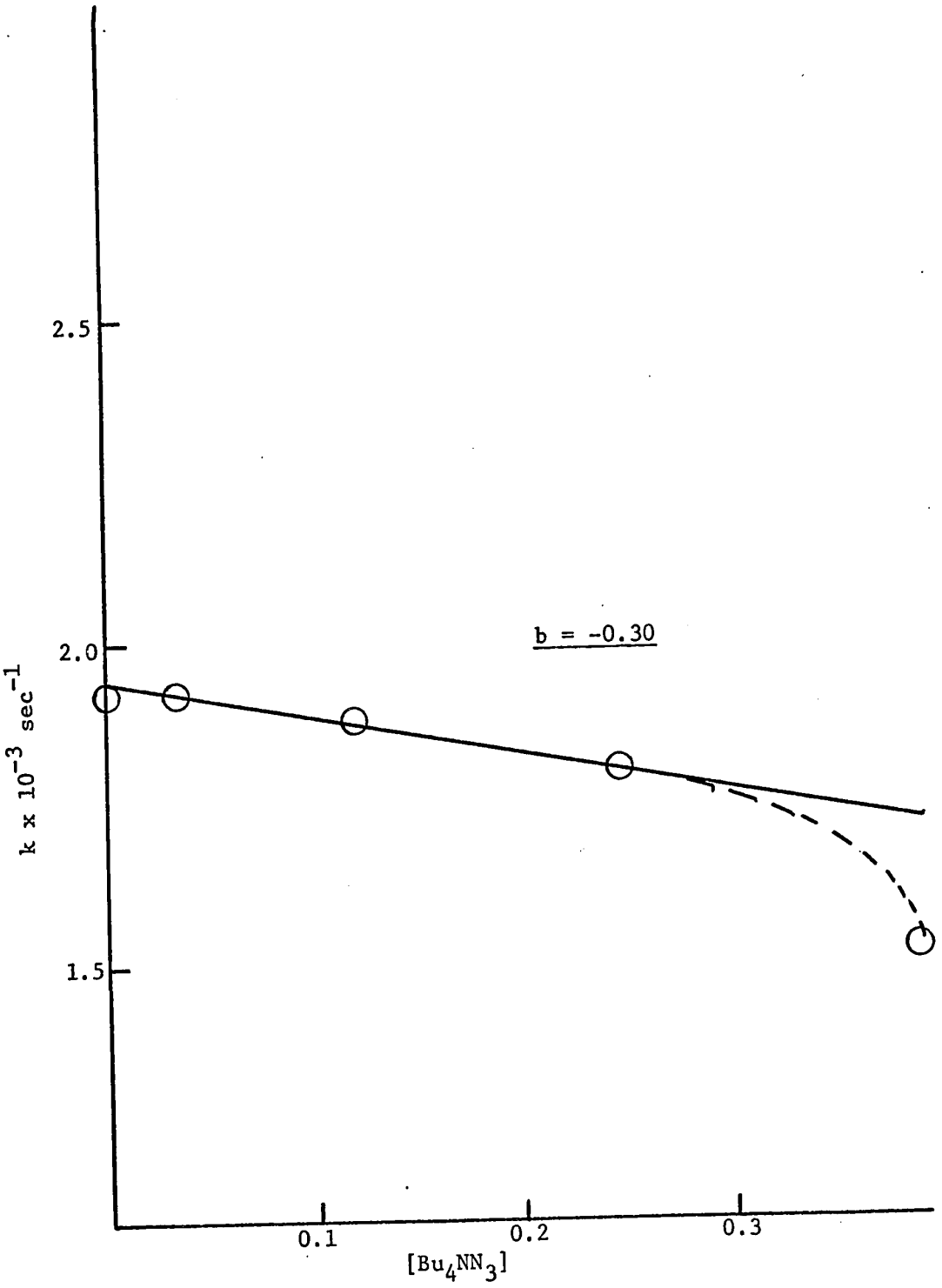


Figure XII. The effect of added tetrabutylammonium azide on the rate of reaction of benzhydryl chloride in 80% aqueous ethanol at 25°.

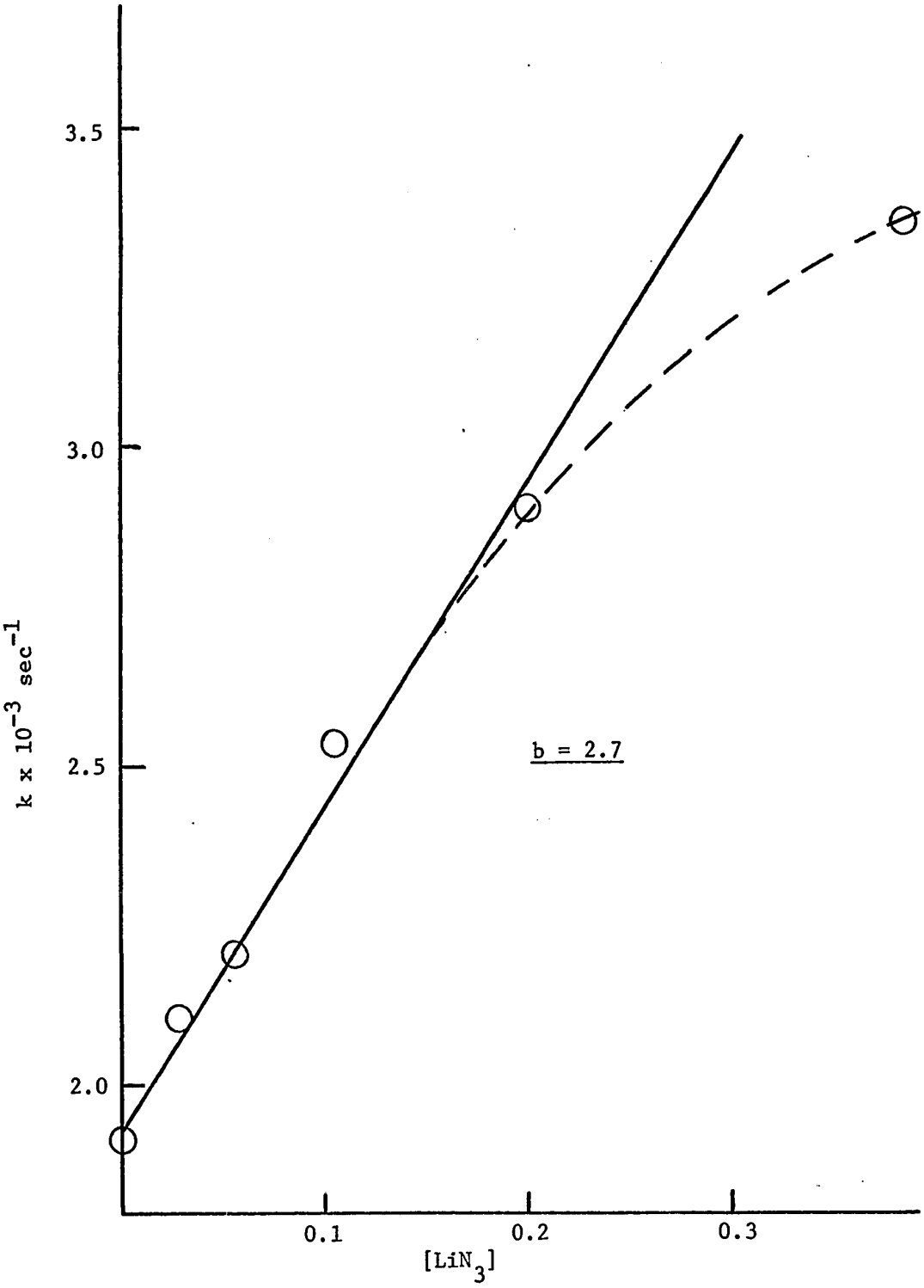


Figure XIII. The effect of added lithium azide on the rate of reaction of benzhydryl chloride in 80% aqueous ethanol at 25°.

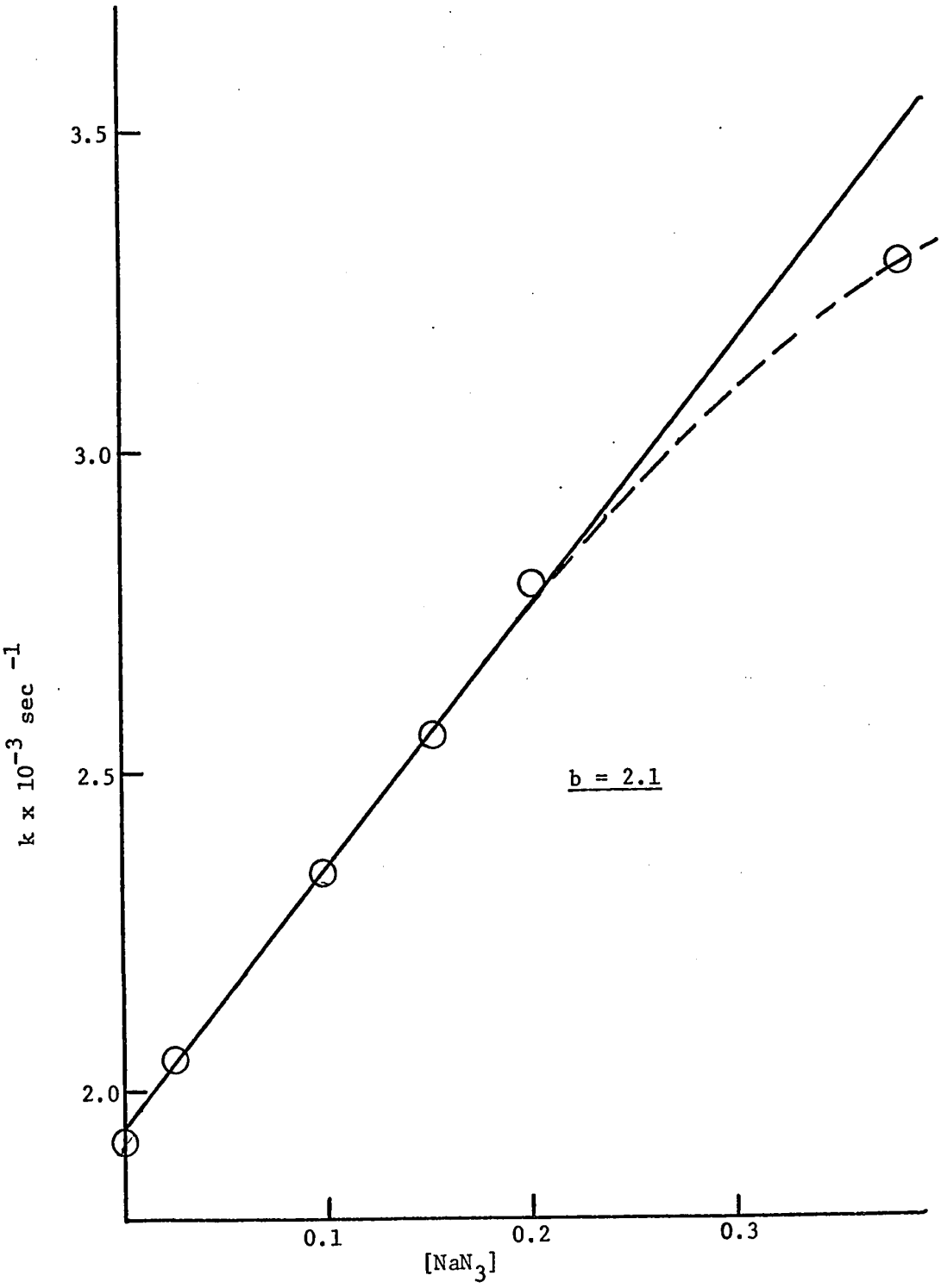
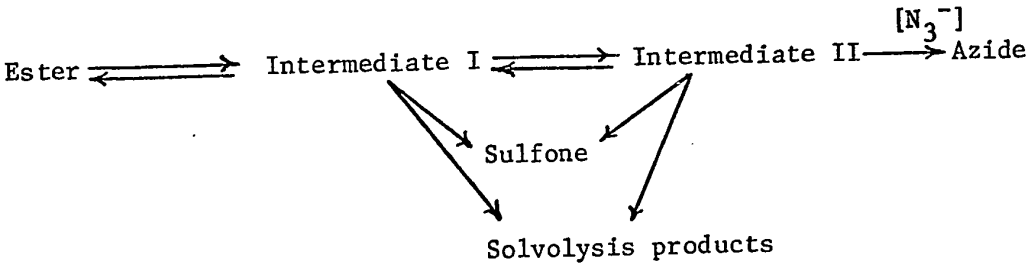


Figure XIV. The effect of added sodium azide on the rate of reaction of benzhydryl chloride in 80% aqueous ethanol at 25°.

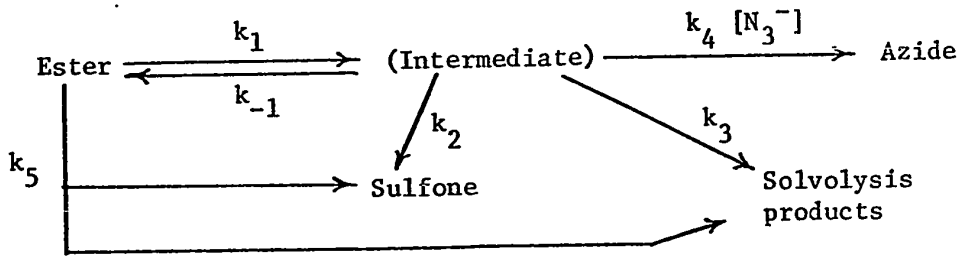
DISCUSSION

It is clear from the results that added azide salts react with both benzhydryl chloride and benzhydryl 2,6-dimethylbenzenesulfinate to yield benzhydryl azide during the course of the solvolysis reactions. Incomplete conversion of the compounds to benzhydryl azide is observed even at the highest salt concentrations employed. If more than one species is formed as an intermediate in the reaction the additional intermediates would be expected to differ in their behavior toward an added nucleophile. For an ionic reaction passing through more than one ionic intermediate the following scheme may be set up. Here reaction



proceeding through Intermediate I is proceeding through an intermediate which is incapable of being captured by added azide ion. Intermediate II is capable of chemical capture by azide ion to give alkyl azide. To simplify a kinetic treatment of this scheme, it may be rewritten as shown in Scheme VII.

In this modified scheme k_5 represents formation of solvolysis products and sulfone by all paths other than through an intermediate which is capable of capture by azide ion.



SCHEME VII

Applying the steady-state approximation:

$$(1)\quad \frac{-\,d\,[\text{Ester}]}{dt} = k_1\,[\text{Ester}] + k_5\,[\text{Ester}] - \frac{k_1\,k_{-1}\,[\text{Ester}]}{k_{-1} + k_2 + k_3 + k_4\,[N_3^-]}$$

$$(2)\quad \frac{d\,[\text{Azide}]}{dt} = \frac{k_1\,k_4\,[N_3^-]\,[\text{Ester}]}{k_{-1} + k_2 + k_3 + k_4\,[N_3^-]}$$

$$(3)\quad \frac{d\,[\text{products}]}{dt} = \frac{k_1\,[\text{Ester}]\,(k_2 + k_3)}{k_{-1} + k_2 + k_3 + k_4\,[N_3^-]} + k_5\,[\text{Ester}]$$

$$(4)\quad \frac{[\text{Products}]}{[\text{Azide}]} = \frac{k_2 + k_3}{k_4\,[N_3^-]} + \frac{k_5\,\{k_{-1} + k_2 + k_3 + k_4[N_3^-]\}}{k_1\,k_4\,[N_3^-]}$$

$$\text{Defining } F_{azide} = \frac{[\text{Azide}]}{[\text{Azide}] + [\text{Products}]} \qquad \text{and } k_5 = R\,k_1$$

$$(5)\quad \text{then } \frac{1}{F_{azide}} = \frac{k_2 + k_3 + k_4\,[N_3^-]}{k_4\,[N_3^-]} + \frac{R\,k_1\,\{k_{-1} + k_2 + k_3 + k_4\,[N_3^-]\}}{k_1\,k_4\,[N_3^-]}$$

collecting terms gives

$$(6)\quad \frac{1}{F_{azide}} = \frac{\{k_2 + k_3 + k_4\,[N_3^-]\}\,(1 + R)}{k_4\,[N_3^-]} + \frac{R\,k_{-1}}{k_4\,[N_3^-]}$$

$$(7)\quad \frac{1}{F_{azide}} = \frac{R\,(k_{-1} + k_2 + k_3) + k_2 + k_3}{k_4\,[N_3^-]} + (R + 1)$$

It can be seen from equation (7) that a plot of $1/F_{azide}$ against $1/[N_3^-]$ will yield a straight line with a slope of $\frac{R\,(k_{-1} + k_2 + k_3) + k_2 + k_3}{k_4}$ and an intercept, $(R + 1)$.

Equation (7) may be rearranged to give equation (8) in which the

$$(8)\quad [N_3^-]/F_{azide} = [N_3^-]\,(R + 1) \div \frac{R\,(k_{-1} + k_2 + k_3) + k_2 + k_3}{k_4}$$

roles of the slope and intercept are interchanged when $[N_3^-]/F_{azide}$ is plotted against $[N_3^-]$. Either equation (7) or (8) may be used to evaluate the term $(R + 1)$. In practice equation (8) may give a more accurate determination of the value, $(R + 1)$, since when determining this value from the intercept, the number obtained is outside the range of values experimentally measured, i.e. it is obtained by extrapolation. When the value for $(R + 1)$ is obtained using equation (8), the value is obtained from the slope of the line formed and no extrapolation is necessary.

If the intercept (or slope in the case of equation 8) is determined to be equal to 1.0, then $R = 0$ and $k_5 = 0$. This would indicate that at infinitely high azide ion concentration complete conversion of the ester to benzhydryl azide should be obtained. Values of $(R + 1)$ greater than 1.0 would permit the determination of the relative values of k_5 and k_1 and a determination of the theoretical maximum amount of conversion of benzhydryl 2,6-dimethylbenzenesulfinate to benzhydryl azide. This means that the amounts of the reaction pro-

ceeding through trappable and non-trappable species may be determined.

The above kinetic treatment would also be applicable to the treatment of the solvolysis of benzhydryl chloride. In the case of benzhydryl chloride there is no isomerization product formed and thus the rate constant k_2 would be absent from the kinetic expression.

Using the data presented in Tables XXVI and XXVII which give the amounts of benzhydryl azide formed by reaction of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol and 80% aqueous ethanol with tetrabutylammonium azide, Figures XV - XX were constructed. The values used for the fraction of azide in anhydrous ethanol were the values which had been corrected to eliminate the contribution of sulfur-oxygen bond fission in ethanol. Since, as has been discussed in Chapter I, there is no sulfur-oxygen bond fission expected in 80% aqueous ethanol, no correction factors were applied to the data in this solvent. Similarly the Figures XXI - XXXII were constructed using the data presented in Tables XXXV - XL which show the amounts of benzhydryl azide formed in the solvolyses of benzhydryl chloride in ethanol and aqueous ethanol in the presence of various azide salts.

The slopes and intercepts of the lines were computed from the data to obtain values for the expression, (R + 1). A least squares computer program (LSEFIT) provided by Drs. J. S. Martin and R. D. Green was used for the computations. As values of F_{azide} were determined by infrared measurements they were subject to

some error. The error was assumed to be a value of ± 1% absolute. This assumption results in relatively high percentage errors in the determination of low concentrations of benzhydryl azide. When the yield of benzhydryl azide is found to be 6%, the error of 1% absolute corresponds to nearly 17% relative error in the value. However, when the yield of benzhydryl azide is 20% the error of 1% absolute corresponds to an error of only 5% in the determination of this value. A weighting factor was included in the program such that each point in an individual data set was weighted inversely proportionately to its relative error in the data set for the calculation of the best fit line to the points. Thus if one point was three times more accurate than another point, the computer would effectively plot the more accurate point three times rather than once.

A summary of the information presented in all of these figures is shown in Table XLI for reactions of benzhydryl 2,6-dimethylbenzenesulfinate and in Table XLII for reactions of benzhydryl chloride.

