6747

NATIONAL LIBRARY
OTTAWA

CANADA

BIBLIOTHÈQUE NATIONALE
OTTAWA

NAME OF AUTHOR..... Anita Po .....

TITLE OF THESIS..... Mechanisms of Racemization .....
.... and .... Nmr. Studies of Sulfonium Salts
.....

UNIVERSITY.. of ... Alberta .....

DEGREE FOR WHICH THESIS WAS PRESENTED..... Ph. D. .....

YEAR THIS DEGREE GRANTED..... 1970 .....

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)..... Anita Po .....

PERMANENT ADDRESS:

..... 1107 Juan Luna St. .....
..... Tondo Manila .....
..... Philippines .....

DATED..... Sept. 23 1970

NL-91 (10-68)

THE UNIVERSITY OF ALBERTA

MECHANISMS OF RACEMIZATION AND NMR STUDIES OF SULFONIUM SALTS

by

© ANITA PO

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

FALL, 1970

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 'Mechanisms of Racemization and Nmr Studies of Sulfonium Salts' submitted by Anita Po, B. Sc., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

David Dolphin

Supervisor

External Examiner

Date Sept. 18, 1970

To my Father and Mother

ACKNOWLEDGEMENTS

The author wishes to express her sincere gratitude and appreciation to:

Dr. David Darwish, Research Director, for his encouragement, understanding and stimulating guidance throughout the progress of this work.

Past and present members of the research group for helpful discussions and occasional supply of chemicals and equipment.

The faculty and technical staff of the Department of Chemistry for their interest and assistance in various aspect of the work.

The University of Alberta and National Research Council of Canada for generous financial support.

ABSTRACT

The racemizations and solvolyses of substituted benzylethylmethylsulfonium salts were investigated. The five perchlorate salts studied carried the following substituents: m-nitro(IX), 3-methyl-4-methoxy(X), 3,5-dimethyl-4-methoxy(XI), p-chloro(XII) and p-methyl (XIII). The racemization of p-chlorobenzylethylmethylsulfonium bromide (XIV) was also studied.

The relative racemization rate constants, $k_{rac.} = k_{\alpha} - k_{t}$, for compounds IX to XIII compared to benzylethylmethylsulfonium perchlorate(V), in methanol at 50.00° are IX : X : XI : XII : XIII : V : 0.96 : 48.2 : 1.79 : 0.95 : 0.99 : 1. The relative solvolysis rate constants, k_t, under the same conditions are IX : X : XI : XII : XIII : V : 0.36 : 3840 : 63.5 : 0.75 : 3.25 : 1.

The racemization rate constants for compounds IX, XII and XIII are very close to that for V. The electronic effect of the substituents did not influence the racemization rate significantly. This is consistent with a pyramidal inversion about the sulfur atom serving as the major pathway for racemization of compounds IX, XII and XIII. This mechanism also explains the excess of polarimetric rate constants, k_{α}, over the titrimetric rate constants, k_t. For example, compound IX was found to have a ratio of $k_{\alpha}/k_t = 90$.

Previous studies on the racemization of benzylethylmethylsulfonium perchlorate(V) and p-nitrobenzylethylmethylsulfonium perchlorate (VI) showed that their relative rate constants are 1 : 0.99. However, p-methoxybenzylethylmethylsulfonium perchlorate(VIII) was found to

racemize 15 times faster than benzylethylmethylsulfonium perchlorate(V) in methanol at 50.00°. To distinguish between racemization by pyramidal inversion and a process involving carbon-sulfur bond heterolysis, m-nitro-p-methoxybenzylethylmethylsulfonium perchlorate(VII) was studied. This compound was found to racemize and solvolyze with rate constants comparable to those of benzylethylmethylsulfonium perchlorate(V). In this work, it has been shown that a m-nitro group, like a p-nitro group, has no significant effect upon racemization by pyramidal inversion. This observation confirms the suggestion that p-methoxybenzylethylmethylsulfonium perchlorate(VIII) racemizes predominantly by a process other than pyramidal inversion. The racemization of VIII is best accounted for by a process involving carbon-sulfur bond heterolysis to yield an ion-neutral molecule pair which can return to give racemic salt or react with the solvent to yield solvolysis products. The 4-methoxy and 3-methyl groups in 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X) also exert an accelerative effect on the racemization process. Hence, compound X must also racemize by way of an ion-neutral molecule species.

The racemization and solvolysis of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(XI) are slower than VIII and X. The decrease in rates are accounted for by steric inhibition of resonance by the two methyl groups which prevent the methoxy group in becoming planar with the aromatic ring.

Changing the anion from perchlorate to bromide did not affect the racemization rate significantly. p-Chlorobenzylethylmethylsulfonium bromide(XIV) racemizes 1.18 times faster than the corresponding perchlorate

salt. The racemization rate constant of XIV is comparable to that of benzylethylmethylsulfonium perchlorate(V). The relative rate constants for racemization at 50.00^{o} in anhydrous methanol are V : XIV : 1 : 1.12. Under the same conditions, XIV has a decomposition rate constant, $k_{dec.}$, 15 times larger than the solvolysis rate constant, k_t, for V. The major pathway for the racemization of p-chlorobenzylethylmethylsulfonium bromide involves pyramidal inversion about the sulfur atom.

Racemization by nucleophilic displacement on the primary benzylic carbon by the ethyl methyl sulfide was shown to be of minor importance.

Nmr studies on various sulfonium and ammonium salts gave evidence of ion pairs formation. No evidence was found which requires the formation of tetravalent sulfur species for sulfonium halides in solution.

TABLE OF CONTENTS

LIST OF TABLES

in a Variety of Solvents at the Temperature of the Probe.

Table XXXVIII. A Comparison of the Nmr Spectra of 3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate and bromide ($3,5\text{-di}CH_3\text{-}4\text{-}OCH_3C_6H_2CH_2\overset{+}{\underset{CH_3}{S}}CH_2CH_3\ X^-$) in a Variety of Solvents at the Temperature of the Probe.

Table XXXIX. A Comparison of the Nmr Spectra of p-Chlorobenzylethylmethylsulfonium bromide, fluoroborate and perchlorate ($p\text{-}ClC_6H_4CH_2\overset{+}{\underset{CH_3}{S}}CH_2CH_3\ X^-$) in CD_2Cl_2 at -40^o.

Table XL. Nmr Spectra of tetra-n-Butylammonium salts[$(CH_3CH_2CH_2CH_2)_4N^+\ X^-$] in CD_2Cl_2 at the Temperature of the Probe.

Table XLI. A Comparison of the Nmr Spectra of Benzyltrimethylammonium salts[$\emptyset CH_2\overset{+}{N}(CH_3)_3\ X^-$] in a Variety of Solvents at the Temperature of the Probe.

Table XLII. Nmr Spectra of Mixtures of p-Chlorobenzylethylmethylsulfonium perchlorate and bromide($p\text{-}ClC_6H_4CH_2\overset{+}{\underset{CH_3}{S}}CH_2CH_3\ X^-$) at the Temperature of the Probe in a Variety of Solvents.

Table XLIII. Nmr Spectra of Mixtures of 3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate and bromide($3,5\text{-di}CH_3\text{-}4\text{-}OCH_3C_6H_2CH_2\overset{+}{\underset{CH_3}{S}}CH_2CH_3\ X^-$) in a Variety of Solvents at the Temperature of the Probe.

Table XLIV. Nmr Spectra of Mixtures of Benzylmethylethoxysulfonium fluoroborate($\emptyset CH_2\overset{+}{\underset{OCH_2CH_3}{S}}CH_3\ BF_4^-$) and p-Chlorobenzylethylmethylsulfonium bromide($p\text{-}ClC_6H_4CH_2\overset{+}{\underset{CH_3}{S}}CH_2CH_3\ Br^-$) in CD_2Cl_2 at Various Temperature.

LIST OF FIGURES

in Anhydrous Methanol at 25.00°. Runs III-75, III-94 and III-96.

Figure IX. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the Racemization of 3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate in Anhydrous Methanol at 50.00°. Runs II-264, III-10 and III-11.

Figure X. $Log(V_\infty - V_t)$ vs. Time for the Solvolysis of p-Methylbenzylethylmethylsulfonium bromide with Added 2,6-Lutidine in Anhydrous Methanol at 90.00°. Runs III-171.

Figure XI. $Log(\alpha_\infty - \alpha_t)$ vs. Time for the Racemization of (+)-p-Chlorobenzylethylmethylsulfonium bromide with Added 2,6-Lutidine in Anhydrous Methanol at 50.00°. Run II-66.

Figure XII. $Log(V_\infty - V_t)$ vs. Time for the Solvolysis of p-Chlorobenzylethylmethylsulfonium perchlorate with Added 2,6-Lutidine in Anhydrous Methanol at 70.00°. Run II-280.

Figure XIII. $Log(\alpha_\infty - \alpha_t)$ vs. Time for the Racemization of (-)-p-Chlorobenzylethylmethylsulfonium perchlorate with Added 2,6-Lutidine in Anhydrous Methanol at 50.00°. Run II-266.

Figure XIV. Plot of $k_{obs.}$ vs. [EtSMe] for the Solvolysis of p-Chlorobenzyl bromide in Anhydrous Methanol at 50.00 with Added 2,6-Lutidine. Runs IV-13, IV-18, IV-12, IV-16, IV-17, IV-6, IV-9, IV-19, IV-10, IV-15, IV-20.

Figure XV. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the Racemization of p-Chlorobenzylethylmethylsulfonium bromide with Added 2,6-Lutidine in Anhydrous Methanol at 50.00°. Runs IV-66, IV-23, IV-24 and IV-69.

Figure XVI. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the Racemization of p-Methylbenzylethylmethylsulfonium perchlorate with Added 2,6-Lutidine in Anhydrous Methanol at 50.00°. Runs II-267, III-47 and III-63.

Figure XVII. Plot of $Log(V_\infty - V_t)$ vs. Time for the Solvolysis of p-Chlorobenzyl bromide in Anhydrous Methanol at 50.00° in the presence of Ethyl methyl sulfide and 2,6-Lutidine using the Volhard method.

Figure XVIII. Plot of $[p\text{-}ClC_6H_4CH_2Br]$ in terms of mls. of KSCN vs. Time for the Solvolysis of p-Chlorobenzylethylmethylsulfonium bromide in Anhydrous Methanol at 50.00°, in the presence of 2,6-Lutidine. Run IV-11.

Figure XIX. Calibration Curve for the Product Analysis of Solvolysis of p-Methylbenzylethylmethylsulfonium perchlorate in Anhydrous Methanol with Added 2,6-Lutidine using Naphthalene as the Internal Standard. Run III-152.

INTRODUCTION

The application of basic theories and methods of physical chemistry has helped tremendously in the understanding of mechanisms of organic reactions.