At first the effect of added azide salt upon the reactions was studied with added 2,6-lutidine as the base in the solvolysis of the ester and no added base in the solvolysis of benzhydryl chloride. It may be seen from Tables XLI and XLII that the entries corresponding to the chloride solvolysis in the absence of added bases have values of (R + 1) which are less than 1.0. The theoretically anticipated minimum value of (R + 1) is 1.0. A possible explanation for these unexpectedly low values might be

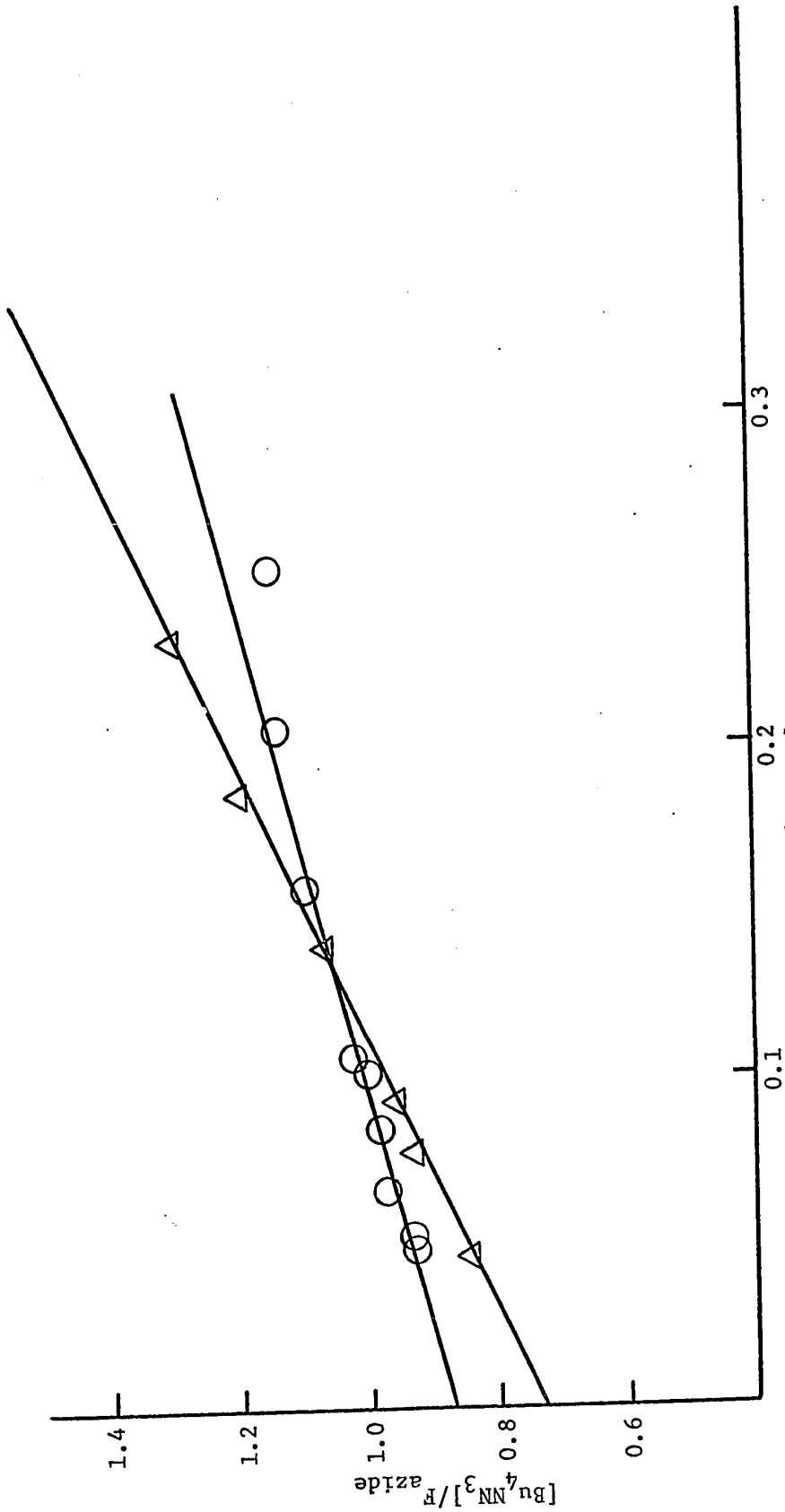


Figure XV. The relationship between $[Bu_4NN_3]/F_{azide}$ and $[Bu_4NN_3]$ for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol. ○ with 2,6-lutidine. △ with triethylamine.

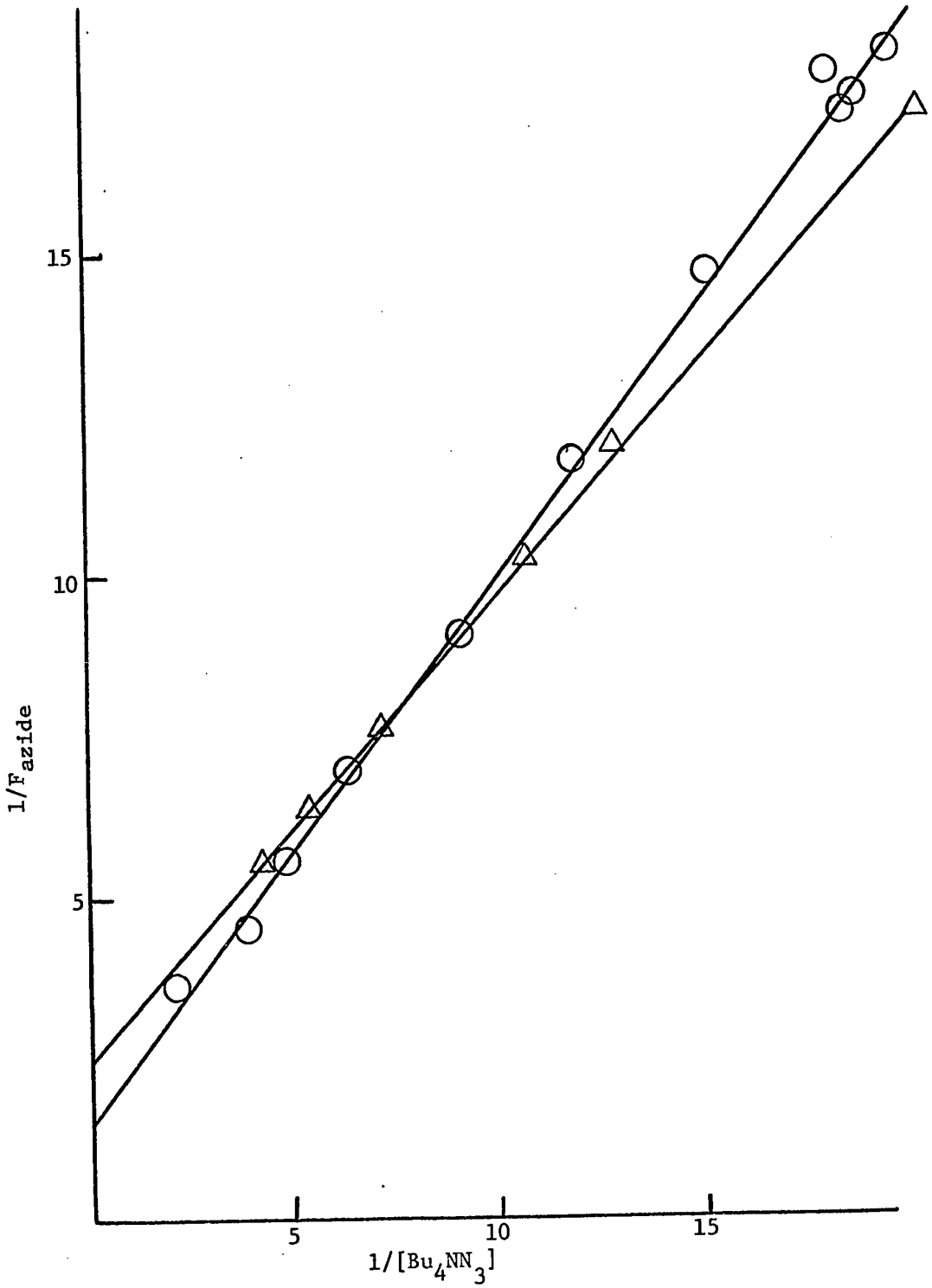


Figure XVI. The relationship between $1/F_{azide}$ and $1/[Bu_4NN_3]$ for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol. ◯ with 2,6-lutidine. △ with triethylamine.

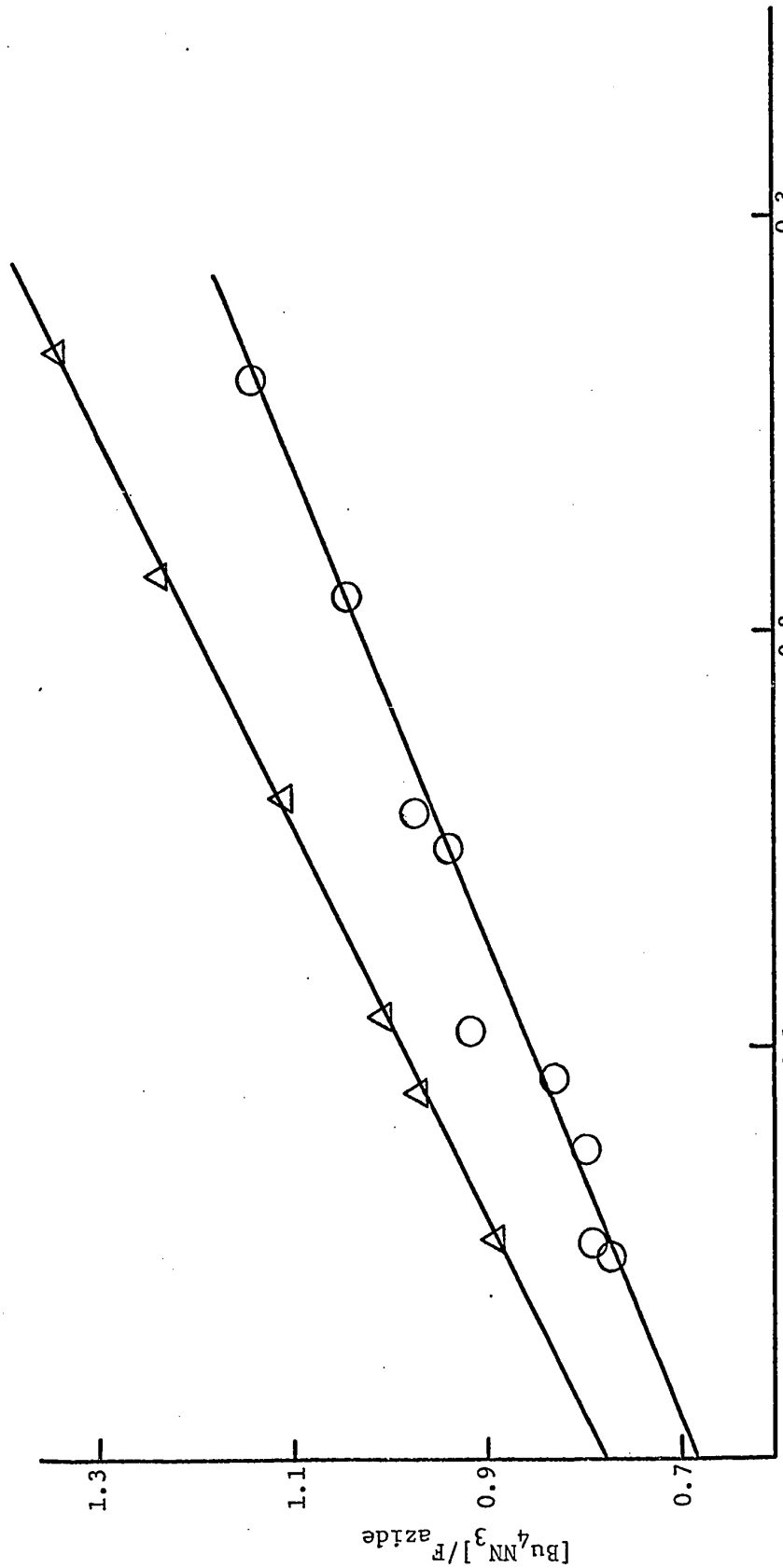


Figure XVII. The relationship between $[Bu_4NN_3]/F_{azide}$ for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in 80% aqueous ethanol. ○ with 2,6-lutidine. △ with triethylamine.

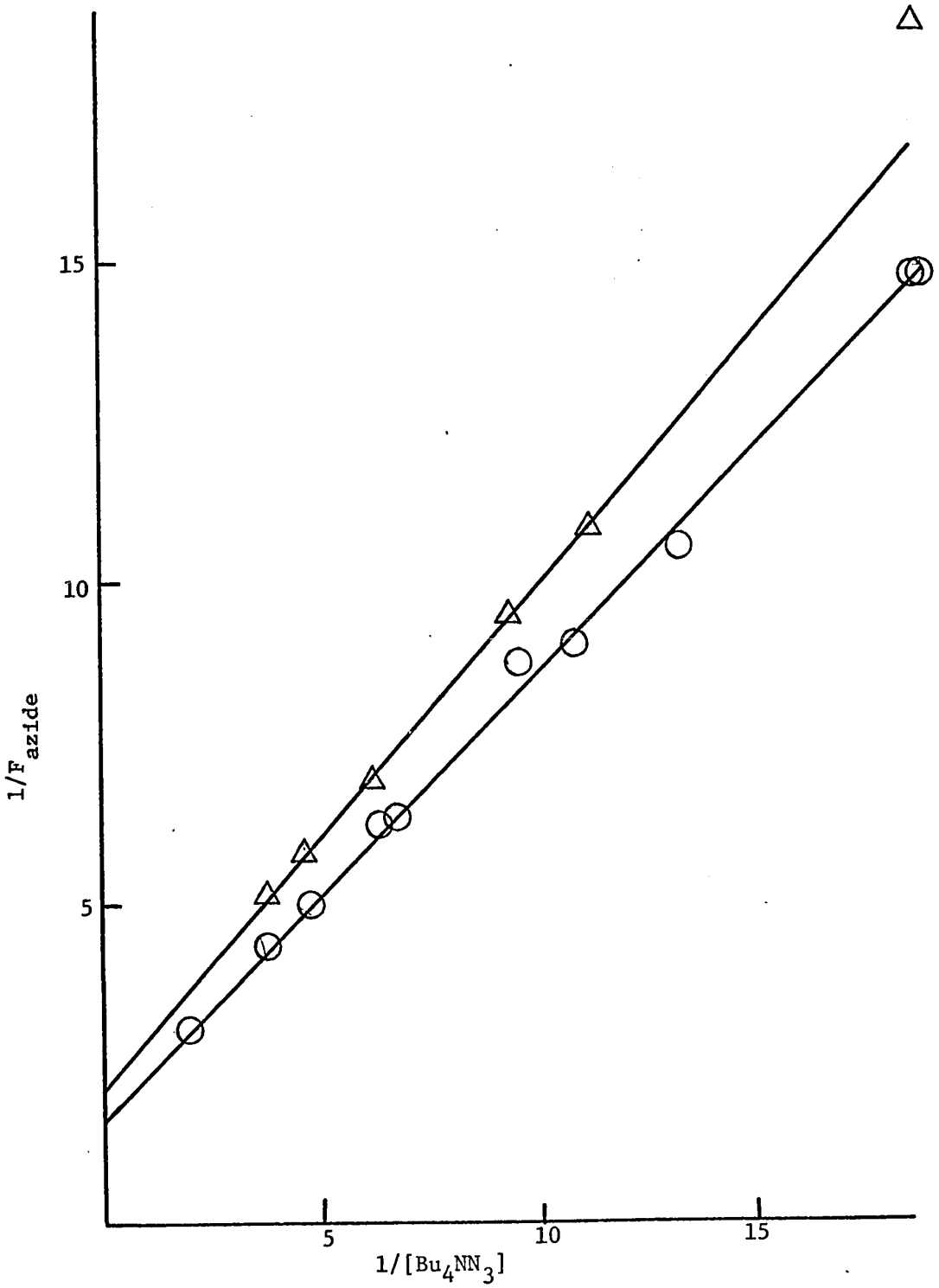


Figure XVIII. The relationship between $1/F_{azide}$ and $1/[Bu_4NN_3]$ for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in 80% aqueous ethanol. ○ with 2,6-lutidine. △with triethylamine.

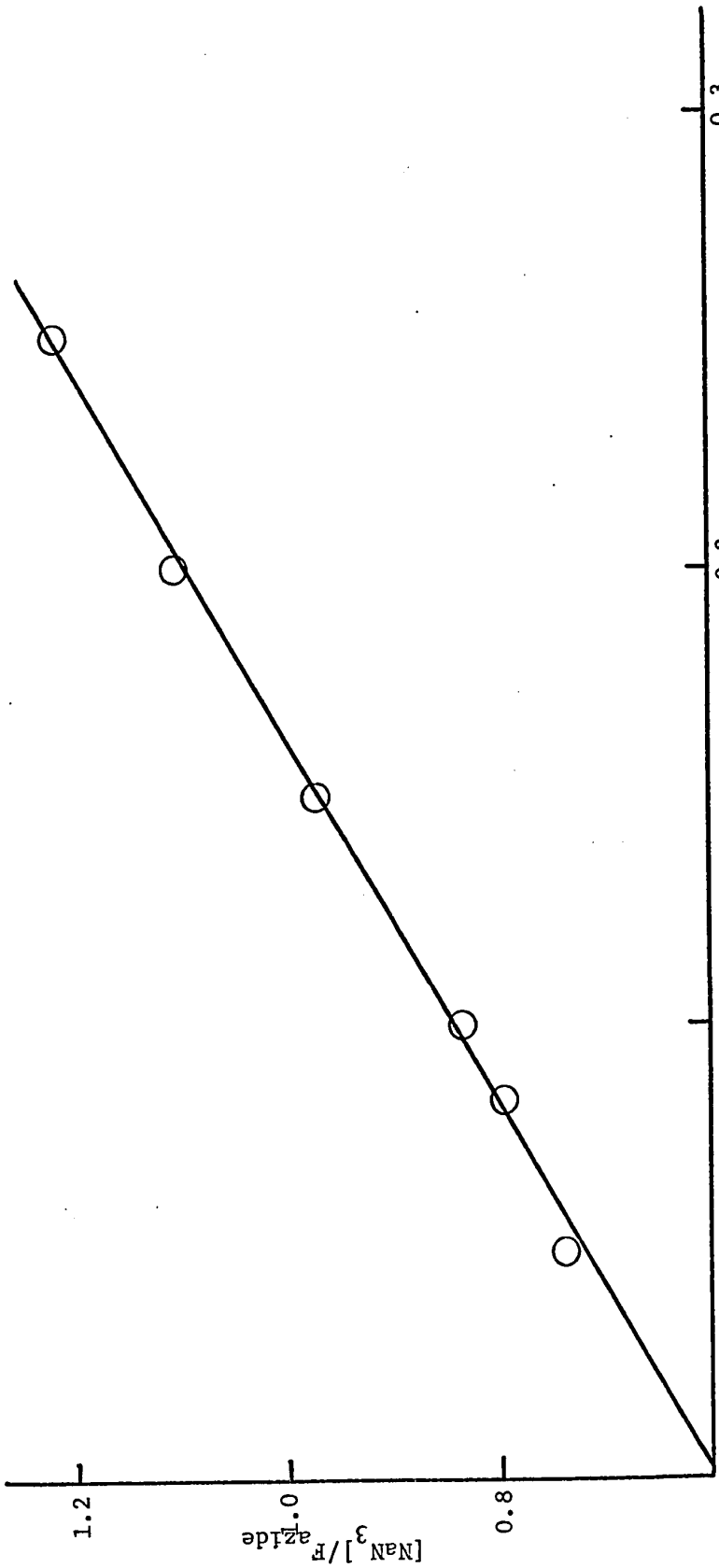


Figure XIX. The relationship between $[NaN_3]/F_{azide}$ and $[NaN_3]$ for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in 80% aqueous ethanol with added triethylamine.