The two well-known mechanisms for nucleophilic substitution reactions were postulated by Ingold and co-workers(1). Namely:

(i). S_N1 or unimolecular nucleophilic substitution mechanism.

(ii). S_N2 or bimolecular nucleophilic substitution mechanism.

The former mechanism involves two steps: a slow heterolysis of the substrate to form a carbonium ion and a rapid coordination between the carbonium ion and the substituting agent. The first step is the rate determining step in the process. The mechanism is illustrated by the following equations:

$$R - X \xrightarrow{\text{slow}} R^+ + X^-$$

$$Y^- + R^+ \xrightarrow{\text{fast}} Y - R \qquad S_N1$$

The latter mechanism contains only one stage. It involves an electron transfer from the substituting agent to the seat of substitution and from the latter to the displaced group. This can be expressed by the equation:

$$Y^- + R - X \longrightarrow Y - R + X^- \qquad S_N2$$

The choice of S_N1 or S_N2 mechanism depends not only on the structure of Y, R and X, but also on the solvent molecules surrounding these reactants. These solvent molecules can have profound effects on

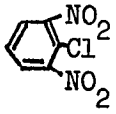
the free energy of the reactants, intermediates and transition states. In some cases, it is possible to observe a changeover in mechanism, a given reaction proceedings by the S_N1 path in some solvents and by the S_N2 path in other solvents.

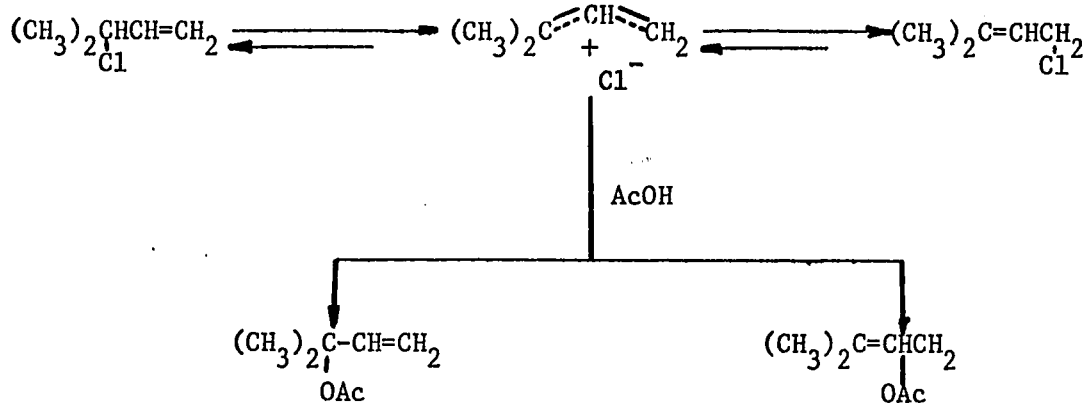
By studying the effect of small changes in substrate structure on the products and rates of reactions, one can obtain valuable information of the mechanism involved. For example, electrical effects can be investigated in the absence of steric effects by inserting a rigid structure between the reacting center and the point where the structure is changed. The effect of p-alkyl substituents in a benzyl compound on the rates of various bimolecular and one unimolecular substitution reaction has been investigated by Bevan, Hughes and Ingold(2) who have presented a summary of a variety of substitution reactions on benzylic system. Their relative rates are recorded in Table I. The data for the reaction of benzyl bromides with pyridine(top line of Table I) are by J. W. Baker and W. S. Nathan(3). They found that reactions which require electron supply are accelerated by alkyl groups and reactions which require electron withdrawal are decelerated by alkyl groups.

The 'mass law depression' as evidence for a unimolecular S_N1 reaction was also postulated by Hughes, Ingold and co-workers(4). Winstein and co-workers(5) in the early 1950's in their studies of the acetolysis of α ,α- dimethylallyl chloride suggested return of an ionized but undissociated intermediate back to the allylic halide or a similar species. This was termed 'internal return' distinct from 'mass law' or external ion return(6).

TABLE I

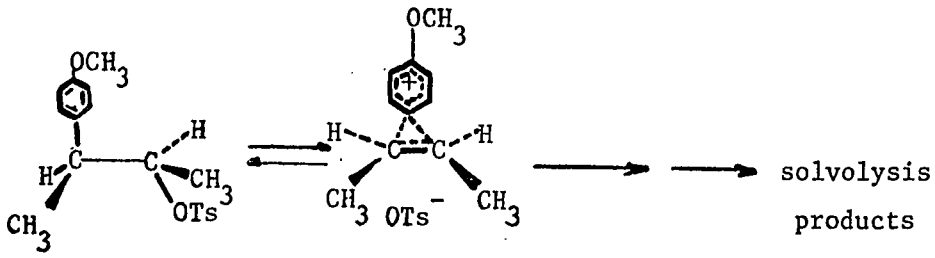
RELATIVE RATES OF SOME NUCLEOPHILIC SUBSTITUTION OF ARALKYL AND ARYL COMPOUNDS AND OF THEIR p-METHYL AND p-t-BUTYL DERIVATIVES(BEVAN AND HUGHES) (2).

Reactants	Solvent	Temp. (°C)	Molecularity	Relative Rates p-H	p-Me	p-t-Bu
$\phi CH_2Br + C_5H_5N$	$(CH_3)_2C{=}O$	20	2	1	1.66	1.35
$\phi CH_2Br + I^-$	$(CH_3)_2C{=}O$	0	2	1	1.45	1.35
$\phi CH_2Br + EtO^-$	EtOH	25	2	1	1.48	1.36
$\phi CH_2Br + t\text{-}BuO^-$	t-BuOH	60	2	1	1.32	1.18
$\phi CH_2Cl + EtO^-$	EtOH	25	2	1	1.58	1.47
$\phi CH_2Br + H_2O$	HCO_2H	25	1	1	57.9	28.0
$\phi CH_2\overset{+}{N}C_5H_5 + EtO^-$	EtOH	20	2	1	0.507	0.629
$\phi CO_2Et + OH^-$	85% aq. EtOH	25	2	1	0.486	0.616
$\phi COCl + EtOH$	EtOH	0	2	1	0.531	0.667
 $+ EtO^-$	EtOH	50	2	1	0.173	0.310



The possibility that ions of opposite charge could co-exist in solution as ion pairs, held together by electrostatic attraction, had long been recognized as a consequence of the Debye-Huckel and Onsager theories on strong electrolytes. Mathematical methods for estimation of the importance of ion pairs from conductivity data had already been elaborated(7-10). However, it was the work of Winstein and his co-workers which provided the kinetic and stereochemical evidences for the formation of ion pairs as intermediate in solvolytic reactions.

In the study of the optically active norbornyl or threo-3-p-anisyl-2-butyl systems, Winstein et al.(11) found that racemization rates were faster than the solvolysis rates. For example, the racemization of optically active threo-3-p-anisyl-2-butyl-p-bromo-benzenesulfonate in acetic acid at 25° was four times faster than its solvolysis. This was again attributed to ion pair return which produces racemic starting material.



Extensive studies on solvolyses of sulfonium salts were done by Ingold and co-workers(12-19). They studied the temperature and solvent effects on the rate of solvolysis of primary, secondary and tertiary substituted sulfonium salts. Swain, Kaiser and Knee(20) found that the decomposition of trimethyl- and tribenzylsulfonium halides in 90% acetone-10% water solution at 50-100° in the absence of strong bases involves neither carbonium ion formation nor solvolysis in the rate determining step, but instead a reaction with the anion. The kinetics appear first-order only because of exactly compensating salt effects. No reaction occurs under the same conditions, when a relatively non-nucleophilic anion such as perchlorate is used. They suggested that in 90% acetone-10% water, the reactants are dissociated ions. In solvents like pure acetone, tetrachloroethane, etc., they are probably mostly ion pairs or even larger aggregates. Reactions involving dissociated ions and ion pairs are illustrated respectively in Equations 1 and 2.

$$X^- + (CH_3)_3S^+ \longrightarrow XCH_3 + (CH_3)_2S \qquad \text{Eq. 1}$$

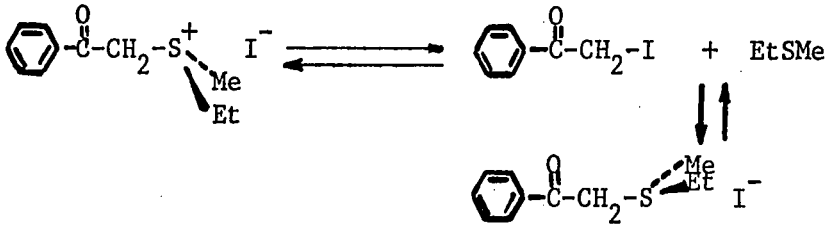
$$X^-(CH_3)_3S^+ \longrightarrow XCH_3 \qquad \text{Eq. 2}$$

Hyne and co-workers have published a series of papers on the solvolysis of sulfonium salts(21-27). They have studied the effect of concentration, anion type, solvent variation, added salts and alkyl group variation on the rates of solvolysis of sulfonium salts. The results were interpreted in terms of an increasing importance of an ion pair mechanism as the composition of the medium became less polar.

Just as kinetic and stereochemical evidence was used to

provide evidence for the importance of ion pairs as intermediates in solvolytic reactions of the norbornyl and threo-3-p-anisyl-2-butyl systems, the elucidation of the mechanisms of the reactions of sulfonium salts can also be greatly aided by sterochemical as well as kinetic studies. The stereochemical studies can be accomplished using optically active sulfonium salts and determining their rates of racemization.

Balfe, Kenyon and Phillips(28) studied the racemization of phenacylethylmethylsulfonium iodide. They concluded that racemization involved a nucleophilic displacement on carbon by halide ion to produce inactive phenacyl iodide and ethyl methyl sulfide followed by formation of the racemic salt.

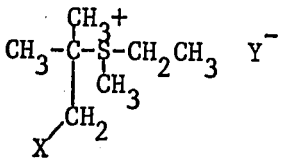


Two other mechanisms which could account for racemization are: (i). Inversion about the central sulfur atom without cleavage of any of the carbon-sulfur bond analogous to the inversion of an ammonia molecule and (ii). For systems which can yield a stable carbonium ion, carbon-sulfur bond cleavage to yield cation and ethyl methyl sulfide ion-neutral molecule pair which would return to starting material or react with solvent to form products.

The first evidence for the inversion of sulfur in sulfonium ions was reported by Darwish and Tourigny(29). They found that t-butyl-ethylmethylsulfonium salts racemized more rapidly than they decomposed.

At 50°, in anhydrous ethanol, the polarimetric rate constant, k_α, is about 10 times larger than the titrimetric rate constant, k_t. A similar behavior was found in other solvents.

In order to determine the mechanism which could account for the major path of racemization, a hydrogen in the t-butyl moiety was substituted by electron withdrawing or electron donating group. The four compounds studied denoted by I, II, III and IV have the following structures:



I, X=H

II, X=OCH_3

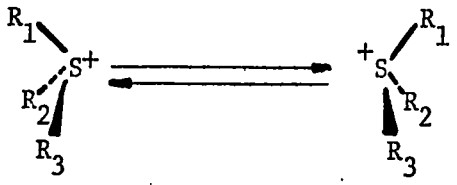
III, X=CH_3

IV, X=C_6H_5

The relative rates of ethanolysis at 50° of compounds I : II : III : IV were 1 : 0.06 : 6.3 : 1.1, while the relative rates of racemization in ethanol at 50° of I : II : III : IV were 1 : 1.7 : 3.8 : 4.7.

Electron donating substituents accelerated the rate of solvolysis and electron withdrawing group slow down the solvolysis rate. This is consistent with a mechanism involving heterolytic cleavage of the carbon-sulfur bond. On the other hand, the replacement of a hydrogen of the t-butyl group by a substituent accelerates the rate of racemition whether the substituent is electron withdrawing or electron donating. This result indicates that racemization of t-butylethylmethylsulfonium cation involves a pyramidal inversion mechanism which was not influenced by the electronic effect of the substituents but

was influenced by the steric effect. If a hydrogen was replaced by some other bulkier group, either electron withdrawing or electron donating, the inversion mechanism will be accelerated by a steric effect since any group will increase the non-bonded interactions in the ground state which can be relieved at the transition state. Equation 3 illustrates the pyramidal inversion mechanism.

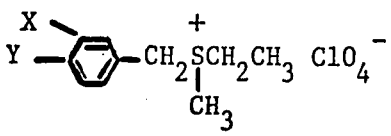


Eq. 3

The racemization and solvolysis of phenacylethylmethylsulfonium perchlorate and of ethylmethylsulfonium phenacylide were investigated by Darwish and Tomilson(30).

Mislow and Scartazzini(31) have also shown that this mechanism accounts for the racemization of the 1-adamantylethylmethylsulfonium system.

A study was made on the benzylethylmethylsulfonium system by Darwish and Hui(32). By introducing substituents into the p- and m-positions of the aromatic ring and studying their effects on the rates of solvolysis and racemization, they suggested two mechanisms to account for the behavior of the sulfonium salts on racemization. The compounds studied were V, VI, VII and VIII.



V, X=H, Y=H

VI, X=H, Y=NO_2

VII, X=NO_2, Y=OCH_3

VIII, X=H, Y=OCH_3

They showed that the major portion of the racemization for compounds V, VI and VII was accounted for by a pyramidal inversion about the central sulfur atom. Electron withdrawing or electron donating groups were found not to affect the rate of racemization significantly. At 50°, in anhydrous methanol, all three compounds racemized with a rate constant($k_{rac.}=k_{\alpha} - k_{t}$) of about 6×10^{-6} sec.$^{-1}$. Under the same condition, the relative rates of solvolysis of V : VI were 1 : 0.2. At 90°, the relative rates of methanolysis of V : VII were 1 : 0.65.

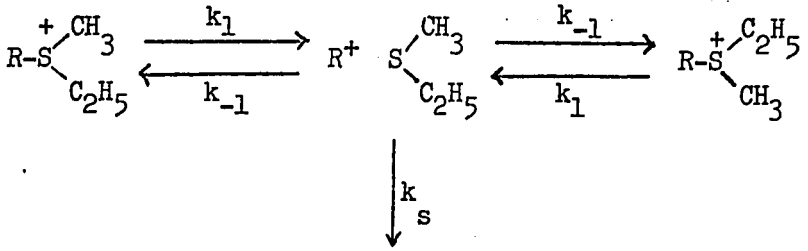
Compound VIII was found to exhibit markedly different behavior from compounds V to VII. This compound undergoes solvolysis over three powers of 10 faster than V, in solvent methanol at 50°, the rate constant for racemization of VIII, $k_{\alpha} - k_{t}$, is larger than that for V by a factor of about 15. Since racemization by inversion was found not to be influenced by electron withdrawing or electron donating substituent, the accelerative effect of the p-methoxy group can not be explained by this mechanism.

Two other processes might have accounted for the racemization of VIII. These are: (i). nucleophilic displacement on the primary benzylic carbon by the methyl ethyl sulfide, produced on the solvolysis of the sulfonium salt as shown in Equation 4.

$$RCH_2\overset{+}{S}(CH_3)CH_2CH_3 + CH_3SCH_2CH_3 \xrightarrow{k_2} RCH_2\overset{+}{S}(CH_3)CH_2CH_3 + CH_3SCH_2CH_3 \quad \text{Eq. 4}$$

and (ii). carbon-sulfur heterolysis to yield ion-neutral molecule pair

which could react to give solvolysis product or return to racemic sulfonium salt as shown in Equation 5.



Eq. 5

solvolysis product

To investigate the first process, ethyl methyl sulfide was added. The addition of ethyl methyl sulfide was found to speed up the rate of loss of optical activity. The second-order rate constant, k_2, for the reaction shown in Equation 4 was found to be 7.4×10^{-4} l.mole^{-1}sec.$^{-1}$ at 50°. For the racemization which accompanies solvolysis, it was shown that after 50% loss of optical activity, 36.6% of the sulfonium salt was found to have undergone solvolysis and 21% of the unreacted salt was racemic. Only about 1.3% of the unreacted salt could have been racemized by nucleophilic displacement reaction. Since this process accounted only for a very small portion of racemization. The carbon-sulfur bond heterolytic cleavage mechanism was suggested to be a major pathway for racemization. This scheme accounted for the acceleration of both the solvolysis and racemization reactions by the p-methoxy group. This was also suggested to be a reasonable process, since the highly stabilized p-methoxybenzyl cation would be formed on bond heterolysis.

This thesis will present further studies on both possible types of mechanism for racemization of sulfonium salts. Chapter I will present the results of further studies on ion-neutral molecule pair

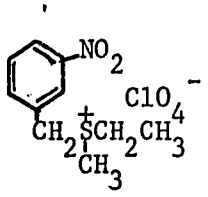
reaction. Chapter II will be concerned with a more detailed description of the pyramidal inversion mechanism.

In Chapter III, the nuclear magnetic resonance spectra of a number of sulfonium salts will be presented and discussed. Recently, G. K. Helmkamp et al.(33) and C. R. Johnson et al.(34) proposed on the basis of nmr studies that tetracovalent sulfur species exist as intermediates in some reactions of episulfonium and alkoxysulfonium salts. We present nmr data to show that the chemical shift of substituents in sulfonium salts are influenced by the anions. These results and the work of Helmkamp et al. (33) and Johnson et al.(34) will be discussed in Chapter III.

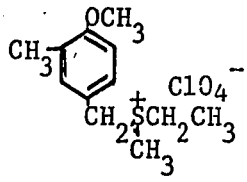
CHAPTER I

THE ION-NEUTRAL MOLECULE PAIR MECHANISM

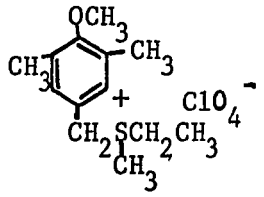
In this chapter, the syntheses and resolutions of m-nitrobenzylethylmethylsulfonium perchlorate(IX), 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X) and 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(XI) are described. The kinetics of their racemization and solvolysis are presented. Results of product analyses are also given. The results obtained will be discussed with reference to the following topics: the ratio of racemization to solvolysis, temperature effects and solvent effects. The mechanisms of racemization of IX, X and XI are deduced from the results.



IX



X



XI

SYNTHESIS AND RESOLUTION

m-Nitrobenzylethylmethylsulfonium salt

The route followed for the synthesis of m-nitrobenzylethylmethylsulfonium salts is outlined in Figure I.

m-Nitrobenzaldehyde was reduced to m-nitrobenzyl alcohol with sodium borohydride. The m-nitrobenzyl bromide was obtained by bubbling hydrogen bromide through a benzene solution of m-nitrobenzyl alcohol. m-Nitrobenzylethylmethylsulfonium bromide was obtained by treating m-nitrobenzyl bromide with ethyl methyl sulfide. m-Nitrobenzylethyl-

methylsulfonium bromide was an oil. It could not be crystallized despite numerous attempts.

Exchange of the anion of the sulfonium salt was accomplished by conversion to the hydroxide using a Dowex 1-x8 anion exchange resin in its hydroxide form followed by neutralization of the basic eluent with the appropriate acid. Resolution was accomplished by recrystallizing the d(+)-dibenzoylhydrogentartrate salt several times from a methanol-ether mixture. The less soluble dibenzoylhydrogentartrate salt gave the (+)-perchlorate salt. The (-)-perchlorate salt was obtained from the mother liquor.

3-Methyl-4-methoxybenzylethylmethylsulfonium salts

o-Methylanisole was obtained by treating o-cresol with a basic solution of dimethyl sulfate. The preparation of 3-methyl-4-methoxybenzyl bromide was based on a procedure described by R. Quelet et al.(35) for the synthesis of 3-methyl-4-methoxybenzyl chloride. The conditions had to be carefully controlled to insure formation of the desired product and to avoid formation of polymers. From this point on, the synthesis of 3-methyl-4-methoxybenzylethylmethylsulfonium salt was conducted in the same manner as described for m-nitrobenzylethylmethylsulfonium salt outlined in Figure I.

Figure II summarizes the route used for the synthesis of 3-methyl-4-methoxybenzylethylmethylsulfonium salt.