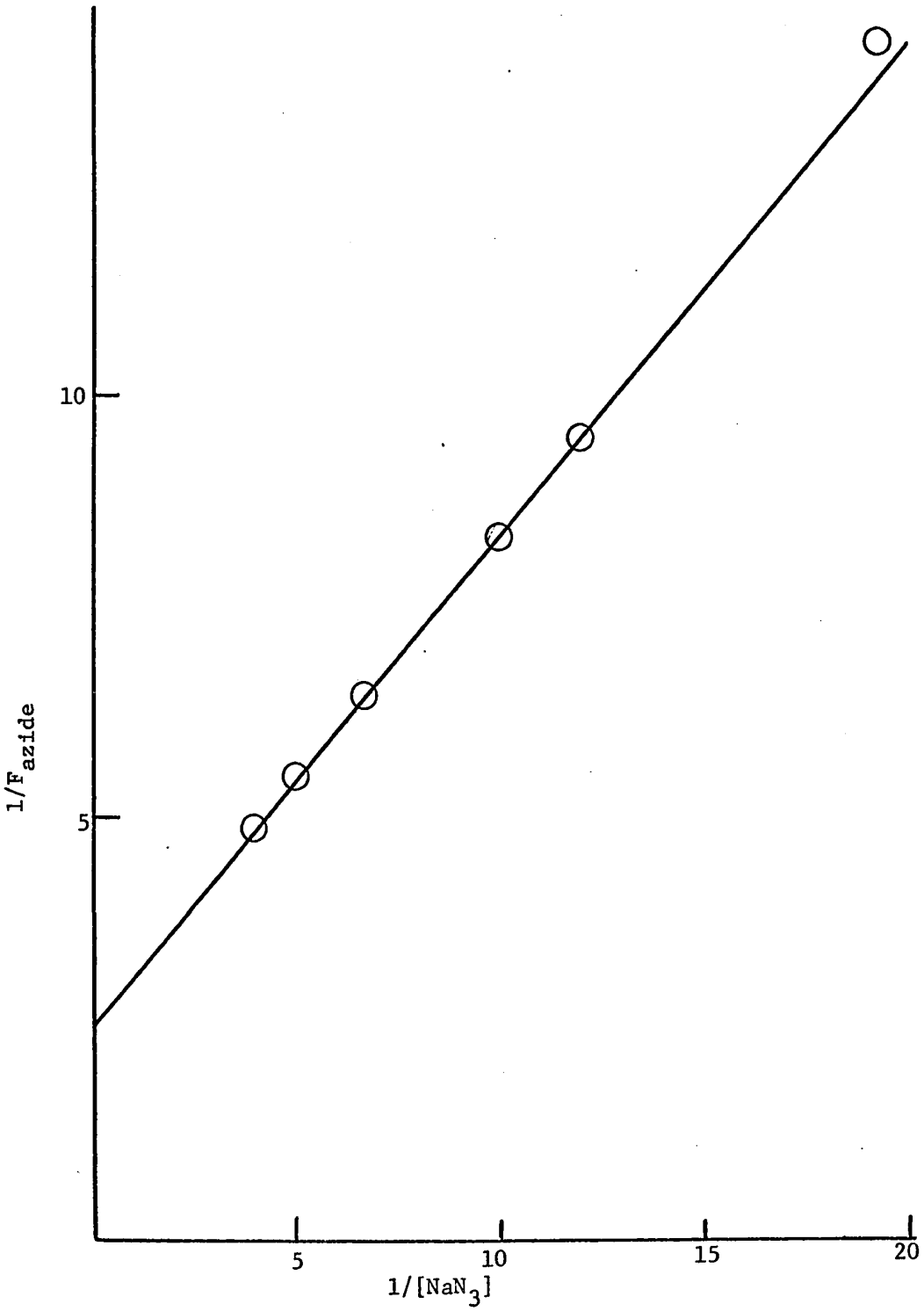


Figure XX. Relationship between $1/F_{azide}$ and $1/[NaN_3]$ for the reaction of benzhydryl 2,6-dimethylbenzenesulfinate in 80% aqueous ethanol with added triethylamine.

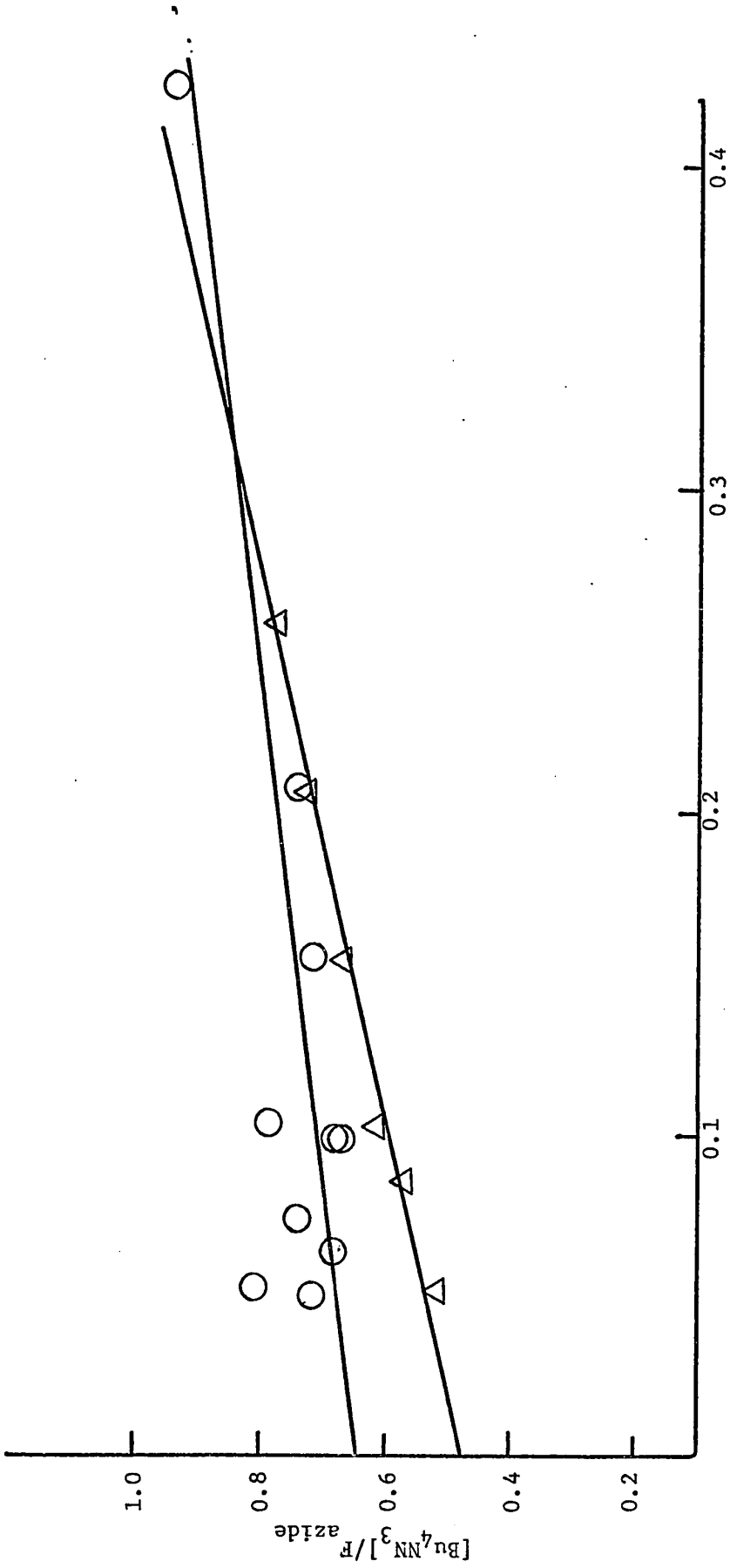


Figure XXI. The relationship between $[Bu_4NN_3]/F_{azide}$ and $[Bu_4NN_3]$ for the reaction of benzhydryl chloride in ethanol. ○ with no added base. △ with triethylamine.

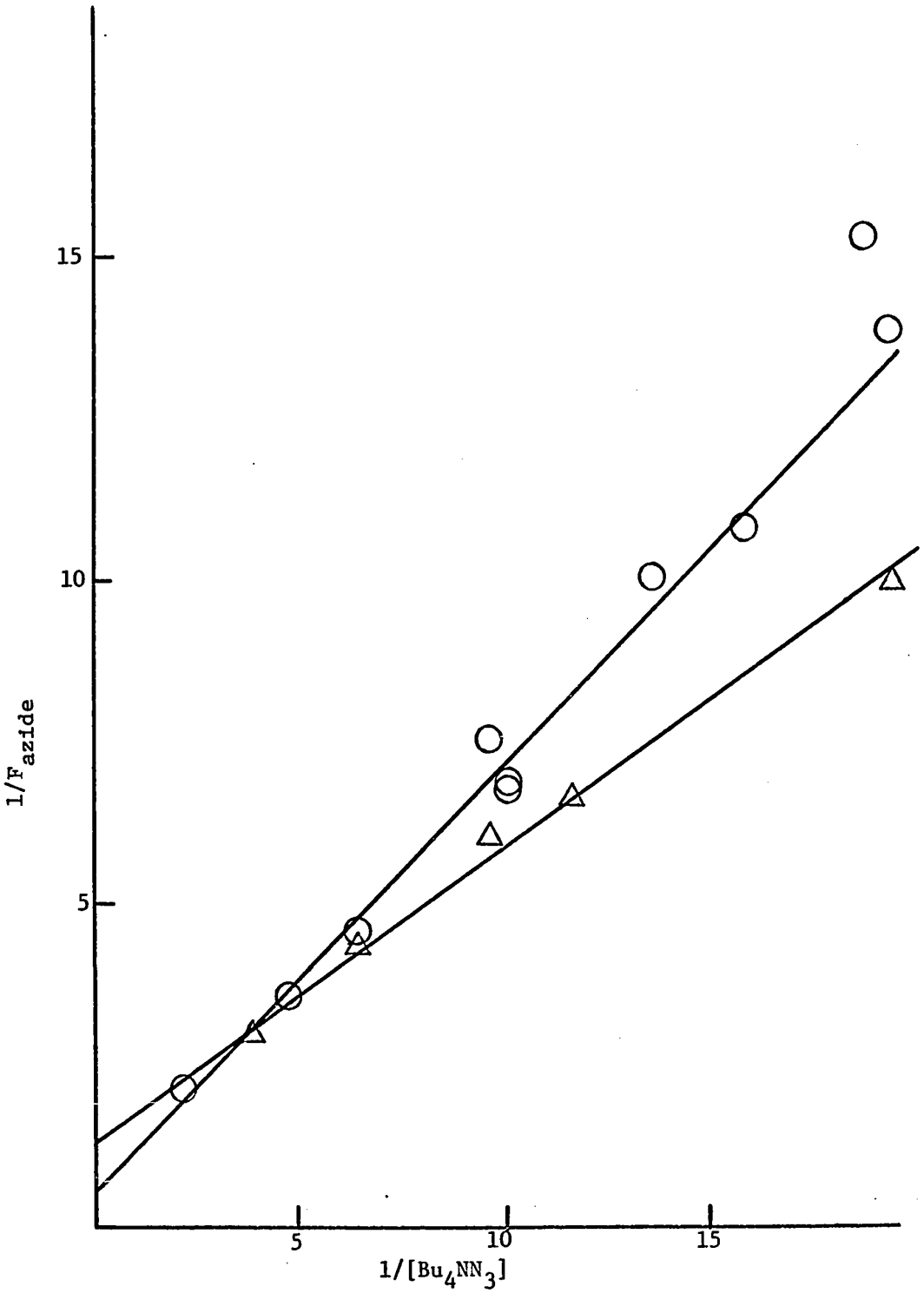


Figure XXII. The relationship between $1/F_{azide}$ and $1/[Bu_4NN_3]$ for the reaction of benzhydryl chloride in ethanol. ○ with no added base. △ with triethylamine.

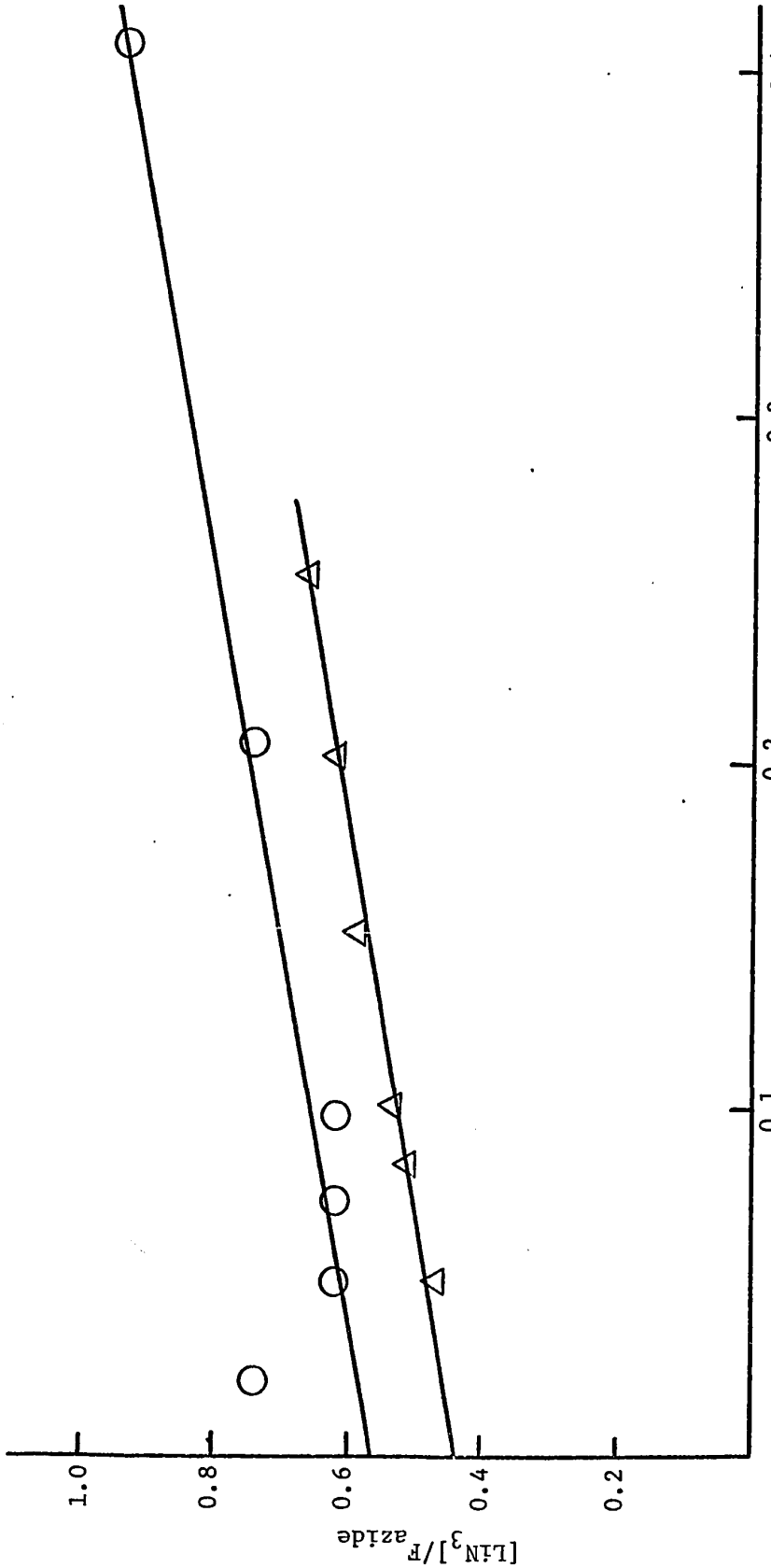


Figure XXIII. The relationship between $[LiN_3]/F_{azide}$ and $[LiN_3]$ for the reaction of benzhydryl chloride in ethanol. ○ in the absence of base. △ with lithium ethoxide.

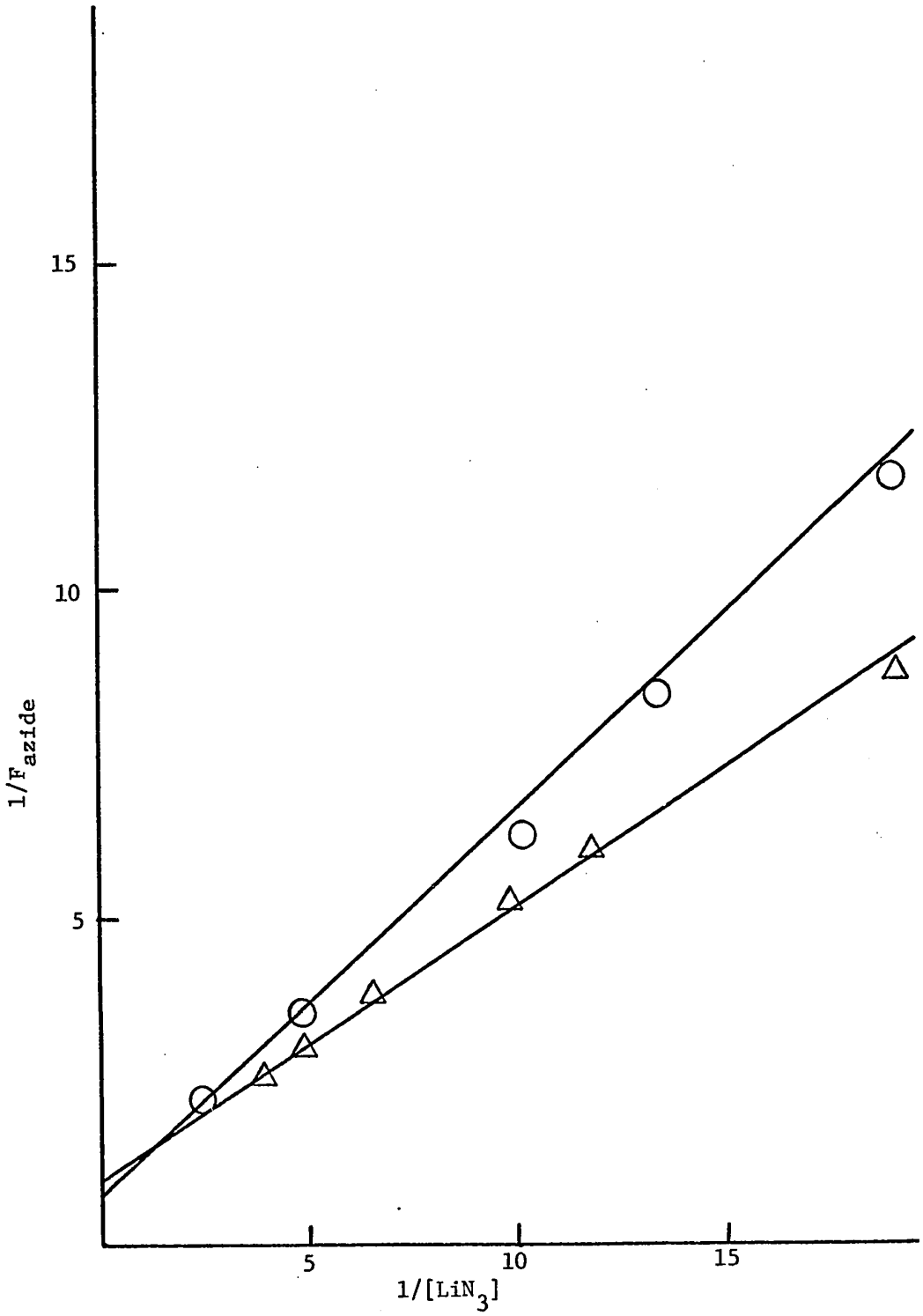


Figure XXIV. The relationship between $1/F_{azide}$ and $1/[LiN_3]$ for the reaction of benzhydryl chloride in ethanol. ○ with no added base. △ with lithium ethoxide.

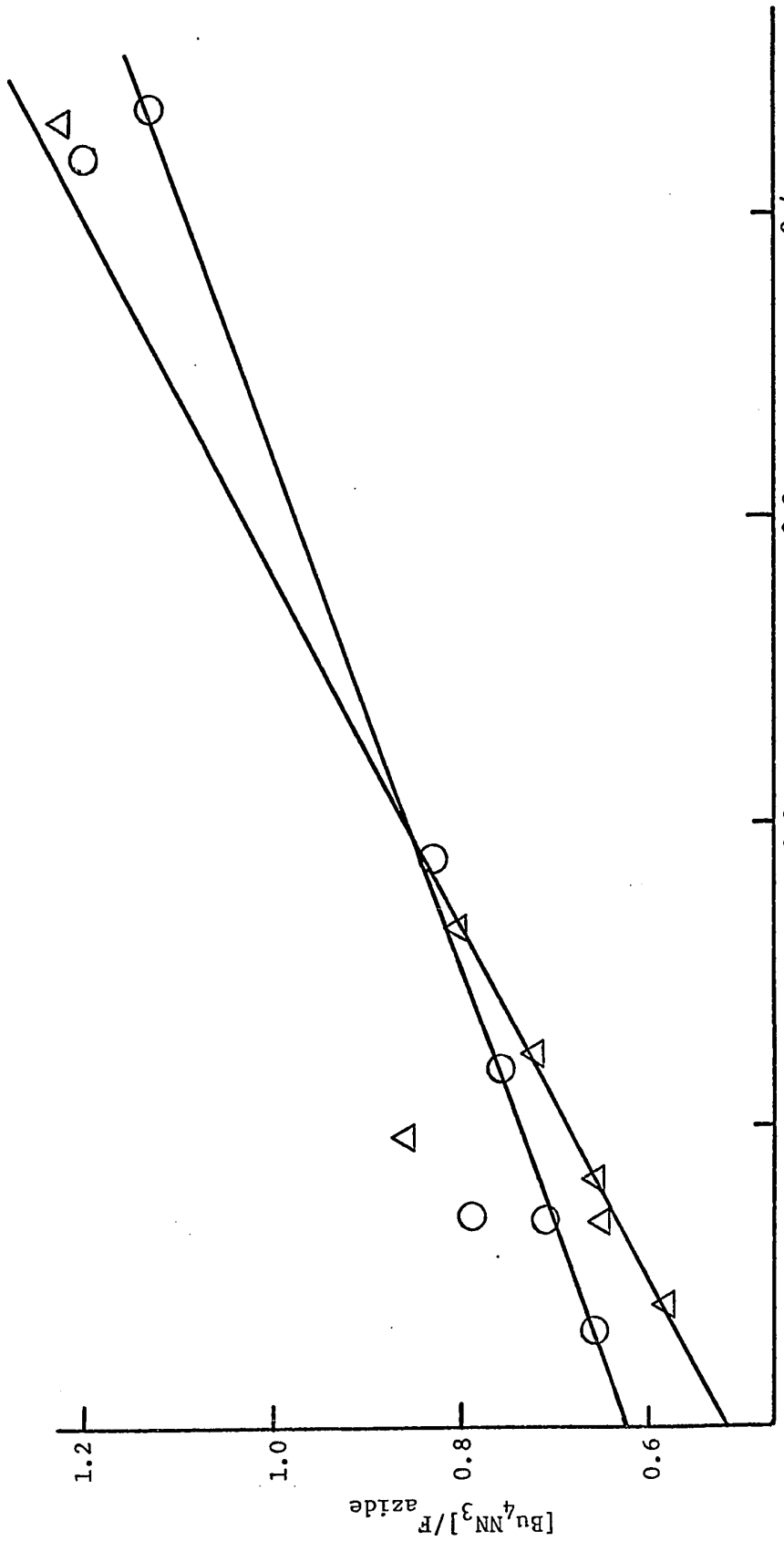


Figure XXV. The relationship between $[Bu_4NN_3]/F_{azide}$ and $[Bu_4NN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol. ○ with no added base. △ with triethylamine.