3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium salts

2,6-Dimethylphenol was converted to 3,5-dimethyl-4-hydroxy-

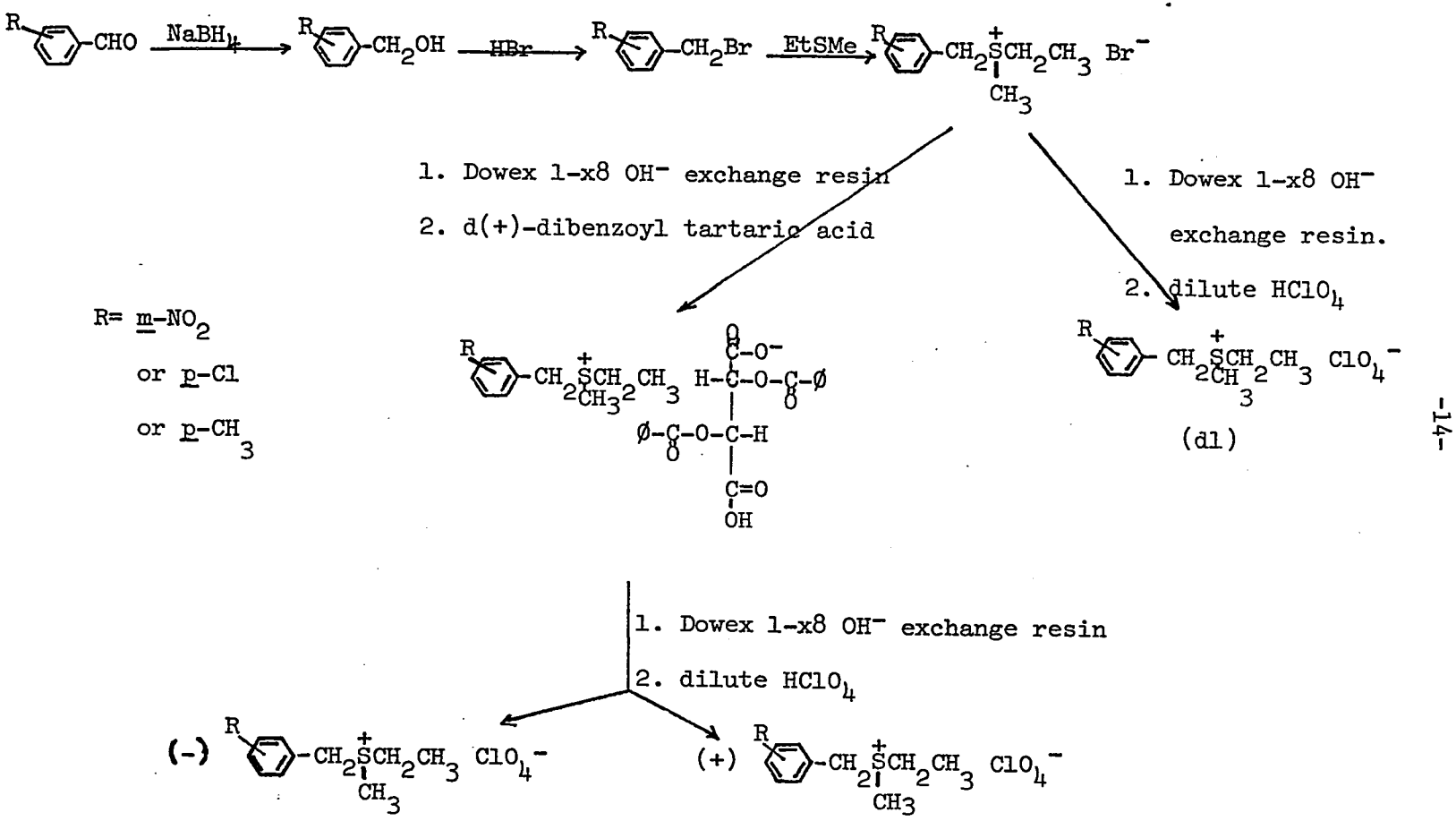


Figure I. Synthetic route for m-nitro-, p-chloro- and p-methylbenzylethylmethylsulfonium salts.

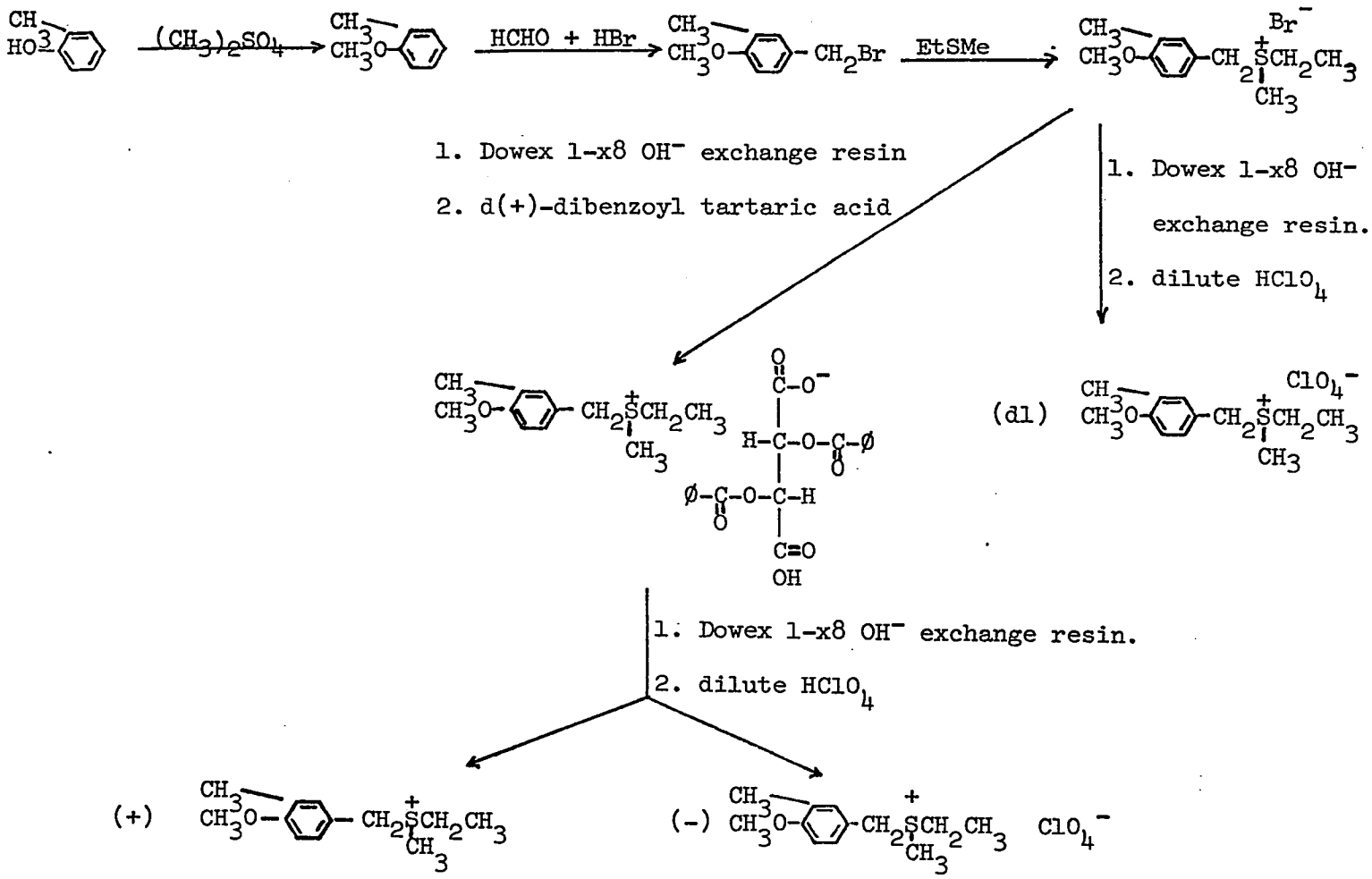


Figure II. Synthetic route for 3-methyl-4-methoxybenzylethylmethylsulfonium salts.

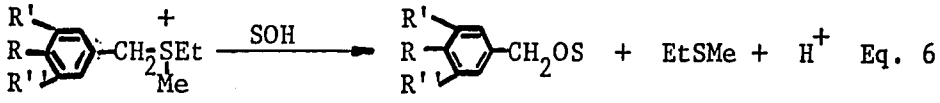
benzyl alcohol by reaction with a basic solution of formaldehyde. 3,5-dimethyl-4-methoxybenzyl alcohol was obtained by treating 3,5-dimethyl-4-hydroxybenzyl alcohol with a basic solution of dimethyl sulfate. From this point on, the synthesis of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium salt was conducted in the same manner as described for m-nitrobenzylethylmethylsulfonium salt outlined in Figure I.

Table II summarizes the properties of some m-nitro-, 3-methyl-4-methoxy- and 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium salts.

The nmr and ir spectra of the optical isomers were superimposable upon those of the corresponding racemic salts. All compounds gave satisfactory analyses.

KINETIC RESULTS:

The kinetics of the solvolyses of the different sulfonium salts were studied by measuring the rate of appearance of acid. One mole of acid was produced for every mole of sulfonium salt solvolyzed as shown in Equation 6.

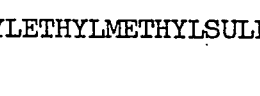


Eq. 6

Unlike the t-butylethylmethylsulfonium salts, the substituted benzylethylmethylsulfonium salts gave no elimination product.

The reactions follow first-order kinetics. The titrimetric rate constants, k_t, was calculated from the relationship:

TABLE II

PROPERTIES OF SOME m-NITRO-, 3-METHYL-4-METHOXY- AND 3,5-DIMETHYL-4-METHOXY-BENZYLETHYLMETHYLSULFONIUM SALTS ().

R	X⁻					
	Br^-	$CH_3SO_4^-$	dBT(1) (+)	(-)	ClO_4^- (+)	(dl)
m-NO_2	oil	m.p.76-78°	m.p.165°		m.p.76-78°	m.p.76°
					$[\alpha]_{589}^{25}$=13.9	
					$[\alpha]_{436}^{25}$=31.7	
					(c 0.05046, MeOH)	
3-CH_3-4-OCH_3	oil		m.p.127°	m.p.87-88°	m.p.81-82°	
			$[\alpha]_{589}^{25}$=-69.5	$[\alpha]_{589}^{25}$=-2.73	$[\alpha]_{436}^{25}$=26.5	m.p.91°
			$[\alpha]_{436}^{25}$=-172.8	$[\alpha]_{436}^{25}$=-6.17	$[\alpha]_{365}^{25}$=50	
			(c 0.1094, MeOH)	(c 1.833, MeOH)	(c 1.095, MeOH)	
3,5-diCH_3-4-OCH_3			m.p.134-135°	m.p.114.5°	m.p.111-112°	m.p.115°
	m.p.106-107°		$[\alpha]_{589}^{25}$=-67.4	$[\alpha]_{365}^{25}$=-1.7	$[\alpha]_{589}^{25}$=14.1	
			$[\alpha]_{436}^{25}$=-162.4	(c 0.599, MeOH)	$[\alpha]_{436}^{25}$=32.1	
			(c 0.257, MeOH)		(c 0.6108, MeOH)	

(1) Dibenzoylhydrogentartrate

$$k_t = \frac{2.303}{t} \log \frac{V_\infty - V_o}{V_\infty - V_t}$$

where V_t= the titer at time t, V_∞= infinity titer, V_o=the titer at time 0.

Reactions were usually followed to about 85% completion. Good first-order rate constants were obtained. A straight line was obtained when logarithm of $(V_\infty - V_t)$ was plotted vs. time. A typical titrimetric rate analysis is shown in Table III(Run II-220). Figure III illlustrates the corresponding plot of $\log(V_\infty - V_t)$ vs. time for Run II-220.

The rate of loss of optical activity was studied by following the change of optical rotation vs. time. A Perkin-Elmer Model 141 Polarimeter using incident light beams of 436 mμ and 365 mμ was employed. At these wavelengths the optical rotations are larger than at the sodium D line, thus permitting a greater precision in rate determinations. A sealed ampoule method was used(Method I). Occassionally reactions were run in a thermostated polarimetric tube(Method II). These two methods are described in detail in the experimental section. The first-order rate constants were calculated from the relationship:

$$k_\alpha = \frac{2.303}{t} \log \frac{\alpha_\infty - \alpha_o}{\alpha_\infty - \alpha_t}$$

where α_o, α_t, α_∞ are the optical rotations at time 0, time t and time ∞, respectively. Reactions were usually followed to about 85 per cent completion and a good straight line was obtained when

TABLE III

SOLVOLYSIS OF m-NITROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE(0.02286 M) WITH ADDED 2,6-LUTIDINE(0.04835 M) IN ANHYDROUS METHANOL AT 90.00°. RUN II-220.

Aliquot:5.00 ml. Titrant:$NaOCH_3$, 0.03186 M. Indicator:Phenolphthalein.

Theoretical infinity titer:3.6 ml.

Time (sec.)	Titer (ml.)	$\log(V_\infty - V_t)$	$10^6 k_t$ ($sec.^{-1}$)
0	0.07	0.5224	
8160	0.22	0.5024	5.62
13560	0.29	0.4928	5.06
24360	0.47	0.4669	5.27
47100	0.79	0.4166	5.18
67140	1.04	0.3729	5.13
82860	1.28	0.3263	5.45
100380	1.43	0.2945	5.23
123480	1.66	0.2405	5.26
184500	2.16	0.0934	5.35
244140	2.51	$\bar{1}$.9494	5.41
512160	3.2	$\bar{1}$.3010	5.49
1280340	3.4	Average	5.31 ±0.14

V_∞ =3.4 ml., 94% of the theoretical infinity.

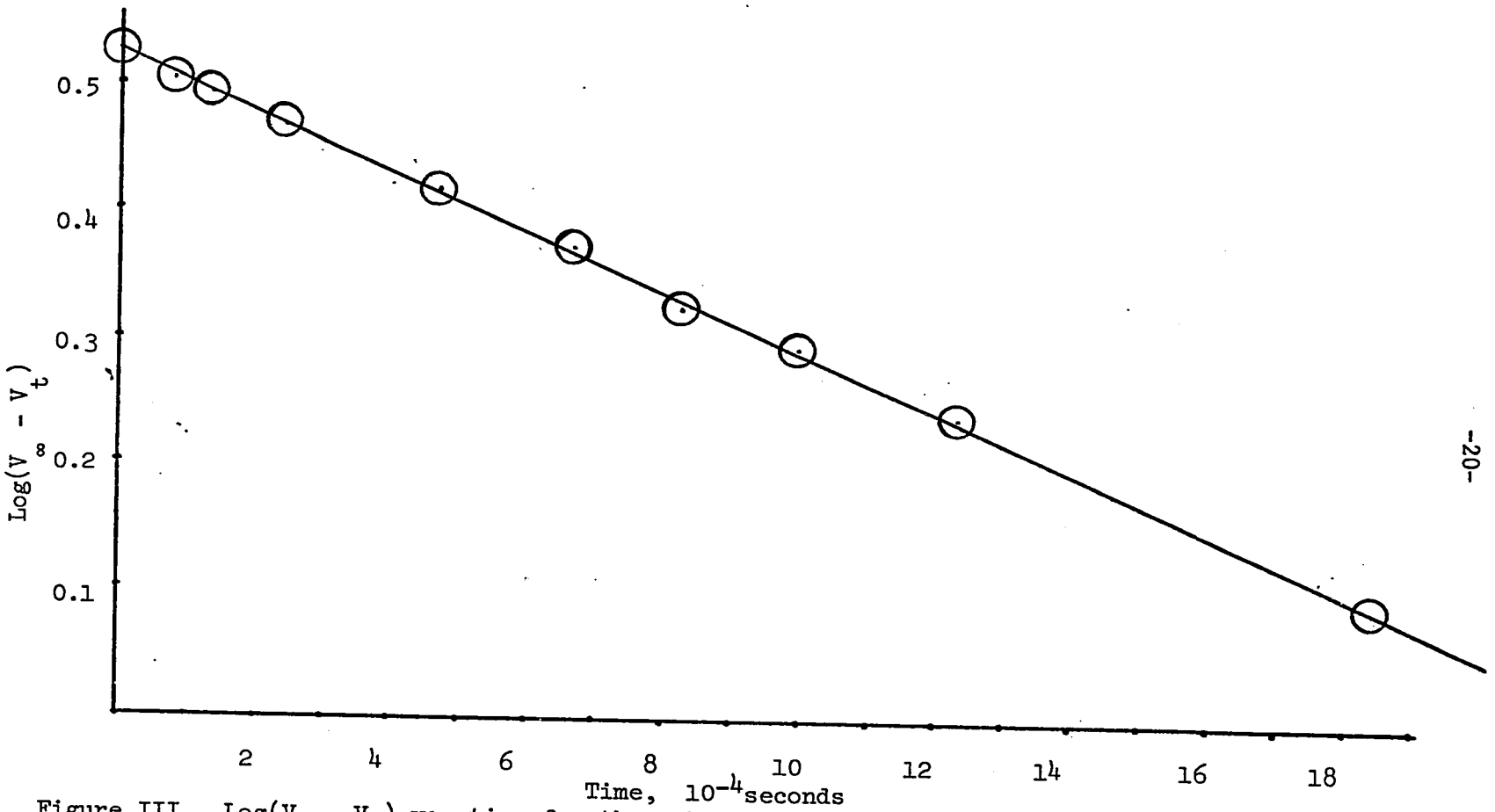


Figure III. $Log(V_\infty - V_t)$ vs. time for the solvolysis of m-nitrobenzylethylmethylsulfonium perchlorate(0.02286 M) with added 2,6-lutidine(0.04835 M) in anhydrous methanol at 90.00°. Run II-220.

$\log(\alpha_\infty - \alpha_t)$ was plotted vs. time. Typical examples of Methods I and II for measuring polarimetric rate constants of 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate are shown in Table IV(Run III-75) and Table V(Run III-5), respectively. The corresponding plots of $\log(\alpha_\infty - \alpha_t)$ vs. time are illustrated in Figures IV and V. Tables VI and VII show typical examples of rate runs for solvolysis and racemization of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate. The corresponding plots of $\log(V_\infty - V_t)$ and $\log(\alpha_\infty - \alpha_t)$ vs. time are shown in Figures VI and VII, respectively.

Tables VIII, IX, X and XI summarize the titrimetric rate constants, k_t, polarimetric rate constants, k_α, and racemization rate constants, $k_{rac.}$, found for m-nitrobenzylethylmethylsulfonium perchlorate(IX), 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate (X) and 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(XI).

The addition of ethyl methyl sulfide increases the rate of racemization of X and XI as shown in Tables IX and X. Plots of concentration of ethyl methyl sulfide vs. the rate constant of loss of optical activity, $k_{\alpha obs.}$, are shown in Figures VIII and IX.

Product analyses of methanolyses of IX, X and XI at 90° were performed using the procedure as described in detail in the experimental section. The results are shown in Table XII. In each case, the corresponding methyl ether and acid were recovered in 94-102% of the theoretical yields.

TABLE IV

RACEMIZATION OF (-)-3-METHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE(0.03285 M) IN ANHYDROUS METHANOL AT 25°. RUN III-75.

Time (sec.)	$\alpha^{25}_{365m\mu}$	$\log(\alpha_\infty - \alpha_t)$	$10^5 k\alpha$ (sec.$^{-1}$)
0	-0.523	$\bar{1}.7185$	
3600	-0.474	$\bar{1}.6758$	2.73
5100	-0.457	$\bar{1}.6599$	2.65
7560	-0.428	$\bar{1}.6314$	2.65
11100	-0.388	$\bar{1}.5888$	2.69
14700	-0.352	$\bar{1}.5465$	2.69
18300	-0.323	$\bar{1}.5092$	2.63
54900	-0.116	$\bar{1}.0645$	2.74
57900	-0.108	$\bar{1}.0334$	2.73
62700	-0.094	$\bar{2}.9731$	2.74
67200	-0.085	$\bar{2}.9294$	2.70
84300	-0.054	$\bar{2}.7324$	2.69
326100	0	Average	2.69±0.03