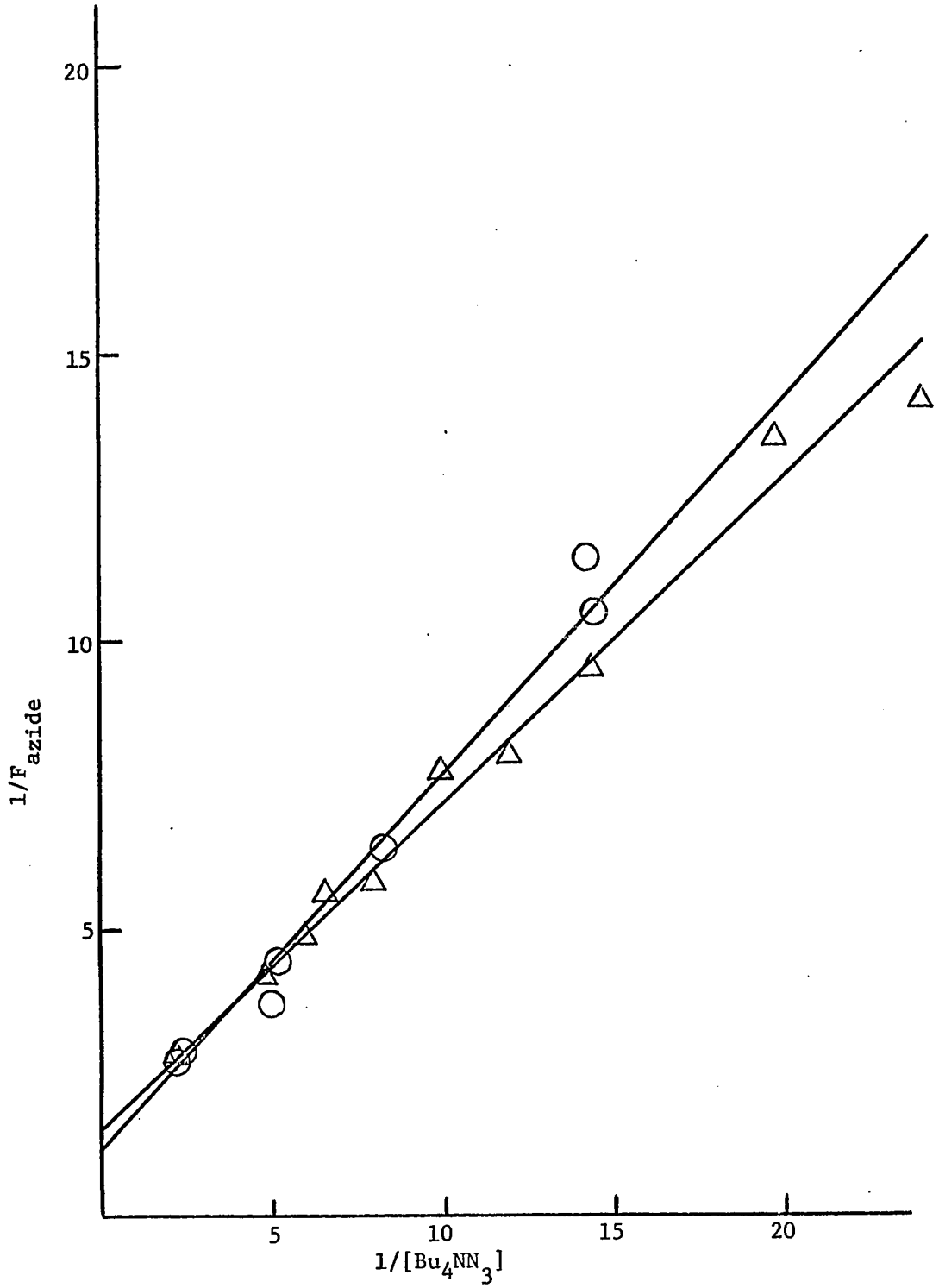


Figure XXVI. The relationship between $1/F_{azide}$ and $1/[Bu_4NN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol.

○ with no added base. △ with triethylamine.

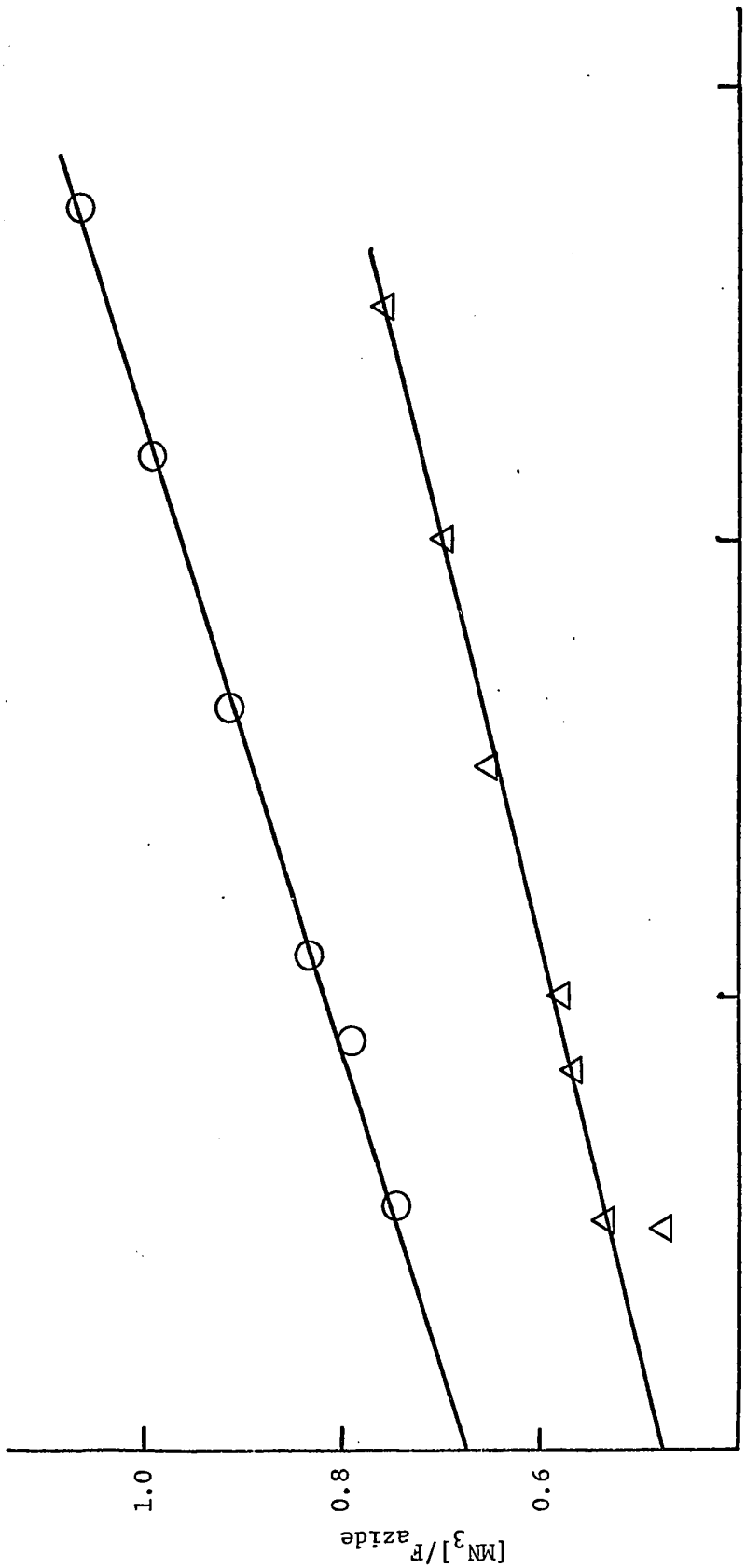


Figure XXVII. The relationship between $[MN_3]/F_{azide}$ and $[MN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol. ○ with Bu_4NN_3 and Bu_4NOH. △ with NaN_3 and triethylamine.

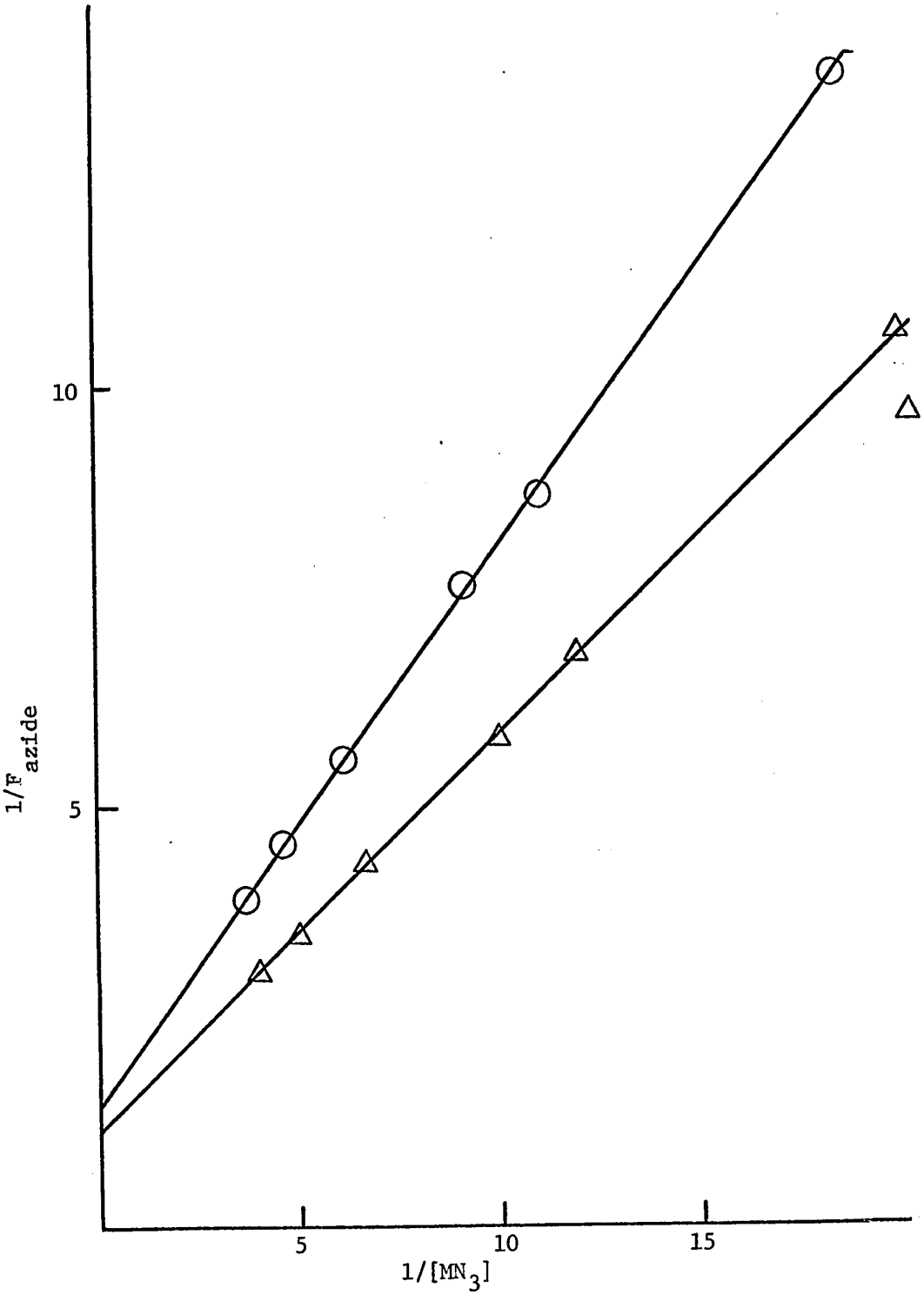


Figure XXVIII. The relationship between $1/F_{azide}$ and $1/[MN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol.

○ with Bu_4NN_3 and Bu_4NOH. △ with NaN_3 and triethylamine.

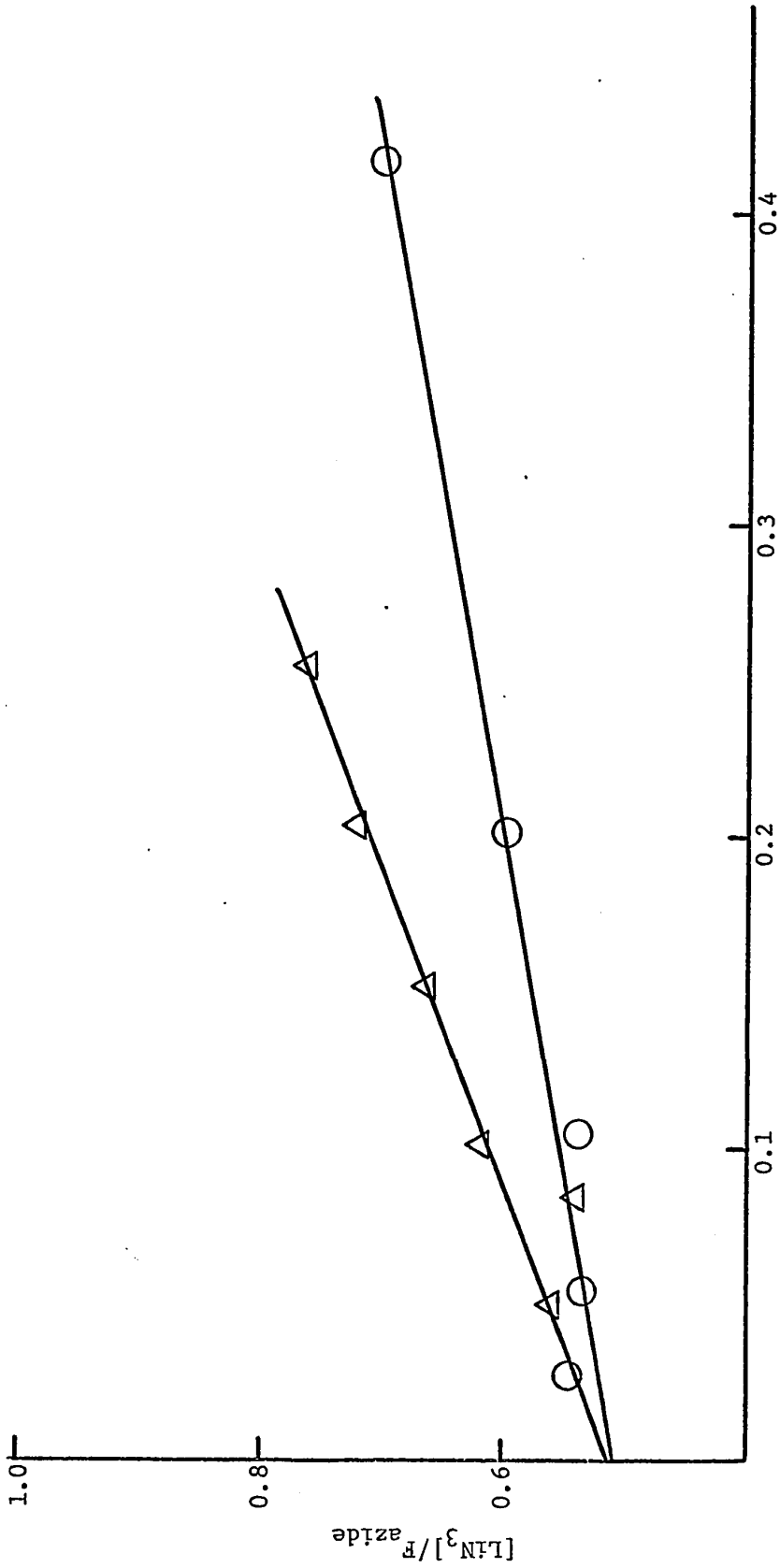


Figure XXIX. The relationship between $[LiN_3]/F_{azide}$ and $[LiN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol. ○ with no added base. △ with added lithium ethoxide.

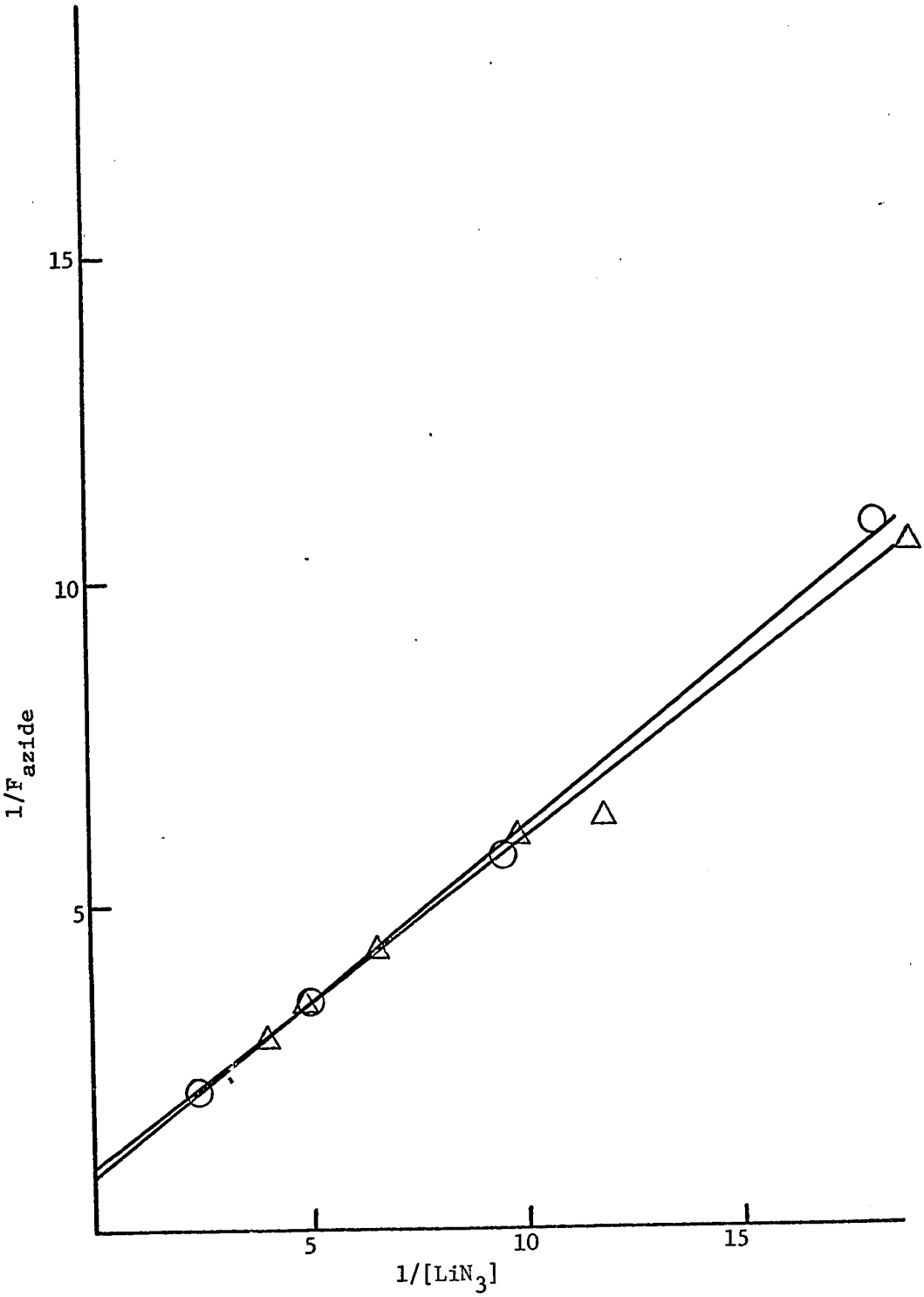


Figure XXX. The relationship between $1/F_{azide}$ and $1/[LiN_3]$ for the reaction of benzhydryl chloride in aqueous ethanol. ○ with no added base. △ with lithium ethoxide.