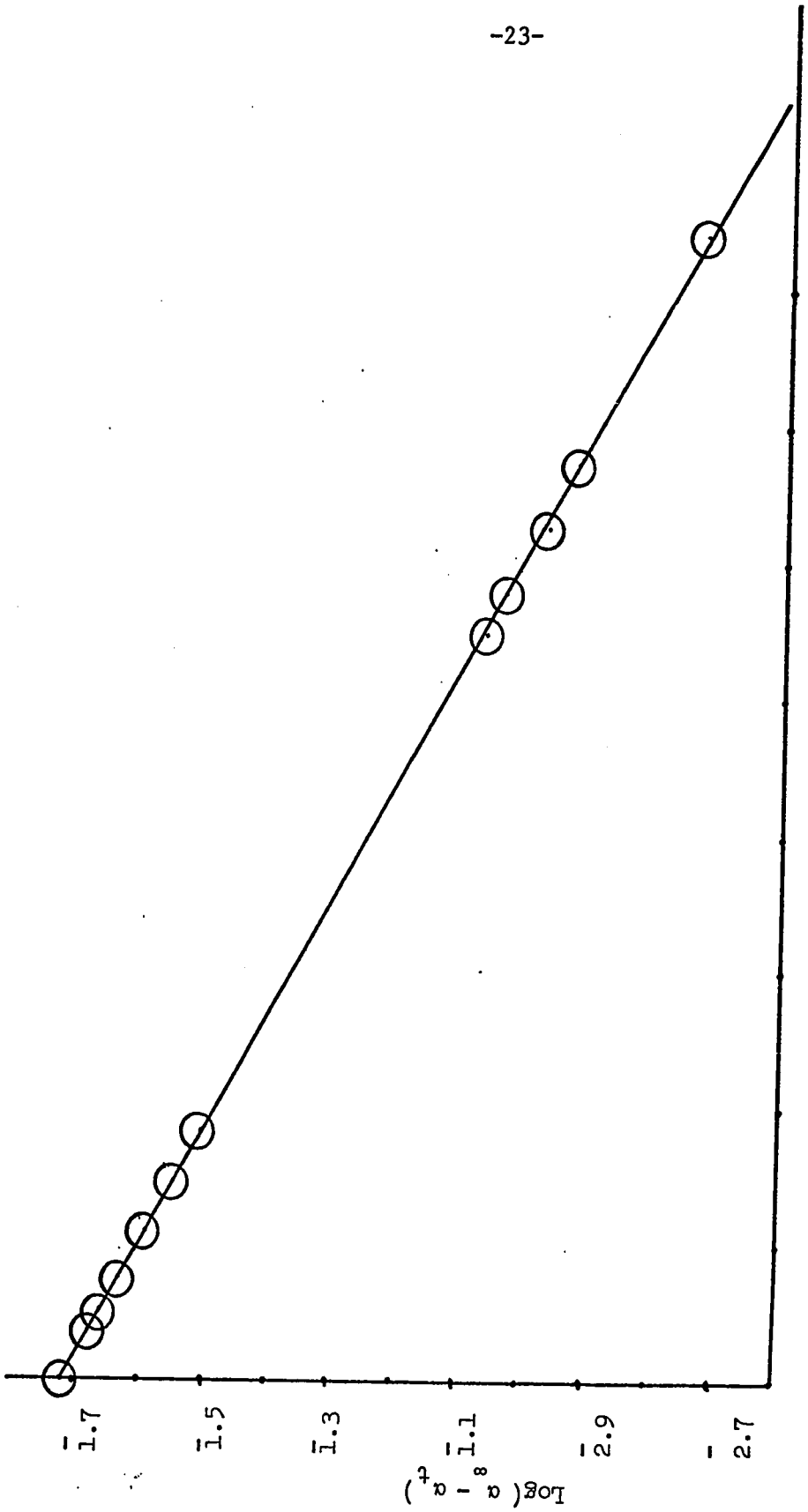


Figure IV. Log($\alpha_\infty - \alpha_t$) vs. time for the racemization of (-)-3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(0.03285 M) in anhydrous methanol at 25.00°. Run III-75.

TABLE V

RACEMIZATION OF (+)-3-METHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE(0.03523 M) WITH ADDED 2,6-LUTIDINE(0.07468 M) IN ANHYDROUS METHANOL AT 50.00°. RUN III-5.

Time (sec.)	$\alpha^{25}_{365m\mu}$	log($\alpha_\infty - \alpha_t$)	$10^4 k_\alpha$ (sec.$^{-1}$)
0	0.468	$\bar{1}$.6702	
120	0.414	$\bar{1}$.6170	10.21
300	0.342	$\bar{1}$.534	10.46
480	0.278	$\bar{1}$.4440	10.85
600	0.250	$\bar{1}$.3979	10.45
720	0.210	$\bar{1}$.3222	11.13
1080	0.147	$\bar{1}$.1673	10.72
1260	0.116	$\bar{1}$.0645	11.07
1440	0.095	$\bar{2}$.9777	11.08
2700	0.026	$\bar{2}$.4150	10.71
6600	0	Average	10.96±0.32

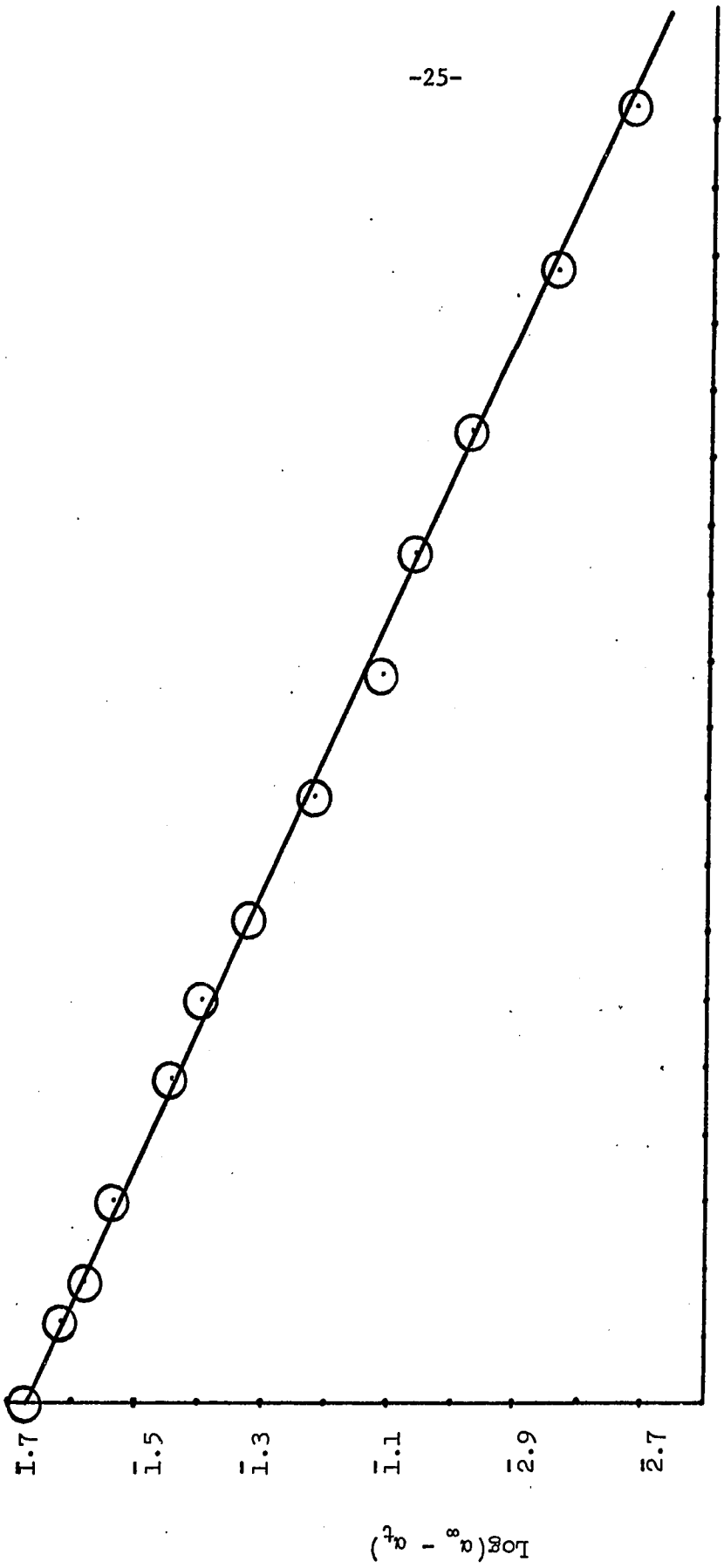


Figure V. Log($\alpha_\infty - \alpha_t$) vs. time for the racemization of (+)-3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(0.03523 M) with added 2,6-lutidine(0.07468 M) in anhydrous methanol at 50.00°. Run III-5.

TABLE VI

SOLVOLYSIS OF (+)-3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE(0.03104 M) WITH ADDED 2,6-LUTIDINE(0.08898 M) IN ANHYDROUS METHANOL AT 50.00°. RUN II-262.

Aliquot:5.00 ml. Titrant:$NaOCH_3$, 0.03186 M. Indicator:Phenolphthalein

Theoretical infinity titer:4.88 ml.

Time (sec.)	Titer (ml.)	$\log(V_\infty - V_t)$	$10^6 k_t$ ($sec.^{-1}$)
0	0.48	0.6405	
7200	0.85	0.6021	1.23
10800	1.06	0.5786	1.31
14460	1.2	0.5623	1.24
18060	1.36	0.5429	1.24
31920	1.91	0.4683	1.24
39240	2.23	0.4183	1.30
49020	2.525	0.3664	1.29
81720	3.35	0.1761	1.31
95880	3.51	0.1271	1.23
82740*	4.85	Average	1.27±0.03

V_∞ = 4.85 ml., 99% of the theoretical infinity.

* at 90°.

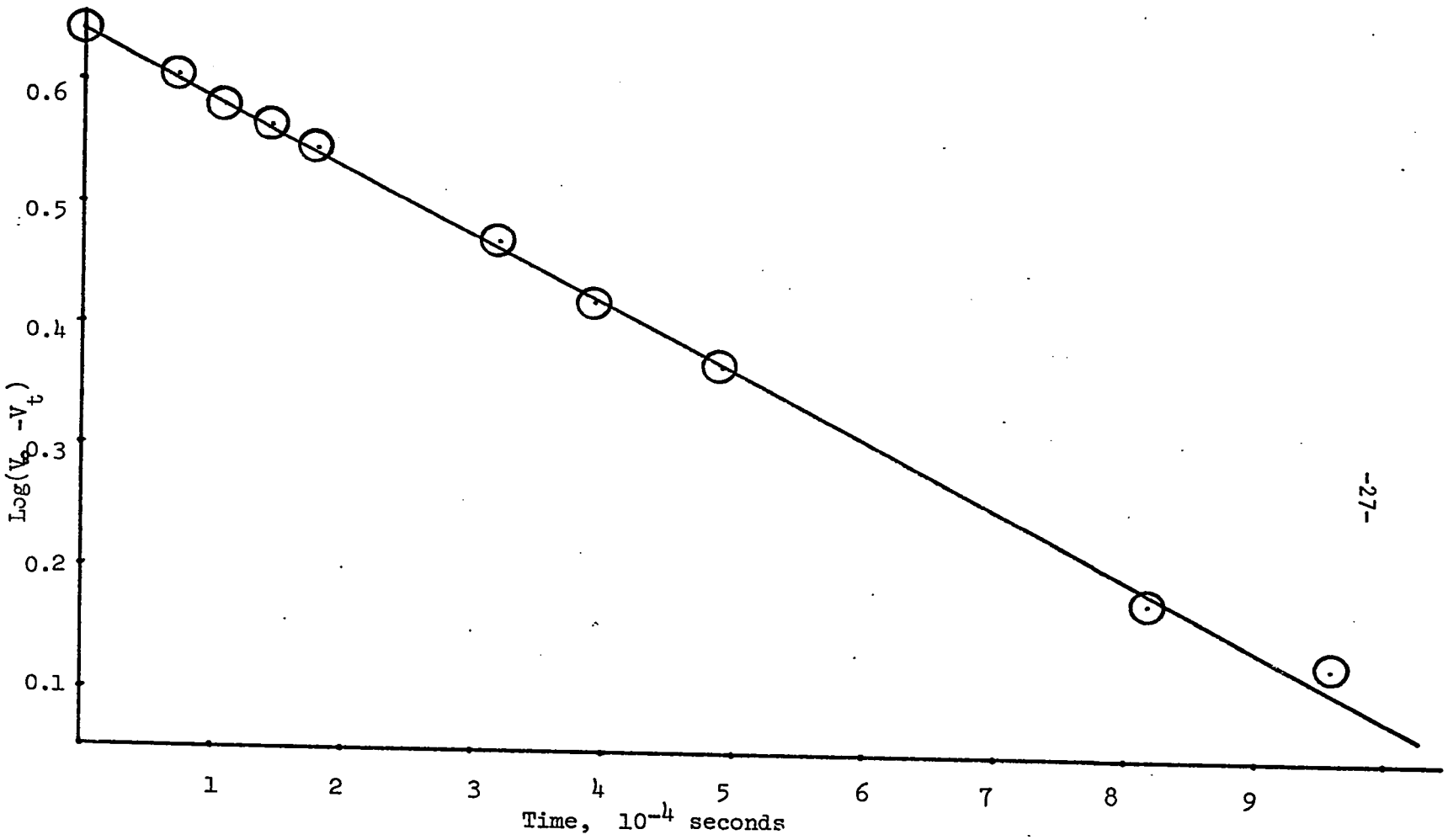


Figure VI. Log($V_\infty - V_t$) vs. time for the solvolysis of(+)-3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(0.03104 M) with added 2,6-lutidine(0.08898 M) in anhydrous methanol at 50.00°. Run II-262.

TABLE VII

RACEMIZATION OF (+)-3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE(0.03104 M) WITH ADDED 2,6-LUTIDINE(0.08898 M) IN ANHYDROUS METHANOL AT 50.00°. RUN II-264.

Time (sec.)	α^{25}_{365m}	$\log(\alpha_\infty - \alpha_t)$	$10^5 k_\alpha$ (sec.$^{-1}$)
0	0.556	$\bar{1}$.7404	
4260	0.499	$\bar{1}$.6928	2.57
7560	0.464	$\bar{1}$.6609	2.42
11160	0.421	$\bar{1}$.6180	2.53
14760	0.382	$\bar{1}$.5821	2.47
18360	0.361	$\bar{1}$.5514	2.37
22020	0.330	$\bar{1}$.5105	2.40
25620	0.301	$\bar{1}$.4698	2.43
29280	0.266	$\bar{1}$.4150	2.56
39480	0.208	$\bar{1}$.3054	2.54
46800	0.174	$\bar{1}$.2253	2.53
56580	0.140	$\bar{1}$.1271	2.5
103500	0.045	$\bar{2}$.5911	2.56
277200	0.006	Average	2.49±0.06

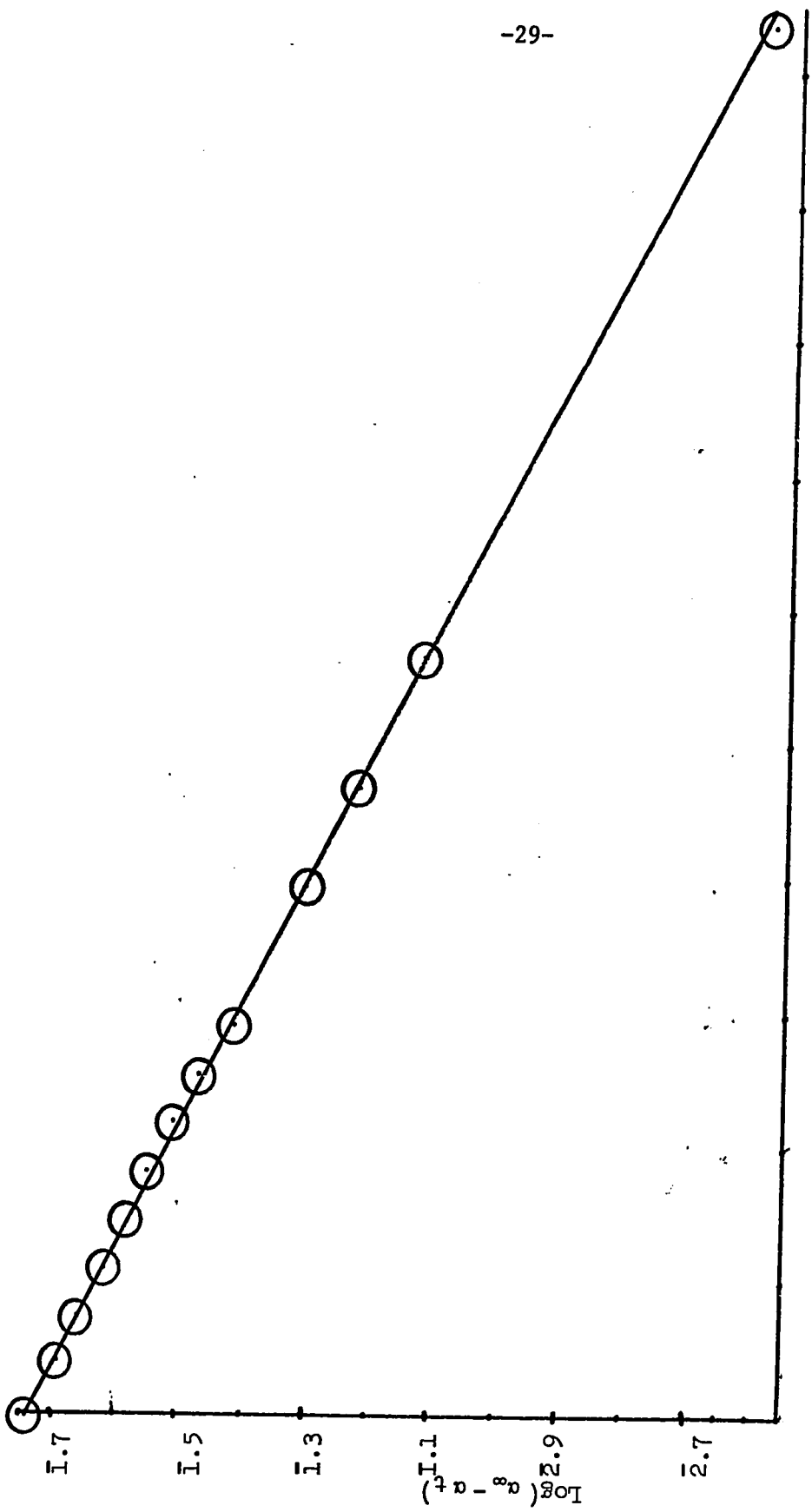


Figure VII. Log($\alpha_\infty - \alpha_t$) vs. time for the racemization of(+)-3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(0.03104 M) with added 2,6-lutidine (0.08898 M) in anhydrous methanol at 50.00°. Run II-264.

TABLE VIII

SOLVOLYSIS OF m-NITROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN ANHYDROUS METHANOL.

Run	Temp. (°C)	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_{rac.}$ [c] ($sec.^{-1}$)
II-220	90	dl	0.02286	0.04835	5.31±0.14		
II-221	70	dl	0.02286	0.04835	0.666±0.02		
III-205	70	+	0.01963	0.05167		93.2±1.6	92.5
II-223	50	dl	0.02286	0.04835	0.0725		
II-222	50	+	0.03020	0.05608		6.56±0.16	6.5

a). Titrimetric rate constant. b). polarimetric rate constant, both runs were done by method I using λ= 436 mμ . c). $k_{rac.} = k_\alpha - k_t$.

d). extrapolated value.

TABLE IX

SOLVOLYSIS OF 3-METHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN ANHYDROUS METHANOL.

Run	Temp. (°C)	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	[EtSMe] (M)	$10^6 k_t$[a] ($sec.^{-1}$)	$10^6 k_\alpha$[b] ($sec.^{-1}$)	$10^6 k_{rac}$[c] ($sec.^{-1}$)
III-3	50	+	0.03523	0.07468	0	768±16		
III-5	50	+	0.03523	0.07468	0		1096±32	328
III-6	50	dl	0.02830	0.06	0	774±21		
III-43	50	dl	0.02839	0.05687	0	781±47		
III-20	50	+	0.03009	0	0		1250±50	
III-21	50	+	0.03009	0	0	772±13		478
III-48	25	dl	0.03188	0.05401	0	16.3±0.6		
III-75	25	-	0.03285	0	0		26.9±0.3	
III-103	25	-	0.03209	0	0	16.5±1		10.4
III-16	50	dl	0.0236	0.07618	0.05325	731±26		
III-17	50	+	0.02995	0	0.066		1191±55	
III-22	50	+	0.02995	0	0.066	711±29		480
III-24	50	+	0.03006	0	0.1329		1278±39	
III-25	50	+	0.03006	0	0.1329	738±9		540
III-40	50	dl	0.02877	0.09771	0.1336	673±15		
III-41	50	-	0.02902	0.09587	0.1307		1151±112	
III-42	50	-	0.02902	0.09587	0.1307	723±37		428
III-49	25	dl	0.03206	0.06918	0.1165	14.6±0.3		

Run	Temp. (°C)	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	[EtSMe] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_{rac.}$ [c] ($sec.^{-1}$)
III-46	25	dl	0.03187	0.07776	0.05812	15.6±0.5		
III-94[f]	25	-	0.02842	0	0.1224		30.4±0.9	
III-98[e]	25	-	0.02842	0	0.1224	15.5±0.7		15
III-95[d]	25	-	0.02842	0	0.1224		31.5±1.0	
III-96[f]	25	-	0.02852	0	0.06661	27.2±1.8		
III-97[d]	25	-	0.02852	0	0.06661		31.6±0.5	
III-99	25	-	0.02852	0	0.06661	17.2±1.9		14.4
III-100-A[e]	25	dl	0.02902	0	0.1383	14.1±0.6		
III-100-B	25	dl	0.02902	0	0.1383	17±0.2		
III-101-A[e]	25	dl	0.02845	0	0.06261	14.9±0.7		
III-101-B	25	dl	0.02845	0	0.06261	16.6±0.5		

a). Titrimetric rate constant. b). polarimetric rate constant using Method I with λ= 365 mμ unless otherwise specified. c). $k_{rac.} = k_\alpha - k_t$. d). polarimetric rate constant using Method II. e). theoretical infinity used for calculating titrimetric rate constant. f). From these runs, $k_{\alpha obs.}$ was plotted against [EtSMe], from the slope of the straight line drawn, $k_{exchange}=2.03 \times 10^{-5}$ 1. $mole^{-1} sec.^{-1}$ was obtained.