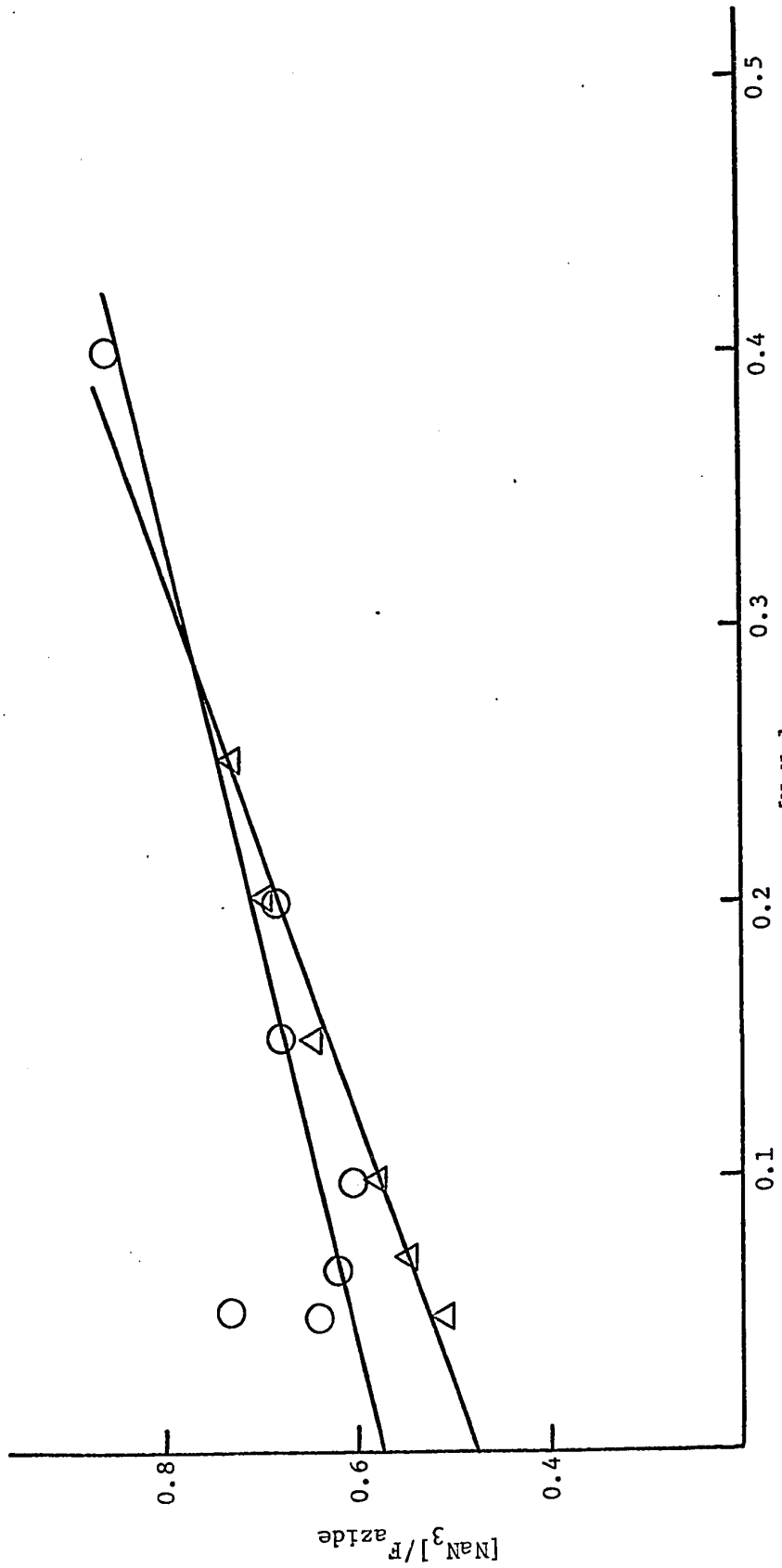


Figure XXXI. The relationship between $[NaN_3]/F_{azide}$ and $[NaN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol. ○ with no added base. △ with added sodium ethoxide.

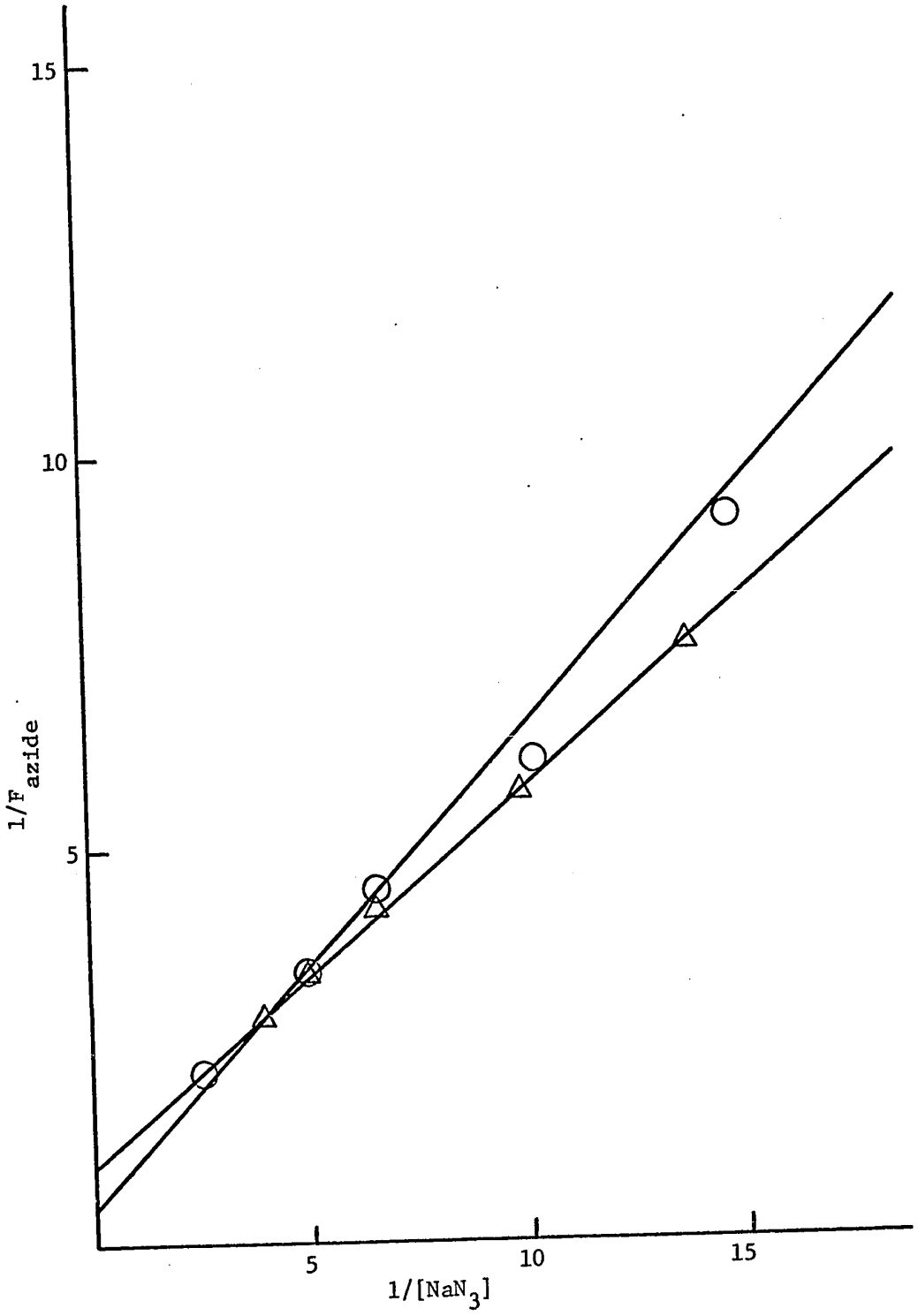


Figure XXXII. The relationship between $1/F_{azide}$ and $1/[NaN_3]$ for the reaction of benzhydryl chloride in 80% aqueous ethanol.

○ with no added base. △ with added sodium ethoxide.

TABLE XLI

SUMMARY OF VALUES OBTAINED FOR THE QUANTITY, (R + 1), IN THE SOLVOLYSIS OF BENZHYDRYL 2,6-DIMETHYLBENZENESULFINATE IN ETHANOL AND 80% AQUEOUS ETHANOL AT 90.0°.

Azide salt	Solvent	Base	(R + 1) from slope	(R + 1) from intercept
Bu_4NN_3	EtOH	2,6-lut.	0.81 ± .17	0.94 ± .16
Bu_4NN_3	EtOH	TEA[a]	1.93 ± .04	1.97 ± .05
Bu_4NN_3	80% EtOH	2,6-lut.	1.71 ± .14	1.62 ± .17
Bu_4NN_3	80% EtOH	TEA[a]	2.12 ± .03	2.11 ± .03
NaN_3	80% EtOH	TEA[a]	2.48 ± .05	2.44 ± .06

[a] Triethylamine.

TABLE XLII

SUMMARY OF VALUES OBTAINED FOR THE QUANTITY, (R + 1), IN THE SOLVOLYSIS OF BENZHYDRYL CHLORIDE IN ETHANOL AND 80% AQUEOUS ETHANOL AT 25.0°.

Azide salt	Solvent	Base	(R + 1) from slope	(R + 1) from intercept
Bu_4NN_3	EtOH	----	0.64 ± .08	0.50 ± .15
Bu_4NN_3	EtOH	TEA[a]	1.19 ± .08	1.28 ± .09
LiN_3	EtOH	----	0.89 ± .08	0.71 ± .20
LiN_3	EtOH	LiOET[b]	0.88 ± .06	0.94 ± .07
Bu_4NN_3	80% EtOH	----	1.28 ± .15	1.16 ± .23
Bu_4NN_3	80% EtOH	Bu_4NOH[c]	1.48 ± .03	1.49 ± .03
Bu_4NN_3	80% EtOH	TEA[a]	1.54 ± .09	1.60 ± .14

Continued . . .

Azide salt	Solvent	Base	(R + 1) from slope	(R + 1) from intercept
NaN_3	80% EtOH	----	0.67 ± .10	0.53 ± .16
NaN_3	80% EtOH	NaOEt[d]	1.02 ± .05	1.07 ± .06
NaN_3	80% EtOH	TEA[a]	1.23 ± .07	1.28 ± .11
LiN_3	80% EtOH	----	0.82 ± .05	0.75 ± .10
LiN_3	80% EtOH	LiOEt[b]	1.11 ± .11	1.11 ± .14

[a] Triethylamine.
[b] Lithium ethoxide.
[c] Tetrabutylammonium hydroxide.
[d] Sodium ethoxide.

that the solvolysis of the chloride results in the formation of hydrochloric acid which reacts with the azide salt to give hydrazoic acid. This acid would be largely undissociated and would thus lower the concentration of the available azide ion in the solution. In the case of the solvolysis of the ester it was possible that 2,6-lutidine was not a strong enough base to prevent hydrazoic acid formation. This would result in a decrease in the available azide ion concentration as was suggested for the solvolysis of the chloride. If this effect were taking place in the reactions of these compounds the result would be an incorrectly low value for the sum (R + 1).

For this reason later runs carried out used various added bases in the solvolysis of the chloride to determine whether there was an effect upon the values obtained for (R + 1). The solvolysis of the ester was carried out in the presence of triethylamine

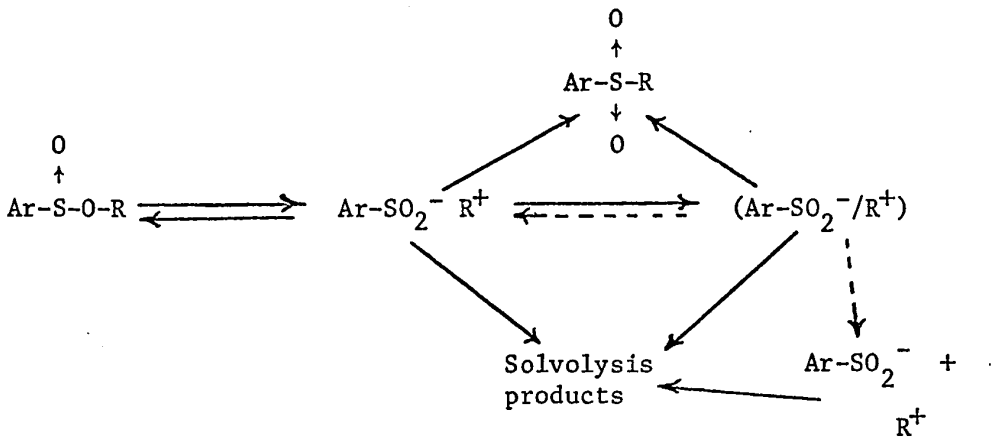
rather than 2,6-lutidine. The results of these further experiments are included in Tables XLI and XLII. and in these cases a value of nearly 1.0 is obtained for (R + 1) in the solvolysis of benzhydryl chloride. It is indicated that benzhydryl chloride will undergo total conversion to benzhydryl azide if the concentration of sodium azide or lithium azide is raised to a sufficiently high level. In the case of the reaction of the chloride in aqueous ethanol the results are not clear cut. The values of (R + 1) of approximately 1.5 render it difficult to state whether total trapping would be expected or not. It may be that some of the reaction of the chloride in this solvent may be taking place through an ion pair species which is not trappable but an unequivocal statement regarding this may not be made.

In the case of the ester, however, it is clear that incomplete conversion of the ester to benzhydryl azide could be effected. The values obtained for (R + 1) are 1.95 in ethanol and 2.1 - 2.5 in 80% ethanol. Thus it is indicated that 49% of the solvolysis and isomerization reactions of the ester in anhydrous ethanol proceeds through a non-capturable intermediate and 51% of these reactions are proceeding through a capturable species. In 80% ethanol these values are 52-60% through a non-capturable species and 48-40% through a capturable intermediate. In addition it may be pointed out that these numbers eliminate the possibility of S_N2 type reaction of the added azide ion with the benzhydryl ester. If attack by the azide ion were taking place directly on the ester, complete conversion to

benzhydryl azide would be predicted at sufficiently high azide ion concentration. However, a maximum of only 40-50% of the reaction may be diverted as is shown by these values of (R + 1).

These results require a minimum of two ionic species, one of which is not trapped by added azide. It was shown in Chapter I that sulfone cannot arise from free ions. Since the amount of sulfone as well as the amount of solvolysis products is decreased by added tetrabutylammonium azide, the capturable species must be a precursor of sulfone and must thus be an ion pair. Therefore, the capturable species, as well as the non-capturable species, is a precursor of sulfone and both intermediates must be ion pair species.

In view of the above discussion the mechanism of the reactions of benzhydryl 2,6-dimethylbenzenesulfinate in ethanol and 80% aqueous ethanol may be written as shown below.



In this scheme $Ar\text{-}SO_2^-\ R^+$ is a non-capturable ion pair, $Ar\text{-}SO_2^-/R^+$ is a capturable ion pair and $Ar\text{-}SO_2^- + R^+$ are free

ions which, if formed, react entirely to give solvolysis products. The possibility exists that free ions are formed, but there is no evidence to show that they are formed in the reactions of this ester.

The preceeding scheme is consistent with the reaction in acetic acid as well. In this solvent, though, it cannot be said that the existence of more than one ion pair species is rigorously proven. Determination of the existence of more than one ion pair species for the reaction of the ester in acetic acid was not possible by the use of the method applied for the reaction in ethanol and aqueous ethanol since addition of an added nucleophile such as the azide ion would result in conversion to the corresponding acid, hydrazoic acid.

EXPERIMENTAL

PHYSICAL MEASUREMENTS

Melting points were determined using a Hershberg melting point apparatus and a set of Anschutz thermometers. All melting points are uncorrected.

Refractive indices were obtained using a Bausch & Lomb, Abbe-3L Refractometer which was thermostated at 25.0°.

Infrared spectra were measured using Perkin Elmer Recording Infrared Spectrophotometers, Models 21, 421 and 337. The Model 21 was used for all kinetic measurements at the 20 cm per μ scale setting and a variable space sodium chloride cell was used to balance out any absorption due to the solvent employed.

Nuclear magnetic resonance spectra were determined on Varian Nuclear Magnetic Resonance Spectrometers A60, A56-60A and HR-100. The Varian A60 was used to determine most spectra.

Mass spectra were determined using either a Metropolitan-Vickers Model MS-2 Mass Spectrometer or a Consolidated Electrodynamics Corporation Residual Gas Analyzer Model 21-614.

Gas chromatography was carried out using a Perkin Elmer Model 154 Vapor Fractometer or an Aerograph A 90-P3 Gas Chromatograph.

SOLVENTS

Ethyl Alcohol.

Anhydrous ethanol for kinetic runs was prepared by one of two

methods. The first of these was that described by Fieser.[51] In this procedure 95% ethanol was heated at reflux with calcium oxide lumps after which it was distilled. The distillate was treated with magnesium turning as described by Lund and Bjerrum,[50] and the anhydrous ethanol was distilled from the magnesium ethoxide formed. The other method was to distil 98% ethanol and discard the first 10% of the distillate. The remainder of the distillate was then treated with magnesium turnings according to the method of Lund and Bjerrum.

The dried ethanol contained less than 0.006% water as determined by Karl Fisher titration.

80% Aqueous ethanol.

80% Aqueous ethanol was prepared by addition of one volume of boiled distilled water at 25.0°C to four volumes of anhydrous ethanol at 25.0°C. Delivery of the solvents was by automatic pipette.

Dioxane.

Anhydrous dioxane was prepared by the method described by Fieser.[52] Reagent grade dioxane was heated at reflux with hydrochloric acid while nitrogen was bubbled through the solution. After cooling the mixture potassium hydroxide pellets were added and the mixture was stirred. The two layers which formed were separated and the aqueous layer was discarded. The dioxane layer was treated with potassium hydroxide pellets a second time. Upon separation the dioxane was heated at reflux with sodium metal until the sodium was shiny. The dioxane was then distilled from the sodium, collected

in clean dry bottles and stored over sodium metal.

Pentane.

Phillips Petroleum technical grade normal pentane was shaken with concentrated sulfuric acid, washed with water and dried by distillation from phosphorous pentoxide.

Acetic acid.

Acetic acid, 0.1 molar in acetic anhydride, which had been prepared as described by Fainberg and Winstein[43] was kindly donated by L. Green.

Tetrahydrofuran.

Tetrahydrofuran which had been distilled from lithium aluminum hydride and stored over sodium wire was kindly donated by S. Grover.

Standard sodium methoxide.

Approximately 3 g sodium metal was added to one gallon reagent grade methanol. The solution obtained was standardized using oven-dried and desiccated Fisher Primary Standard potassium acid phthalate and phenolphthalein indicator. The standardized solution was stored in a tightly stoppered brown bottle and showed no change in normality over the period during which it was used.

Diethyl ether.

Mallinckrodt analytical reagent anhydrous ether was used with no purification.

Pyridine.

Eastman white label pyridine was stored over potassium hydroxide pellets in a brown bottle and was used without further purification.

Acetone.

Shawinigan reagent grade acetone was used with no further purification.

Formic acid.

Mallinckrodt analytical grade formic acid was used without further purification.

REAGENTS

2,6-Lutidine.

Eastman yellow label 2,6-lutidine was purified by the method of Brown.[53] 300 Grams of potassium hydroxide pellets was added to one kg of the amine and this mixture was left at room temperature for 4 days. After decantation the amine was heated at reflux with and fractionally distilled from 200 g of barium oxide. The fraction which distilled from 140-141° was collected. Boron trifluoride gas was added to the distilled 2,6-lutidine to give a concentration of 6.4 mole% boron trifluoride in 2,6-lutidine. After being left at room temperature for two days it was again fractionally distilled. The fraction distilling from 140-142° was collected and stored in a tightly capped brown bottle: n^{25}_D 1.4955 (reported:[4] n^{25}_D 1.4953).

Benzhydryl alcohol.

Eastman white label benzhydryl alcohol was used without further purification: mp 68-9° (reported:[67] mp 68-9°).

Benzhydryl ethyl ether.

To 20 g (.11 mol) of benzhydryl alcohol in 60 ml of anhydrous ethanol was added 6 ml of concentrated hydrochloric acid. The mixture was heated at reflux overnight on a steam bath, then cooled and poured into a separatory funnel containing 200 ml of pentane. The organic solution was washed successively with 75 ml of water, 75 ml of 5% sodium bicarbonate solution and 75 ml of water. The organic layer was dried over granular, anhydrous potassium carbonate and the solvent was removed at a water aspirator. The residual oil was distilled at reduced pressure to give 20.6 g (0.10 mol, 89%) of benzhydryl ethyl ether: bp 105-6° (0.6 mm) [reported[30] bp 137° (5 mm)]; n^{25}_D 1.5532 (reported[30] n^{25}_D 1.5537, [54] n^{25}_D 1.5525); ir (CCl_4) 1095; nmr (CCl_4) τ2.78 (m, 9.7 H), τ4.78 (s, 1 H), τ6.60 (q, 2 H J = 7 Hz), τ8.83 (t, 3 H J = 7 Hz).

2,6-Dimethylbenzenesulfinic acid.

This compound was prepared by the method of Hanke[14] as modified by Mermelstein.[18] To a cooled solution of 80 ml of concentrated sulfuric acid in 600 ml of water in a two liter, three-necked round-bottom flask equipped with a Teflon paddle stirrer and a thermometer was added 100 g (0.83 mol) of 2,6-dimethylaniline. The solution was cooled to 2° using an ice-methanol bath. A solution of 60 g (0.87 mol) of sodium nitrite in 120 ml of water was

added in a dropwise manner. The temperature of the solution was maintained between 0 and 5°. After addition of the sodium nitrite solution was complete, sulfur dioxide was bubbled rapidly into the solution for one hour while cooling and stirring were maintained. At the end of this time the solution was transferred to a 4-l beaker and a cooled solution of 100 ml of concentrated sulfuric acid and 200 ml water was added while sulfur dioxide addition was continued. Stirring was continued and 300 g of copper powder was gradually added. The solution was then allowed to warm to room temperature.

Two to four hours after the mixture had warmed to room temperature it was filtered with suction through a fritted glass filter. The filtrate was discarded. The copper mat was washed with a small amount of cold water and the wash water was discarded. The adsorbed 2,6-dimethylbenzenesulfinic acid was extracted from the copper mat by stirring it with successive portions of saturated sodium carbonate solution. About 750 ml of saturated sodium carbonate solution was used. The resulting basic solution was decolorized with charcoal and filtered to give a clear green solution. This solution was acidified with cold 50% sulfuric acid. The precipitated sulfinic acid was collected by filtering with suction. The product was washed with ice cold water and air dried to give 113.1 g (0.66 mol, 81%) of 2,6-dimethylbenzenesulfinic acid: mp 97-99° (reported[18] mp 98-99°).

2,6-Dimethylbenzenesulfinyl chloride.

To prepare this compound 16.5 g (0.165 mol) of thionyl chloride dissolved in 20 ml of pentane was added in a dropwise manner with stirring to 9.6 g (0.056 mol) of 2,6-dimethylbenzenesulfinic acid. The acid was slurried in 45 ml of pentane. When the reaction appeared to be complete, i.e. when almost all the material had dissolved, the solution was filtered through glass wool into a tared 100 ml round-bottom flask. The solvent was removed first at a steam bath and finally by pumping the flask at a vacuum pump overnight. This yielded 10.0 g (0.053 mol, 94%) of 2,6-dimethylbenzenesulfinyl chloride, a reddish-brown oil which was not characterized but was used immediately to synthesize the ester desired.

Benzhydryl 2,6-dimethylbenzenesulfinate.

To prepare this ester 8.8 g (0.048 mol) of benzhydrol dissolved in 15 ml of pyridine was added to a cooled solution of 10.0 g (0.053 mol) of 2,6-dimethylbenzenesulfinyl chloride in 20 ml of ether. The mixture was cooled in an ice-acetone bath for five minutes and was then stoppered and placed in the refrigerator for one hour.

The reaction mixture was poured into a mixture of 100 ml of water, 100 g of ice and 16 ml of concentrated hydrochloric acid. This mixture was stirred until all the ice had melted and then was poured into a one liter separatory funnel containing 500 ml of ether. The mixture was shaken and separated, the aqueous layer being discarded. The ethereal layer was washed successively with 100 ml portions of 5% sodium bicarbonate solution, 1 N hydro-

chloric acid and 5% sodium bicarbonate solution. The aqueous layers were discarded and the ether layer was dried over granular anhydrous potassium carbonate.

The ether was removed at a water aspirator until crystallization started. At this point 70 ml of pentane was added and the flask was stoppered and placed in the refrigerator. When crystallization appeared to be complete the product was obtained by decantation and was then recrystallized three times from ether-pentane to give 9.5 g (0.028 mol, 59%) of benzhydryl 2,6-dimethylbenzenesulfinate: mp 80-82° (reported[16] mp 80-82°); ir (CS_2) 1132, 952; nmr (CS_2) τ2.54-3.20 (m, 13.1 H) τ3.69 (s, 1.1 H), τ7.56 (s, 6.0 H).

Benzhydryl 2,6-dimethylphenyl sulfone.

This compound was prepared using the general procedure described by Schöbel.[49] A mixture of 3.4 g (0.06 mol) of sodium formate, 175 ml of 88% formic acid, 10.2 g (0.06 mol) of 2,6-dimethylbenzenesulfinic acid and 9.2 g (0.05 mol) benzhydrol was stirred with a magnetic stirrer. The mixture was warmed during this time with a water bath which varied in temperature from 25-40°. After 2.5 hr the reaction mixture was extracted with 1200 ml of ether which was then washed with 200 ml portions of water and saturated sodium carbonate solution. The ether solution was dried over magnesium sulfate and the solvent was then removed at a steam bath. The residue was crystallized from ether to give 6.1 g (0.018 mol, 36%) of benzhydryl 2,6-dimethylphenyl sulfone: mp 180.4-182° (reported[16] mp 180-182°); ir (CS_2) 1312, 1153, 1125; nmr (pyridine-d_5) τ2.1-3.1 (m, 13 H), τ4.1 (s, 1.0 H), τ7.4 (s, 6.0 H).

Benzhydryl 4-methylphenyl sulfone.

This compound was prepared in a manner similar to that used to prepare benzhydryl 2,6-dimethylphenyl sulfone. Sodium p-toluenesulfinate (6.4 g, 0.03 mol) was combined with 5.5 g (0.03 mol) of benzhydrol, and 100 ml of 88% formic acid was added. Twenty drops of concentrated sulfuric acid was added to the mixture and the resulting solution was stirred using a magnetic stirrer for one hour while heating with a 40-50° water bath. Precipitation of the sulfone began 5 min after mixing the reactants.

The reaction mixture was poured into a one liter separatory funnel containing 400 ml of ether and 200 ml water. Very little of the sulfone dissolved. The water layer was separated and the precipitate plus ether solution was washed with 5% sodium bicarbonate solution until the washings remained basic. The mixture of sulfone and ether solution was filtered with suction. The solid obtained was recrystallized once from glacial acetic acid and then once from acetone-ethanol to yield 4.53 g (0.014 mol, 47%) of benzhydryl 4-methylphenyl sulfone: mp 193.5-194.8° (reported[55] mp 193-194°); ir ($CHCl_3$) 1315, 1300, 1140; nmr ($CDCl_3$) τ2.22-3.00 (m, 14.0 H), τ4.71 (s, 1.0 H), τ7.68 (s, 2.8 H).

Benzhydryl phenyl sulfone.

This compound was prepared in the same manner as described above for the preparation of benzhydryl 4-methylphenyl sulfone. A 32% yield of the desired compound was obtained: mp 188.6-190.6° (reported[56] 187-188°); ir ($CHCl_3$) 1318, 1308, 1142, 1082; nmr ($CDCl_3$) τ2.15-2.87 (m, 15 H), τ4.68 (s, 1.0 H).

Benzhydryl 2,6-dimethylbenzenesulfinate-sulfonyl-^{18}O.

The ^{18}O labeled ester was prepared by preparation of 2,6-dimethylbenzenesulfinyl chloride, allowing it to react with water containing 5 atom percent excess oxygen isotope eighteen, converting the labeled acid thus prepared to the acid chloride and allowing the resulting acid chloride labeled with oxygen eighteen to react with benzhydryl alcohol. A typical preparation is described.

To 14.4 g (0.085 mol) of 2,6-dimethylbenzenesulfinic acid slurried in 67 ml of pentane was added 24.7 g (0.27 mol) of thionyl chloride in 30 ml of pentane in a dropwise manner. After reaction ceased the resulting solution was filtered through glass wool into a tared 100 ml round-bottom flask. The pentane and most of the excess thionyl chloride were removed at a steam bath. The flask containing the residual oil was evacuated at an oil vacuum pump for eight hours. The net yield of acid chloride was 15.6 g (0.083 mol, 98%).

A solution of 1.8 g (0.10 mol) of water containing 5 atom percent excess oxygen isotope eighteen in 22 ml of tetrahydrofuran was added to the acid chloride while cooling the reaction solution in an ice bath. Crystallization began within a few minutes and the flask containing the mixture was stoppered and stored in the refrigerator overnight. The solvent was then removed at a rotary evaporator and the residue was dried in a vacuum desiccator over Drierite and solid sodium hydroxide for ten hours. The acid was reconverted to the acid chloride as described in the first step above.

The labeled acid chloride, 14.7 g (0.078 mol) was cooled

using an ice bath. It was then treated with 13.7 g (0.075 mol) of benzhydryl alcohol dissolved in 20 ml of dry pyridine. After five minutes the flask was stoppered and placed in the refrigerator overnight.

The reaction mixture was poured into 300 ml of ether which was then washed in turn with 200 ml of 1 N hydrochloric acid, 100 ml 1 N hydrochloric acid and two 100 ml portions of 5% sodium bicarbonate solution. The ether layer was separated and dried over anhydrous potassium carbonate. It was then filtered and the bulk of the ether was removed at a rotary evaporator. When crystallization began a small amount of pentane (ca. 20 ml) was added and the mixture was placed in the refrigerator. The crystalline product was collected by filtration with suction and was recrystallized from ether-pentane to give 14.5 g (0.043 mol, 57%) of benzhydryl 2,6-dimethylbenznesulfinate-sulfonyl-^{18}O; mp 80-83°. Infrared and nuclear magnetic resonance spectra were superimposable with those obtained from samples of unlabeled ester. Analysis for ^{18}O content in the compound indicated 0.94 atom percent excess ^{18}O which corresponds to 1.88 atom percent excess ^{18}O in the sulfonyl oxygen position. It was shown by basic cleavage of the ester using sodium hydroxide in dioxane-water that all of the excess labeled oxygen was in the sulfonyl oxygen position. The alcohol resulting from the cleavage contained no excess ^{18}O (see section on controls at the end of the Experimental section).

Benzhydryl chloride.

It was found that Aldrich Chemical Co. benzhydryl chloride was sufficiently pure after distillation to be used for kinetic runs: n^{25}_{D} 1.5939 (reported[30] n^{25}_{D} 1.5937); infinity titer on hydrolysis was 98.9-99.2% of theory.

Benzhydryl azide.

Two methods of preparation of benzhydryl azide were investigated. The first method was the solvolysis of the chloride in aqueous acetone with added sodium azide. It was impossible to obtain a good elemental analysis on the product obtained by this method. The benzhydryl azide obtained in this way showed two components on gas chromatography using a silicon oil column. This was at first attributed to decomposition of the azide under the conditions of the chromatography. It was later shown that the secondary component was in fact an impurity, benzhydryl alcohol.

To circumvent the production of benzhydryl alcohol in the synthesis of the azide a second synthetic method was devised. To prepare the compound 6.0 g (0.03 mol) of benzhydryl chloride was dissolved in 70 ml of dry acetone containing 10.0 g (0.035 mol) of tetrabutylammonium azide. A reflux condenser was attached and the solution was heated at reflux for four days. The contents of the flask were poured into a separatory funnel containing 300 ml of pentane and 100 ml of ether. The solution was washed successively with one 200 ml and four 100 ml portions of water. The ether layer was dried over anhydrous granular potassium carbonate. The bulk of the solvent was removed at a steam bath. When 10-15 ml of solution

remained, it was transferred to a 25 ml pear-shaped flask which was then evacuated at a water aspirator to remove the remaining solvent. The residual oil was distilled at reduced pressure to give 5.2 g (0.025 mol, 83%) of benzhydryl azide: bp 93.5-95.0° (0.6 mm) [reported[29] bp 122-123° (1.7 mm)]; n^{26}_D 1.5872 (reported[29] n^{32}_D 1.5851); ir (CCl_4) 2100; nmr (CCl_4) τ2.75 (s, 10 H), τ4.42 (s, 1.0 H).

Anal. Calcd. for $C_{13}H_{11}N_3$: C, 74.62; H, 5.30; N, 20.08.

Found: C, 74.64, 74.94; H, 5.50, 5.42; N, 20.11, 19.81.

Benzhydryl acetate.

To prepare this compound 8.14 g (0.044 mol) of Eastman white label benzhydrol was dissolved in 35 ml of pyridine in a 100 ml round-bottom flask. Acetic anhydride (26 g, 0.255 mol) was added with swirling and after 5 min a reflux condenser was attached and the solution was heated to reflux for five minutes. After cooling the solution was poured onto 75 g of ice in 75 ml of water. After the ice had melted the mixture was poured into a one liter separatory funnel containing 400 ml of 50% pentane-ether. The mixture was shaken and the water layer was discarded. The ether layer was washed successively with 100 ml of water, 200 ml of water, two 100 ml portions of 1 N hydrochloric acid, two 90 ml portions of 5% sodium bicarbonate solution and 100 ml of water. The ethereal layer was dried over anhydrous potassium carbonate and the solvent was then removed at a steam bath. The residual oil was crystallized and recrystallized from pentane to give 8.5 g (0.037 mol, 85%) of benzhydryl acetate: mp 40.2-42.2° (reported[57] mp 39-41°); ir (CCl_4)

1740, 1228; nmr ($CDCl_3$) τ2.79 (m, 10.0 H), τ3.17 (s, 1.0 H), τ7.98 (s, 3.0 H).

Sodium azide.

Fisher purified sodium azide was recrystallized from water-methanol before using for kinetic runs.

Lithium perchlorate.

To purify this salt a saturated solution of anhydrous lithium perchlorate (G. F. Smith Chemical Co.) in 40 ml water at 85° was prepared and diluted with 10 ml of water. The solution was cooled to room temperature and then cooled to 0° in the refrigerator. The resulting crystalline product was filtered with suction. The crystals were pressed between pieces of filter paper and were then allowed to air dry overnight. The melting point of the trihydrate was 94-96.5° (reported[44] mp 94.4-95.6°). Dehydration of the trihydrate in an evacuated Aberhalden apparatus over ethanol heated at reflux resulted in the loss of the theoretical amount of water to give anhydrous lithium perchlorate.

Lithium azide.

Lithium azide was prepared by the method of Hofman-Bang.[58] A solution of 11.70 g (0.18 mol) of sodium azide and 12.7 g (0.10 mol) of lithium sulfate monohydrate in 63 ml of water was prepared. To this solution was added 315 ml of 95% ethanol. The mixture was swirled occasionally over a 10 min period and then the precipitated sodium sulfate was removed by filtration and it was discarded. The filtrate was then pumped at a water aspirator to remove

the solvent.

The residual solid was stored in an evacuated desiccator over calcium chloride for several days. It was then digested for 2 min with 90 ml of anhydrous ethanol at 35°. The mixture was filtered and the ethanol was evaporated at an aspirator. The white solid was ground to a powder and was stored in an evacuated desiccator over phosphorous pentoxide. The yield was 5.4 g (0.083 mol, 46%). The lithium azide produced was analyzed by the method of Van de Mueler[59] and found to contain 99.2% ±.5 of theoretical azide ion.

Tetrabutylammonium bromide.

Eastman tetrabutylammonium bromide, mp 101-103° (reported[60] 102.7-103.5°), was shown to be identical with laboratory prepared tetrabutylammonium bromide, prepared by the reaction of tributylamine and butyl bromide. Comparison of the infrared and nuclear magnetic resonance spectra of the two samples showed no differences.

Tetrabutylammonium azide.

Sixty g (0.186 mol) tetrabutylammonium bromide was dissolved in 175 ml of water and added to a slurry of 41 g (0.177 mol) of silver oxide in 50 ml of water. The mixture was stirred for one hour. At the end of this time a silver nitrate test for bromide ion was negative. The mixture was filtered through an asbestos mat and the silver oxide cake was rinsed with water. The combined filtrate and rinsings were decolorized with charcoal and filtered through an asbestos mat.

A solution of hydrazoic acid was prepared by the dropwise addition

of 56 ml of concentrated sulfuric acid to 21 g (0.31 mol) of sodium azide in a 500 ml round-bottom flask containing 50 ml of water and 50 ml of ether. The ether and hydrazoic acid were then co-distilled. The distillate was added to the aqueous solution of tetrabutylammonium hydroxide. The mixture was swirled to effect mixing of the two phase system. The final pH of the aqueous layer was 5.0.

The ether and excess hydrazoic acid were removed by evacuation of the flask containing the mixture at an aspirator. The solution was transferred to a rotary evaporator and concentrated to a volume of 30-50 ml. The concentrate was extracted with a 150 ml and a 75 ml portion of chloroform. The combined chloroform extracts were dried by stirring with activity II alumina. After filtration the chloroform was removed at a rotary evaporator. The residual oil was poured into a 250 ml Erlenmeyer flask and the original flask was rinsed with three 12.5 ml portions of ethyl acetate which were combined with the oil. This ethyl acetate solution was then cooled in a dry ice-acetone bath and the salt began to crystallize. The flask was stoppered and stored in the freezer compartment of the refrigerator. The product was obtained by quickly filtering with suction. The solid was immediately transferred to a tared beaker and this was placed in a vacuum desiccator over phosphorous pentoxide. The dessicator was continuously pumped at a vacuum pump for three days before weighing the product which was subsequently stored in an evacuated vacuum desiccator over phosphorous pentoxide. The yield of slightly off-white, extremely hygroscopic crystalline tetrabutylammonium azide was 48 g (0.169 mol, 91%):

ir ($CHCl_3$) 2020; nmr (D_2O) τ6.2-7.3 (broad m, 7.8 H), τ7.8-9.5 (broad m, 28.0 H). Spectra were superimposable with those of an authentic sample kindly supplied by R. Mermelstein.

Tetrabutylammonium perchlorate.

Tetrabutylammonium hydroxide was prepared as described in the preceeding synthesis. To this hydroxide solution was added 60% perchloric acid with stirring until the mixture was acidic. Tetrabutylammonium perchlorate precipitated as rapidly as the perchloric acid was added. The precipitate was filtered with suction and was twice slurried with water and refiltered. The solid was dissolved in ethyl acetate and the water layer which formed was separated and discarded. The ethyl acetate solution was dried over anhydrous potassium carbonate and filtered. The ethyl acetate solution was warmed to 35° and pentane was added until crystallization started. The solution was cooled to room temperature and was then placed in a refrigerator until crystallization was complete. The white crystalline product was collected and dried overnight in a vacuum desiccator over phosphorous pentoxide to yield 55.6 g (0.163 mol, 88%) of tetrabutylammonium perchlorate: mp 213-214° (reported[61] mp 212-212.5°).

Tetrabutylammonium 2,6-dimethylbenzenesulfinate.

Tetrabutylammonium hydroxide was prepared from 25 g (0.078 mol) of tetrabutylammonium bromide and 17 g (0.074 mol) of silver oxide as has been described. 2,6-Dimethylbenzenesulfinic acid (13.39 g, 0.079 mol) was added to the hydroxide solution. The final pH of

the solution was 8.5. This solution was decolorized with charcoal. The aqueous solution was concentrated at a rotary evaporator to a volume of 30-40 ml and the concentrate was extracted with chloroform. The chloroform solution was dried by stirring with activity II alumina. The chloroform was removed at a rotary evaporator and the residual oil was stored in an evacuated vacuum desiccator overnight while pumping at a vacuum pump. The yellow solid gummy product was crystallized from ethyl acetate-ether. Three recrystallizations from ethyl acetate-ether yielded 24.2 g (0.058 mol, 75%) of moderately hygroscopic, yellowish crystalline tetrabutylammonium 2,6-dimethylbenzenesulfinate which was stored in a vacuum disiccator over phosphorous pentoxide. Infrared and nuclear magnetic resonance spectra were superimposable with those of an authentic sample kindly supplied by D. Darwish.

Tetrabutylammonium 4-methylbenzenesulfinate.

4-Methylbenzenesulfinic acid was prepared from the commercially available sodium salt. The free acid was obtained in 74% yield from 15 g (0.07 mol) by ether extraction of the acid from an acidified solution of the sodium salt. Evaporation of the dried ether solution nearly to dryness followed by addition of pentane brought about crystallization of the acid which was then collected by filtration with suction and was air dried to give 8.1 g (0.05 mol) of 4-methylbenzenesulfinic acid. The hygroscopic tetrabutylammonium salt of this acid was prepared in an analogous manner to the procedure used for the preparation of tetrabutylammonium 2,6-dimethyl-

benzenesulfinate.

Tetrabutylammonium benzenesulfinate.

Benzenesulfinic acid was obtained from the commercially available sodium salt in the manner described above for obtaining 4-methylbenzenesulfinic acid. A yield of 8.6 g (0.061 mol, 60%) of benzenesulfinic acid was obtained from 16 g (0.1 mol) of the sodium salt. The hygroscopic tetrabutylammonium salt of this acid was prepared in analogous manner to the procedure used for the preparation of tetrabutylammonium 2,6-dimethylbenzenesulfinate.

SPECIAL APPARATUS.

Modified Ünterzaucher apparatus for ^{18}O analysis.

A modified Ünterzaucher apparatus for the determination of oxygen in organic compounds was constructed as described by Oita and Conway[62] with slight modifications. It is shown diagramatically in Figure XXXIII. All joints unless specified otherwise are 10/30 standard taper and all except the sample inlet joint, G, are sealed with black wax. Silicone grease was used on the stopcocks. Furnace settings were checked with an optical pyrometer.

The reducing valve of the nitrogen tank, A, is connected to the flowmeter, B, by gum rubber tubing and the flowmeter was calibrated for flow rates from 5 to 20 ml per minute. The flowmeter is connected by gum rubber tubing to a Burrell copper oxide tube heated at 550°C by a Burrell Perma-Therm catalyst heater, C. The copper oxide was reduced by hydrogen prior to installation.

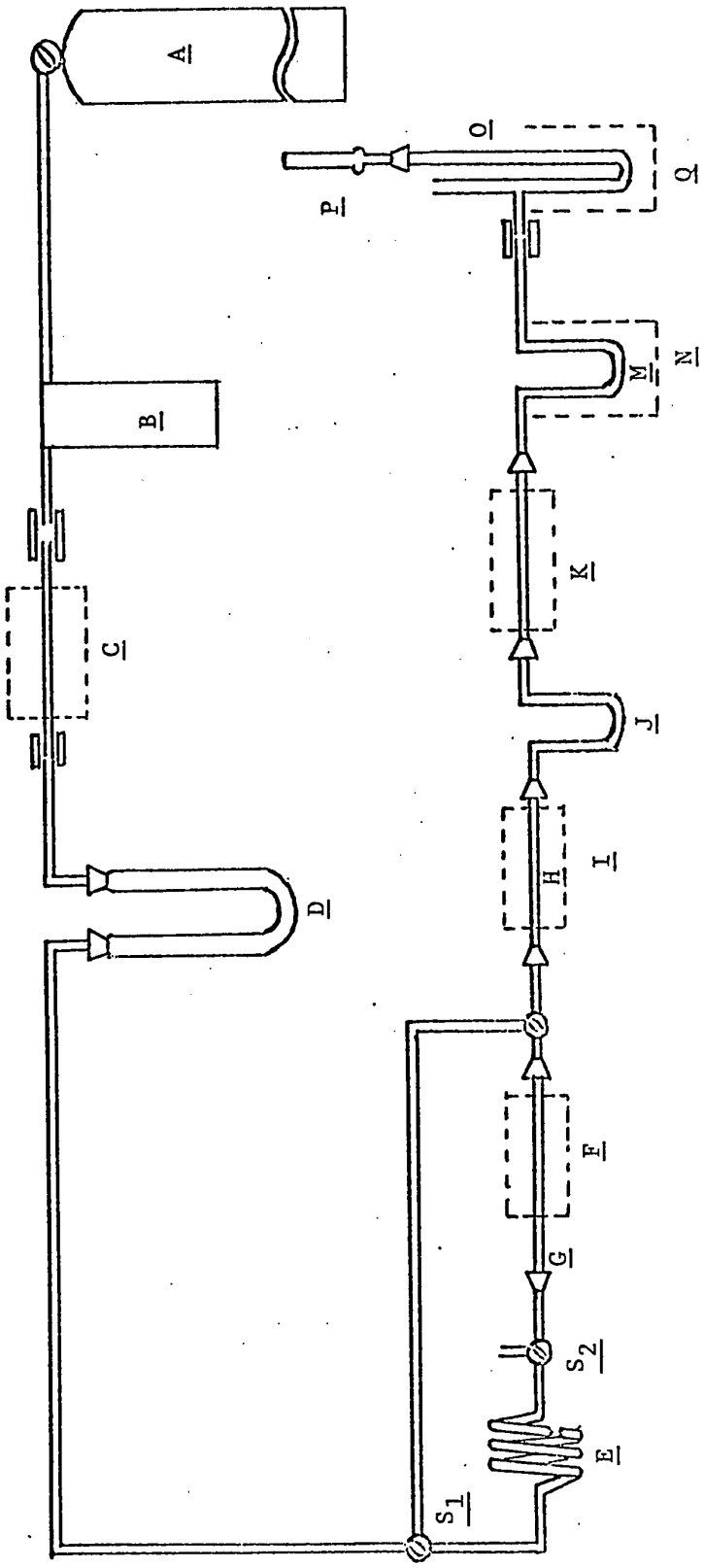


Figure XXXIII. Modified Unterzaucher apparatus.

A. Nitrogen source.
B. Flow meter.
C. Burrell Perma-Therm heater.
D. Drying tube.
E. Glass expansion coil.
F. Furnace.
G. Pyrolysis tube.
H. Copper tube.
I. Furnace.
J. Drying tube.
K. Iodine pentoxide tube.
M. Iodine collection tube.
N. Dry ice-acetone bath.
O. Sample collection tube.
P. Guard tube.
Q. Liquid nitrogen bath.
S_1, S_2, S_3 are stopcocks.

The copper oxide tube is connected by 3 mm o.d. glass tubing to a Drierite-Anhydrone-Drierite drying tube, D, the inlet and outlet of which are 19/38 standard taper joints. The drying tube is 30 cm long and is constructed from 25 mm tubing.

The three-way stopcock, S_1, is connected to the outlet of the drying tube by 3 mm o.d. glass tubing. A bypass tube of 3 mm o.d. glass tubing connects stopcocks S_1 and S_3. Stopcock S_1 is also connected to the glass expansion coil, E, which consists of 10 turns of 3 mm o.d. glass tubing, 10 cm in cross section, spaced 1 cm apart.

The pyrolysis tube, G, is constructed of fused quartz with graded seals at both ends. This tube has a 14/35 standard taper inner joint at the entrance and contains platinized carbon packing separated by rolls of platinum gauze. Details of the construction of this tube are shown in Figure XXXIV. The combustion tube is maintained at 900°C by the furnace, F. The similarly constructed quartz tube, H, is kept at 900°C by the furnace, I. This tube contains a tight roll of copper gauze, 5 cm long. The U-tube, J, contains Ascarite and Drierite and leads to the oxidation tube, K, containing iodine pentoxide. The oxidation tube is heated by Nichrome wire to 120°C ±10°.

A U-tube, M, of 8 mm glass tubing is connected to the end of the oxidation tube and is immersed in a 500 ml Dewar flask, N, which contains a dry ice-acetone mixture. This cold trap serves to trap the iodine released by the oxidation tube. The sample tube, O, is connected to the iodine trapping tube by a piece of gum

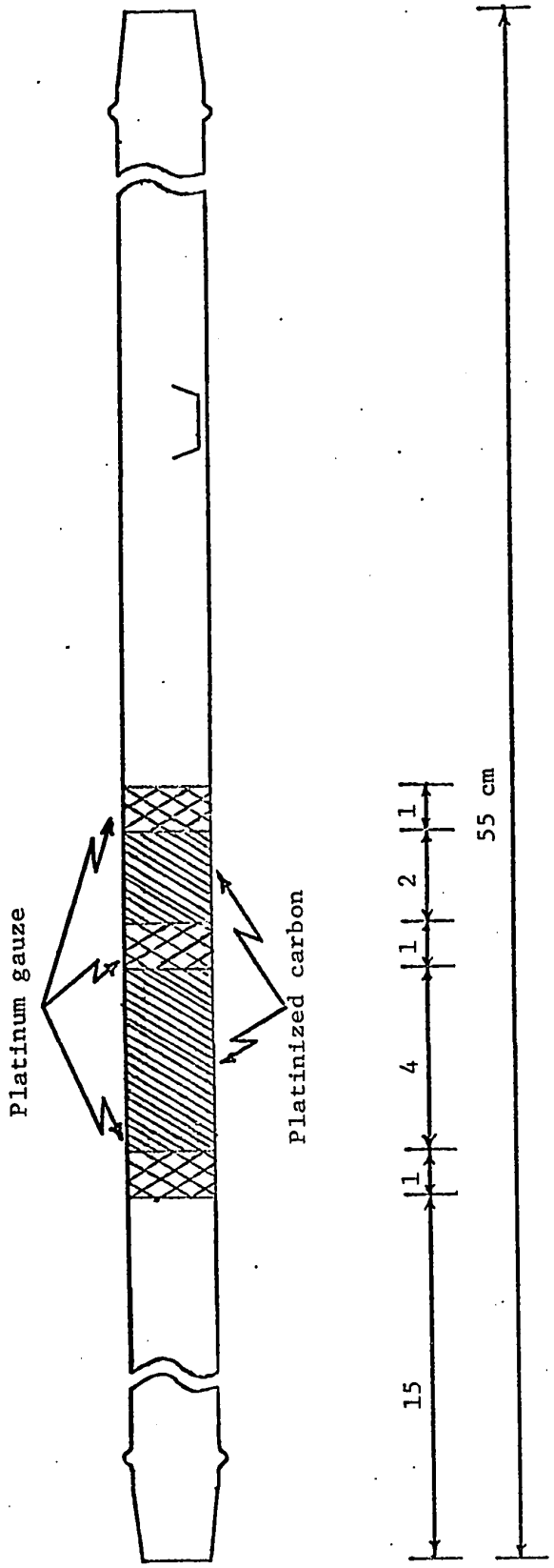


Figure XXXIV. Details of pyrolysis tube.

rubber tubing. The sample tube is immersed in a 500 ml Dewar flask, Q, containing liquid nitrogen. Attached at the exit of the sample tube by a 10/30 standard taper joint which is not sealed with black wax is an Ascarite-Drierite guard tube. Details of the construction of the sample collection tube are shown in Figure XXXV.

Reagents used in the modified Ünterzaucher apparatus.

Nitrogen: Purified nitrogen containing 1% of added hydrogen. This gas mixture is available from the Air Reduction Co. or the Matheson Corp.

Platinum gauze: 52 mesh, 0.004 inch wire.

Platinized carbon: To prepare this material 5 g of platinum was dissolved in hot aqua regia and the solution was evaporated nearly to dryness. The concentrate was then diluted to 500 ml with water and 5 g of Spheron 9 carbon (Godfrey L. Cabot, Inc.) was added and mixed thoroughly. The mixture was evaporated to a paste and was dried in a covered evaporating dish overnight at 110°C. The resulting cake was ground to a coarse powder in an agate mortar and was sieved. The portion between 40 and 100 mesh was retained. The pyrolysis tube was filled as is shown in Figure XXXIV and it was connected to the train. A nitrogen flow of 20 ml per minute in the reverse direction was started and the furnace was slowly brought up to 900°C and was maintained at this temperature for several hours. The combustion tube was then ready for use.

Copper gauze: 40 mesh.

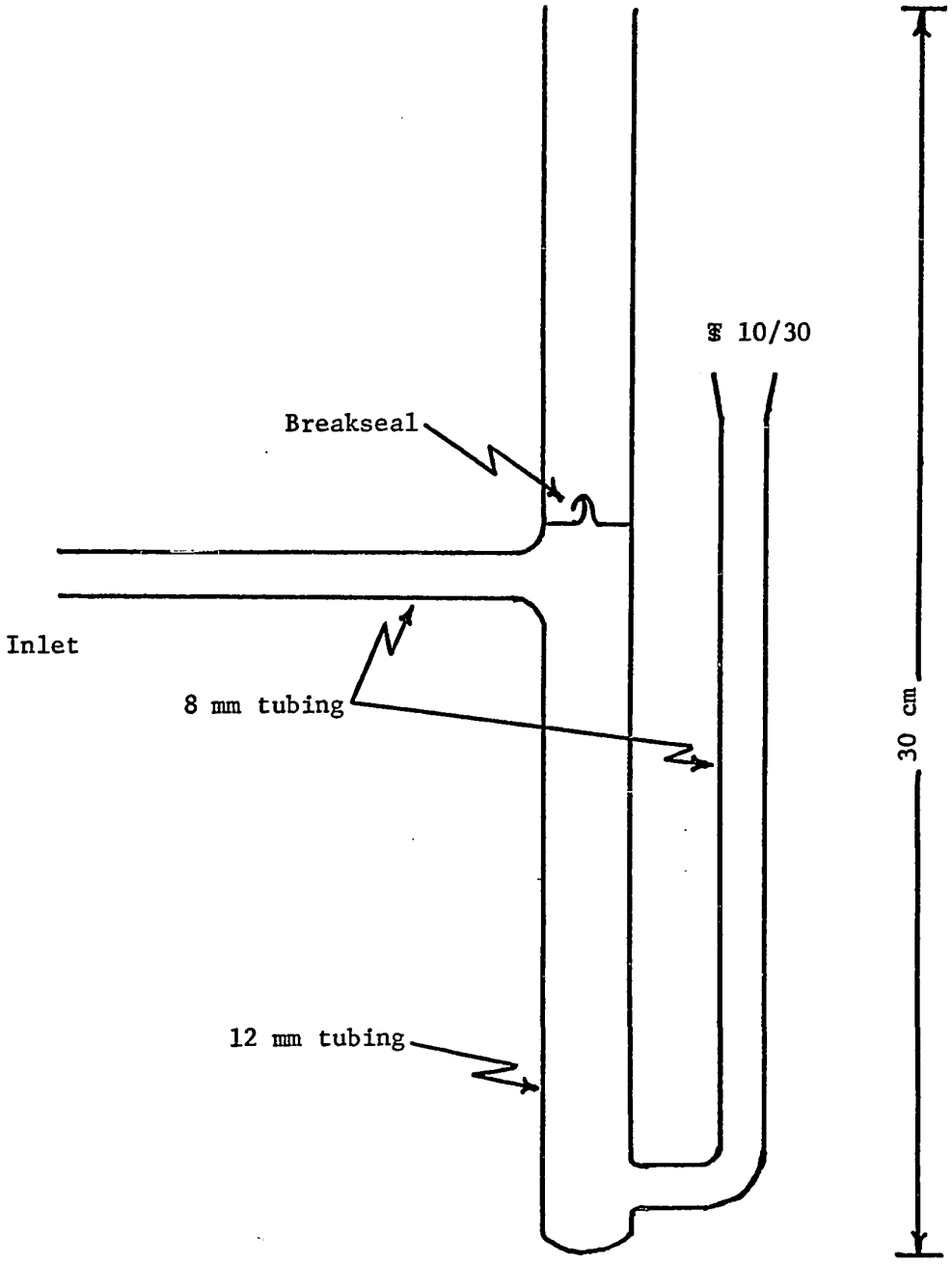


Figure XXXV. Construction of sample collection tube.

Iodine pentoxide: Baker and Adamson iodine pentoxide was treated as described by Clark.[63] The iodine pentoxide was gradually added to a boiling solution of 10 molar nitric acid until an excess was present. The hot solution was filtered through a sintered glass filter after boiling for one hour. The filtrate was left at room temperature for one day. The mother liquor was decanted and reserved for future recrystallizations while the crystals were washed with concentrated nitric acid. The washed crystals were dried several hours by sweeping with a slow stream of filtered dry air. The iodine pentoxide was then dried overnight in an evacuated desiccator over sodium hydroxide pellets and phosphorous pentoxide. The crystals were then ground to a coarse powder and this powder was used to fill the oxidation tube. Plugs of glass wool were used to stopper the ends of the oxidation tube.

Ascarite: 8-20 mesh.

Drierite: Indicating, 8 mesh.

Combustion procedure.

After the carbon packing was conditioned as described all heaters were brought up to operating temperature. When not in use the flow of nitrogen through the apparatus is maintained at 10 ml per minute and the two furnaces are maintained at 700°C. The oxidation tube is maintained at operating temperature.

With the gas flow at 20 ml per minute in the reverse direction a sample in a platinum weighing boat was introduced into the combustion tube and was located about 8 cm from the furnace using a

clean Nichrome wire. The inlet joint was reconnected and the reverse sweep was continued for 5 minutes. The gas flow was then reduced to 10 ml per minute and changed to the forward direction. The collection tube was then connected and cooled with a liquid nitrogen bath.

The initial pyrolysis of the sample was begun by heating with a movable electric furnace at 650°C about 0.5 cm upstream from the sample. As the sample began to vaporize the furnace temperature was increased to 900°C and the furnace was slowly moved forward so that the gas flow rate did not fall below 7 ml per minute. After the sample was completely volatilized the movable furnace was kept directly at the weighing boat for 5 minutes and was then moved forward at 2 cm per minute. When the furnace used to heat the platinized carbon packing was reached the movable furnace was held stationary for 5 minutes and was then turned off. The apparatus was then swept for another 20 minutes before the sample collection tube was sealed at the inlet end and removed from the train. The sample collection tube was kept in the liquid nitrogen bath and was evacuated at a vacuum pump. The collection tube was sealed under vacuum and then was submitted for mass spectrometric analysis.

All analyses for excess ^{18}O were carried out in triplicate. Values obtained were normally ±1% of the average value.

PROCEDURES, CONTROLS AND METHODS OF ANALYSIS.

Lambert-Beer law and extraction procedure controls.

A. For benzhydryl 2,6-dimethylphenyl sulfone from ethanol.

A standard solution of the sulfone was prepared in ethanol. Aliquots of this standard solution were diluted with aliquots of ethanol to provide a series of solutions with known concentrations of the sulfone. To analyze a solution for the amount of benzhydryl 2,6-dimethylphenyl sulfone present an aliquot was withdrawn from the solution using a calibrated automatic 5 ml pipette. The aliquot was delivered into a 60 ml separatory funnel containing 25 ml of 50% pentane- 50% ether and 10 ml of water. The mixture was shaken 40 times, the layers were allowed to separate and the aqueous layer was drawn off and discarded. The organic layer was washed successively with 10 ml portions of water, 1 N hydrochloric acid, 5% sodium bicarbonate solution and water. Each wash was shaken 40 times. The organic layer was then poured into a 50 ml Erlenmeyer flask and the separatory funnel was rinsed with 2-3 ml of ether. The combined extract and rinse was dried over anhydrous granular potassium carbonate and was then filtered through glass wool into a 50 ml pear-shaped flask. The potassium carbonate was rinsed with two 3 ml portions of ether and the rinses were filtered through the glass wool and combined with the extract. The glass wool filter was rinsed with a 3 ml portion of ether and this rinse was combined with the extract. The bulk of the solvent was removed at a steam bath through a 16 inch Vigreux column which was allowed to drain back into the flask. The final amount of solvent was removed by drawing a gentle stream of air over

the surface of the residue. The sample for sulfone analysis was then evacuated at an aspirator for at least 2 hours.

The residue was dissolved in two 1 ml aliquots of carbon tetrachloride delivered by calibrated automatic pipette. The resulting solution was scanned at 1370 cm^{-1} to 1265 cm^{-1} to determine the absorbance due to benzhydryl 2,6-dimethylphenyl sulfone. A Perkin Elmer Model 21 infrared spectrophotometer at the 20 cm per micron scale setting using a 0.5 mm sodium chloride cell balanced against a variable space cell to eliminate absorbance due to the solvent was employed. The optical densities of the solutions are given in Chapter I, Table II and Figure II.

B. For benzhydryl azide from ethanol.

The procedure used for infrared determination of benzhydryl azide differs only slightly from the procedure followed for determination of benzhydryl 2,6-dimethylphenyl sulfone.

Since the azide is volatile, the residue was not evacuated at an aspirator before the optical density was determined. The solution was scanned at 2270 cm^{-1} to 2000 cm^{-1} to determine the absorbance due to benzhydryl azide. The results of the Lambert-Beer law and extraction procedure control are given in Chapter I, Table III and Figure III.

C. For benzhydryl 2,6-dimethylphenyl sulfone from acetic acid.

Standard solutions of benzhydryl 2,6-dimethylphenyl sulfone were prepared in the manner described above. To analyze for the sulfone an aliquot was withdrawn from the solution using a calibrated automatic 5 ml pipette. The aliquot was delivered into a 60 ml

separatory funnel containing 25 ml of 50% pentane-ether and 10 ml of water. The mixture was shaken 40 times, the layers were allowed to separate and the aqueous layer was drawn off and discarded. The organic layer was washed successively with two 10 ml portions of 5% sodium bicarbonate solution and two 10 ml portions of water. All washes were shaken 40 times. The organic layer was poured into a 50 ml Erlenmeyer flask and the separatory funnel was rinsed with 2-3 ml of ether. The combined extract and rinse was dried over anhydrous granular potassium carbonate and was then filtered through glass wool into a 50 ml pear-shaped flask. The potassium carbonate was rinsed with two 3 ml portions of ether and the rinses were filtered through the glass wool and combined with the extract. The glass wool filter was rinsed with a 5 ml portion of ether and this was combined with the extract. The bulk of the solvent was removed at a steam bath through a 16 inch Vigreux column which was allowed to drain back into the flask. The final amount of solvent was removed by drawing a gentle stream of air over the surface of the residue. Samples for sulfone analysis were then evacuated at an aspirator for at least 2 hours.

Using a calibrated automatic pipette the residue was dissolved in two 1.922 ml aliquots of carbon tetrachloride. The resulting solution was scanned at 1370 cm^{-1} to 1265 cm^{-1} to determine the absorbance due to benzhydryl 2,6-dimethylphenyl sulfone. The optical densities of the solutions are given in Chapter I, Table XVII and Figure VII.

D. For benzhydryl acetate from acetic acid.

The procedure used for determination of concentrations of benzhydryl acetate in acetic acid is identical with that used for benzhydryl 2,6-dimethylphenyl sulfone above except that the carbon tetrachloride solutions were scanned from 1850 cm^{-1} to 1665 cm^{-1}. The optical densities of the solutions prepared are given in Chapter I, Table XIX and Figure VIII.

Gas chromatography and extraction procedure control.

A standard solution of benzhydryl azide and benzhydryl ethyl ether in ethanol was prepared from accurately weighed amounts of these compounds in a 100 ml volumetric flask. Aliquots of this standard solution were removed using a calibrated automatic pipette. Dilutions were quantitatively carried out using the same calibrated automatic pipette so that a range of concentrations of these compounds in ethanol which corresponded to the range of concentrations likely to be encountered in product analysis runs was obtained.

The extraction procedure was identical to that used to prepare plots of the relationship between concentration and absorbance for benzhydryl azide in ethanol (see preceeding section). Phenyl ether was used as the internal standard. The residue from an extraction was dissolved in a 1.922 ml aliquot of a standard solution of phenyl ether in chloroform. The response of the gas chromatograph to the constituents of the mixture was determined using a Honeywell recorder equipped with a disc chart integrator.

The recorder was attached to an Aerograph A 90-P3 gas chromatograph. A 6 ft x 1/4 inch column of 20% SE-30 on 60-80 mesh Chromosorb W was used at a column temperature of 185°, an injector temperature of 225° and a detector temperature of 232° with a helium flow rate of 60 ml per minute. The results obtained are shown in Chapter I, Tables XVI and XVII and in Figures V and VI.

KINETIC PROCEDURES.

Ester solvolysis.

Benzhydryl 2,6-dimethylbenzenesulfinate and any desired salt were weighed into a 100 ml volumetric flask. The desired base was either weighed into the volumetric flask or added as an aliquot of a stock solution of the base in the solvent to be used in the reaction. Solvent was added to the mark. The flask was vigorously shaken and inverted 30 times after all components had dissolved. Aliquots of approximately 6.0 ml were withdrawn and delivered into partially drawn out 15 x 125 mm test tubes which were then sealed. One of these ampoules was retained as a blank and the remaining ampoules were placed in an oil bath thermostated at the desired temperature. After 5 minutes one ampoule was withdrawn to serve as a zero point. At appropriate time intervals throughout the reaction ampoules were withdrawn and the reaction quenched by plunging the ampoule into an ice-water mixture. At least 3 ampoules were reserved for infinity points. These were withdrawn after at least 10 half-lives of the reaction had passed. The manner of workup of these samples varied depending upon the method

by which the reaction was to be followed.

A. Titrimetric runs. In the case of runs to be followed by titrimetry alone, the ampoule was equilibrated at 25° and a 5.00 ml aliquot was withdrawn using a calibrated automatic pipette. The aliquot was delivered into 25 ml of water which contained 20 drops of phenolphthalein. The water had previously been titrated to the phenolphthalein end point using standardized sodium methoxide in methanol. The resulting mixture was titrated for developing acid and the rate constant for the reaction was calculated using the equation

$$k = \frac{2.303}{t} \log \frac{(T_\infty - T_o)}{(T_\infty - T_t)}$$

where T_t is the titer at time = t.

B. Infrared spectrometric runs. In the case of runs which were followed by infrared spectrometry or by titrimetry and infrared spectrometry, the aliquot from the ampoule was delivered into a 60 ml separatory funnel containing 25 ml of 50% ether-pentane and 10 ml of water. The mixture was shaken 40 times and the water layer was drawn off and reserved. A second wash with 10 ml of water was carried out and the aqueous layer was combined with that of the first wash. The combined washes were titrated with sodium methoxide in methanol using 20 drops of phenolphthalein indicator. The equation above was employed to calculate the rate constant.

The ether layer was washed 3 more times with 10 ml portions of

water, each wash being shaken 40 times. The organic layer was dried over potassium carbonate, filtered through glass wool and the solvent was removed at a steam bath through a 16 inch Vigreux column which was allowed to drain back into the flask. The last traces of solvent were removed by drawing a gentle stream of air over the surface of the residue.

The residue obtained from the extraction procedure was dissolved in the appropriate amount of carbon tetrachloride and the solution was scanned using a Perkin Elmer Model 21 Recording Spectrophotometer at the 20 cm per micron scale setting. A variable space cell was used to balance out any absorption due to the solvent. The optical density was calculated from the transmittance values at the wavelengths of interest (sulfone, 1305 cm^{-1}; azide, 2100 cm^{-1}; acetate, 1740 cm^{-1}). The rate constant for the disappearance of the ester was calculated using the equation

$$k = \frac{2.303}{t} \log \frac{(D_\infty - D_o)}{(D_\infty - D_t)}$$

where D_t is the optical density at time = t.

Benzhydryl chloride solvolysis.

The rate of solvolysis of benzhydryl chloride in dry ethanol and 80% ethanol was followed either by titration for halide ion using the procedure described by Winstein[43, 42] or by titration of acid produced. The method of titration for halide ion produced was used for only a few kinetic runs.

In solvolyses with no added salts the benzhydryl chloride

was weighed into a 100 ml volumetric flask and the appropriate solvent, equilibrated to 25°, was added. The mixture was vigorously shaken and the volumetric flask was immersed to the neck in a water bath thermostated at 25.00° ±.03°. Aliquots were withdrawn at appropriate time intervals and delivered into 50 ml Erlenmeyer flasks containing 25 ml of acetone which had previously been titrated to the phenolphthalein end point using sodium methoxide in methanol. Twenty drops of phenolphthalein indicator were used. The acetone solutions were titrated immediately for developing acid when the solvent employed was anhydrous ethanol. When 80% aqueous ethanol was used the titration was deferred until all of the kinetic points had been withdrawn. The solvolysis rate constant was calculated using the equation

$$k = \frac{2.303}{t} \log \frac{(T_\infty - T_o)}{(T_\infty - T_t)}$$

where T_t is the titer at time = t.

When added salts were used the salt was weighed into a volumetric flask and the appropriate solvent, equilibrated to 25°, was added nearly to the mark and the flask was shaken to mix the components. Benzhydryl chloride was then rapidly added from a weighing boat and the flask was shaken to effect solution. Solvent was added to the mark and the reactants were mixed. The rest of the procedure was as described above in the absence of added salts.

Oxygen scrambling in benzhydryl 2,6-dimethylbenzenesulfinate-

sulfonyl-^{18}O. (2-237).

The preparation and analysis of a single kinetic point will be described.

Benzhydryl 2,6-dimethylbenezenesulfinate-sulfonyl-^{18}O (5.0103 g) labeled with 2.215 atom % excess ^{18}O in the sulfonyl oxygen position and sodium acetate (4.0967 g) were dissolved in acetic acid in a 500 ml volumetric flask to give 500 ml of a solution 0.02978 molar in the ester and 0.09987 molar in sodium acetate. Aliquots of about 100 ml each were transferred to 170 ml pressure bottles which were then placed in an oil bath thermostated at 50.00° ±.03°. These bottles were removed at appropriate times and were allowed to cool. The analysis of a sample left in the bath for 14 hours and 4 minutes will be described.

After equilibration at 25° a 5.00 ml aliquot was removed from the solution in the pressure bottle. This aliquot was subjected to the standard extraction procedure for spectrometric analysis for benzhydryl 2,6-dimethylphenyl sulfone and benzhydryl acetate in acetic acid solution. The amount of benzhydryl acetate present corresponded to the solvolysis of 20.6% of the starting material and the amount of sulfone formed corresponded to the isomerization of 35.6% of the starting ester.

The remainder of the reaction solution was poured into a one liter separatory funnel containing 400 ml of 50% ether-pentane. The solution was washed in turn with 200 ml of water, with 100 ml of water, twice with 100 ml portions of 5% sodium bicarbonate solution and finally with 100 ml of water. The ether layer was

dried over anhydrous granular potassium carbonate and the solvent was removed at a rotary evaporator. The residue was dissolved in 100 ml of purified dioxane to which 40 ml of water was then added. Ten ml of 1 N sodium hydroxide was added to the dioxane-water solution and the resulting solution was left overnight to effect hydrolysis of the remaining arenesulfinate ester and benzhydryl acetate.

The dioxane solution was poured into a one liter separatory funnel containing 400 ml of 50% ether-pentane. The resulting solution was washed successively with 200 ml of water and three 100 ml portions of 5% sodium bicarbonate solution. The ether layer was dried over potassium carbonate and the solvent was removed at a steam bath. The residue was dissolved in ether and then was chromatographed on a column of 30 g of Woelm activity I alumina. The sulfone was eluted using ether as eluant. The eluting solution was changed to 50% ether-chloroform and then to chloroform to elute benzhydryl alcohol. The benzhydryl alcohol was dissolved in ether, the ether evaporated nearly to dryness and pentane added to bring about crystallization of the alcohol.

Pyrolyses of samples of the alcohol by the standard combustion procedure and mass spectrometric analysis of the carbon dioxide produced gave the results shown in Chapter I, Table XXII. The method of calculation of rate constants of scrambling is shown on p. 30 of Chapter I.

CONTROLS

Control on the cleavage of benzhydryl 2,6-dimethylbenzenesulfinate-sulfonyl-^{18}O.

The possibility that scrambling of the oxygen atoms of the labeled ester might occur during the basic cleavage of the ester had to be considered. To determine whether this occurred a 1.0 g sample of ester containing 1.88 atom percent excess oxygen isotope eighteen in the sulfonyl position was dissolved in 100 ml of ethanol and submitted to the standard workup procedure for kinetic points as described. Pyrolysis and mass spectrometric analysis showed that the alcohol obtained contained no excess ^{18}O.

Control on the chromatography of ^{18}O-containing benzhydryl alcohol.

The possibility existed[64] that oxygen atoms of benzhydryl alcohol might exchange with oxygen atoms of the alumina upon chromatography. To test this possibility a sample of benzhydryl alcohol which had been analyzed to contain 0.188 atom percent excess ^{18}O was rechromatographed on Woelm alumina, duplicating the elution program described in the kinetic analysis procedure. Analysis of the alcohol obtained from the chromatography showed that it still contained 0.188 atom percent excess ^{18}O. Thus no exchange of oxygen atoms occurs during the chromatography.

Control on the possibility of sulfur-oxygen bond fission in the acetolysis of benzhydryl 2,6-dimethylbenzenesulfinate at 50.0°.

The total amount of starting material in the acetolysis of benzhydryl 2,6-dimethylbenzenesulfinate could be accounted for by the amounts of benzhydryl acetate and benzhydryl 2,6-dimethyl-

phenyl sulfone formed in the reaction. In addition gas chromatography of a sample from an acetolysis reaction after 90 hours showed that no benzhydryl alcohol was present. However, the possibility existed that benzhydryl alcohol might be formed by sulfur-oxygen bond fission. The alcohol could then react with the solvent to give benzhydryl acetate. To test this possibility benzhydryl alcohol was dissolved in acetic acid containing 0.1 molar sodium acetate. After 70 hours at 50° 14.8% of the theoretical amount of benzhydryl acetate had been formed. After 96 hours 19.4% of the theoretical amount of benzhydryl acetate had been formed.

Therefore the absence of any detectable amount of benzhydryl alcohol in an acetolysis solution after 90 hours eliminates the possibility of sulfur-oxygen bond fission in acetolysis of the arenesulfinate ester.

BIBLIOGRAPHY

1. W. G. Young, S. Winstein and H. L. Goering, J. Am. Chem. Soc., 73, 1958 (1951).
2. S. Winstein and D. Trifan, J. Am. Chem. Soc., 74, 1154 (1952).
3. S. Winstein, E. Clippinger, A. H. Fainberg, R. Heck and G. C. Robinson, J. Am. Chem. Soc., 78, 328 (1956).
4. S. Winstein and G. C. Robinson, J. Am. Chem. Soc., 80, 169 (1958).
5. A. H. Fainberg and S. Winstein, J. Am. Chem. Soc., 78, 2767 (1956).
6. S. Winstein, B. Appel, R. Baker and A. Diaz, Chem. Soc. (London), Spec. Publ. 19, 109-30 (1964).
7. S. Winstein, A. Ledwith and M. Hojo, Tetrahedron Letters, No. 10, 341 (1961).
8. H. L. Goering and J. F. Levy, J. Am. Chem. Soc., 86, 120 (1964).
9. C. K. Ingold, Structure and Mechanism in Organic Chemistry, Cornell University Press, Ithaca, N. Y. (1953), p. 388.
10. L. P. Hammett, Physical Organic Chemistry, McGraw-Hill Book Co. Ltd., New York (1940), p. 186.
11. S. G. Smith, Tetrahedron Letters, No. 21, 979 (1962).
12. A. Iliceto, A. Fava, U. Mazzucato and O. Rosetto, J. Am. Chem. Soc., 83, 2729 (1961).
13. A. C. Cope, D. E. Morrison and L. Field, J. Am. Chem. Soc., 72, 59 (1950).
14. M. E. Hanke, J. Am. Chem. Soc., 45, 1321 (1923).

15. S. Braverman, Ph. D. Thesis, University of Alberta (1963).

16. D. Darwish and R. A. McLaren, Tetrahedron Letters, No. 26, 1231 (1962).

17. R. A. McLaren, Ph. D. Thesis, University of Alberta (1964).

18. R. Mermelstein, Ph. D. Thesis, University of Alberta (1964).

19. H. H. Persad, Ph. D. Thesis, University of Alberta (1966).

20. D. Darwish and E. A. L. Preston, Tetrahedron Letters, No. 2, 113 (1964).

21. D. Darwish and J. Noreyko, Can. J. Chem., 43, 1366 (1965).

22. J. Kenyon and H. Phillips, J. Chem. Soc., 1676 (1930).

23. J. Kenyon, H. Phillips and F. M. H. Taylor, J. Chem. Soc., 173 (1933).

24. C. L. Arcus, M. P. Balfe and J. Kenyon, J. Chem. Soc., 485 (1938).

25. J. Kenyon, H. Phillips and G. R. Shutt, J. Chem. Soc., 1663 (1936).

26. A. Streitwieser Jr., Solvolytic Displacement Reactions, McGraw-Hill Book Co. Inc., New York (1962).

27. A. H. Wragg, J. S. McFadyen and T. S. Stevens, J. Chem. Soc., 3603 (1958).

28. L. C. Bateman, E. D. Hughes and C. K. Ingold, J. Chem. Soc., 974 (1940).

29. C. H. Gudmundsen and W. F. McEwen, J. Am. Chem. Soc., 79, 329 (1957).

30. S. Winstein, A. H. Fainberg and E. Grunwald, J. Am. Chem. Soc., 79, 4146 (1957).

31. A. H. Fainberg and S. Winstein, J. Am. Chem. Soc., 78, 2763 (1956).

32. L. C. Bateman, E. D. Hughes and C. K. Ingold, J. Chem. Soc., 966 (1940).

33. S. Winstein, M. Hojo and S. Smith, Tetrahedron Letters, No. 22, 12 (1960).

34. S. Winstein, J. S. Gall, M. Hojo and S. Smith, J. Am. Chem. Soc., 82, 1010 (1960).

35. A. F. Diaz and S. Winstein, J. Am. Chem. Soc., 86, 5010 (1964).

36. S. Winstein and J. S. Gall, Tetrahedron Letters, 31 (1960).

37. S. Smith, A. Fainberg and S. Winstein, J. Am. Chem. Soc., 83, 618 (1961).

38. H. Phillips, J. Chem. Soc., 2577 (1925).

39. E. A. Preston, M. Sc. Thesis, University of Alberta (1963).

40. E. Ciuffarin, M. Isola and A. Fava, J. Am. Chem. Soc., 90, 3594 (1968).

41. L. Sagramora, P. Koch, A. Garbesi and A. Fava, Chem. Commun., 985 (1967).

42. J. R. Caldwell and H. V. Moyer, Ind. Eng. Chem., Anal. Ed., 7, 38 (1935).

43. A. H. Fainberg and S. Winstein, J. Am. Chem. Soc., 78, 2770 (1956).

44. S. Winstein and R. Adams, J. Am. Chem. Soc., 78, 840 (1956).

45. J. L. Kice and K. B. Bowers, J. Am. Chem. Soc., 84, 605 (1962).

46. H. L. Goering and G. N. Fickes, J. Am. Chem. Soc., 90, 2848 (1968).

47. J. L. Kice, C. G. Venier and L. Heasley, J. Am. Chem. Soc., 89, 3557 (1967).

48. A. F. Diaz and S. Winstein, J. Am. Chem. Soc., 88, 1318 (1966).

49. Alfons Schöbel and Annemarie Wagner, Methoden der Organischen Chemie, ed. E. Müller, Vol. 9, Georg Thieme Verlag, Stuttgart (1955), pp. 231-3.

50. H. Lund and J. Bjerrum, Ber., 64, 210 (1931).

51. L. F. Fieser, Experiments in Organic Chemistry, Third Edition, D. Heath and Co., Boston (1957), p.285.

52. L. F. Fieser, Ibid., p. 284.

53. H. C. Brown, S. Johnson and H. Podell, J. Am. Chem. Soc., 76, 5556 (1954).

54. J. D. Roberts and W. Watanabe, J. Am. Chem. Soc., 72, 4869 (1950).

55. G. W. H. Cheeseman, J. Chem. Soc., 115 (1957).

56. F. G. Bordwell and B. M. Pitt, J. Am. Chem. Soc., 77, 572 (1955).

57. J. Herzig und Marianne Schlieffer, Ann., 422, 326 (1921).

58. Niels Hofman-Bang, Acta. Chem. Scand., 11, 581 (1957).

59. J. H. Van de Meulen, Rec. Trav. Chim., 67, 600 (1948).

60. S. Winstein, P. E. Klinedienst, Jr. and E. Clippinger, J. Am. Chem. Soc., 83, 4986 (1961).

61. S. Winstein, P. E. Klinedienst, Jr. and G. C. Robinson, J. Am. Chem. Soc., 83, 885 (1961).

62. I. J. Oita and H. S. Conway, Anal. Chem., 26, 600 (1954).

63. S. J. Clark, Quantitative Methods of Organic Microanalysis, Butterworth's Scientific Publications, London (1956), p. 148.

64. D. Samuel and I. Wasserman, Chem. Ind. (London), 21, 891 (1964).

65. W. T. Miller, Jr. and J. Bernstein, J. Am. Chem. Soc., 70, 3600 (1948).

66. C. A. Bunton and B. N. Hendry, J. Chem. Soc., 627 (1963).

67. C. D. Hodgman, ed., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co, Cleveland, Ohio (1959), p. 846.