TABLE X

SOLVOLYSIS OF 3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN ANHYDROUS METHANOL,

Run	Temp. (°C)	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	[EtSMe] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_{rac.}$ [c] ($sec.^{-1}$)
III-27	50	dl	0.03016	0	0	14.6±0.3		
III-69	50	-	0.03074	0	0		22.1±1.0	7.5
II-262	50	+	0.03104	0.08898	0	12.7±0.3		
II-264[d,e]	50	+	0.03104	0.08898	0		24.9±0.6	12.2
II-278	50	dl	0.02948	0.07047	0	12.9±0.09		
III-10[d]	50	+	0.03047	0	0.05292		28.9±0.3	
III-13	50	+	0.03047	0	0.05292	15.3±0.6		13.6
III-11	50	+	0.03058	0	0.1023		32.1±0.8	
III-14	50	+	0.03058	0	0.1023	15.0±0.4		17.1
III-19[e]	50	-	0.03061	0.08876	0.1016		31.4±1.1	
III-72	50	-	0.03061	0.08876	0.1016	12.5±0.3		18.9
III-18[e]	50	-	0.03249	0.08968	0.05429		27.1±0.3	
III-73	50	-	0.03249	0.08968	0.05429	11.9±0.5		15.2
III-206	70	+	0.03194	0.04921	0		369±11	
III-207	70	+	0.03194	0.04921	0	244±8		125
III-208	70	dl	0.03237	0.06039	0	240±3		

a). Titrimetric rate constant. b). polarimetric rate constant using Method I with λ=365mμ. c). $k_{rac.}=k_\alpha - k_t$. d). From these runs, $k_{\alpha obs.}$ was plotted against[EtSMe], from the slope of the straight line $k_{exchange}=7.25\times10^{-5}$ l. $mole^{-1}$ $sec.^{-1}$ was obtained. e). From these runs, $k_{\alpha obs.}$ was plotted against [EtSMe], from the slope of the straight line, $k_{exchange}=6.47\times10^{-5}$ l. $mole^{-1}$ $sec.^{-1}$ was obtained.

TABLE XI

RACEMIZATION OF 3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN A VARIETY OF SOLVENTS.

Run	Temp. (°C)	Solvent	[Salt] (M)	Isomer	[2,6-Lutidine] (M)	$10^6 k_\alpha$ [a] (sec.$^{-1}$)
III-7	50	CH_2Cl_2	0.03611	+	0.08435	48.9±1.3
III-68	50	CH_2Cl_2	0.03579	-	0.08001	48.1±3.7
III-71	50	CH_2Cl_2	0.03603	-	0.04022	43.4±2.0
III-288-A[b]	70	CH_3CN	0.03290	+	0.1076	447±10
III-288-B[c]	70	CH_3CN	0.03290	+	0.1076	452±11
III-206	70	MeOH	0.03194	+	0.04921	369±11
III-289-A[b]	50	CH_3CN	0.03290	+	0.1076	28.4±0.7
III-289-B[c]	50	CH_3CN	0.03290	+	0.1076	28.7±0.8
II-264	50	MeOH	0.03104	+	0.08898	24.9±0.6

a). Polarimetric rate constant using Method I unless otherwise specified.

b). Method II was used for these runs, λ = 436mμ . c). Method II was used for these runs, λ =365mμ .

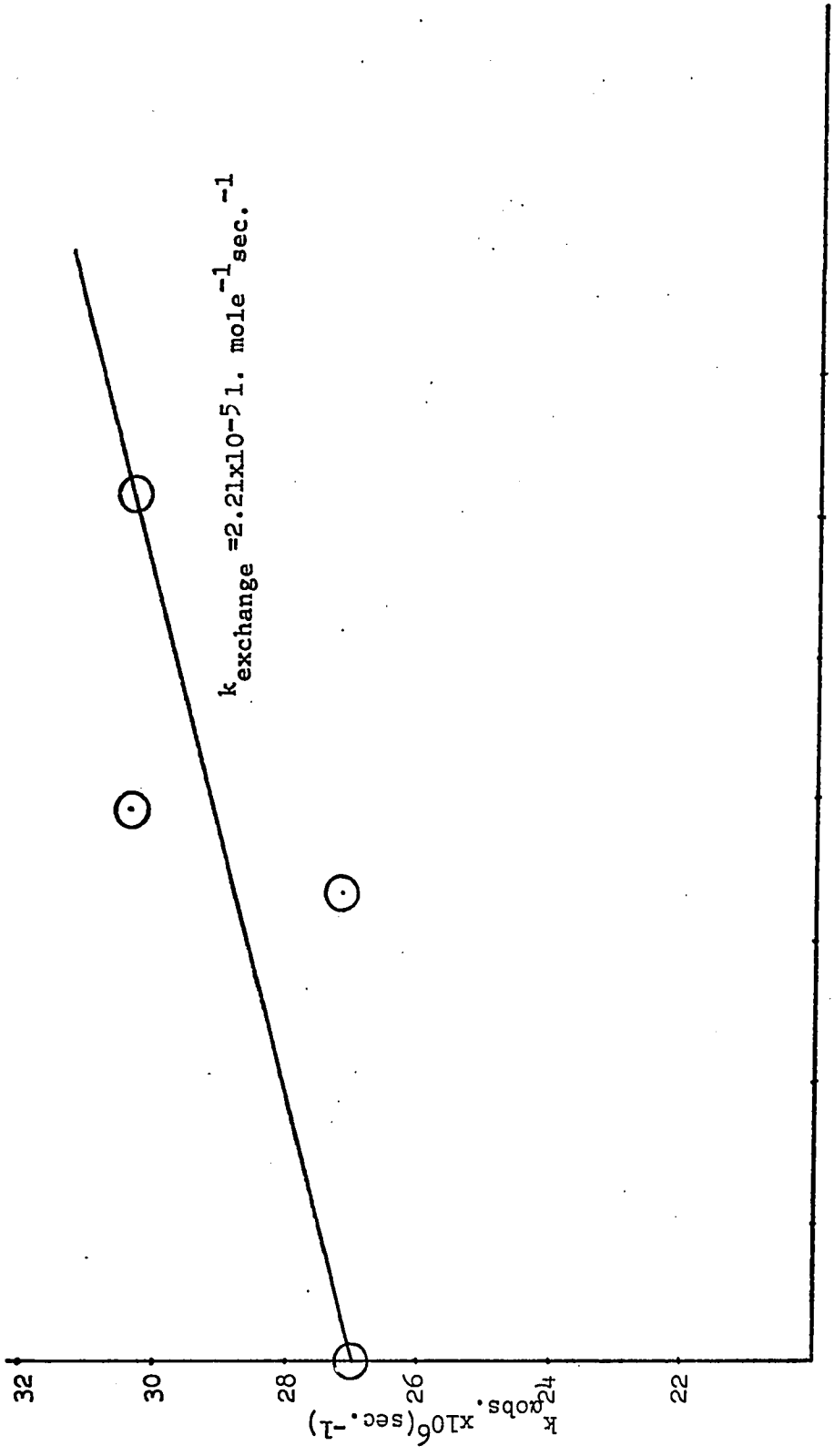


Figure VIII. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the racemization of 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(0.03 M) in anhydrous methanol at 25.00°.

Runs III-75, III-94, IV-72 and III-96.

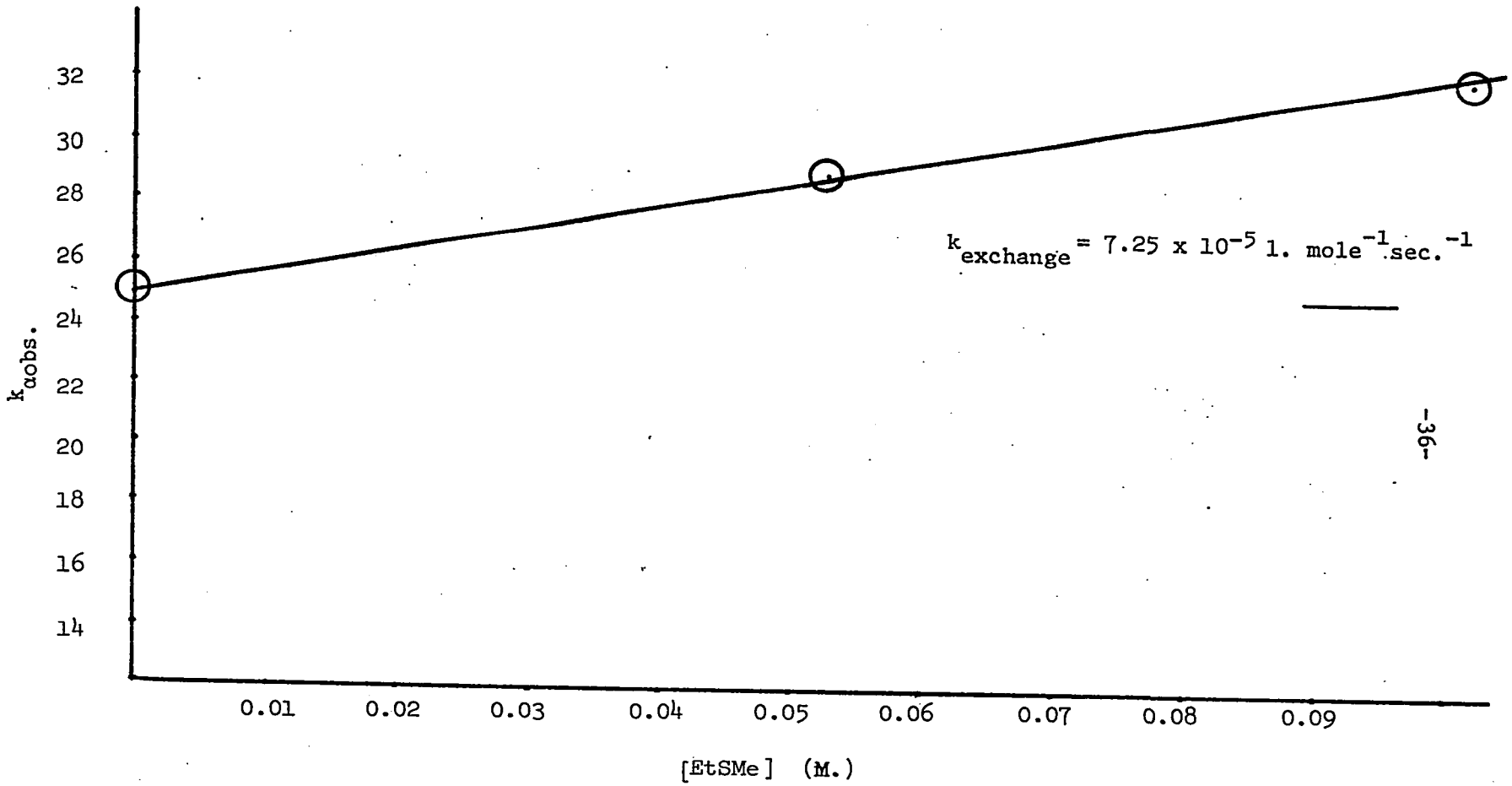


Figure IX. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the racemization of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(0.03 M.) in anhydrous methanol at 50.00°. Runs II-264, III-10 and III-11.

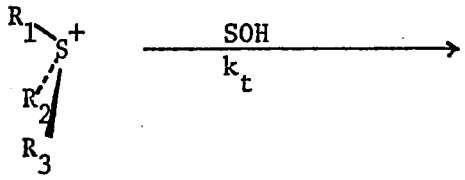
TABLE XII

PRODUCT ANALYSES OF THE METHANOLYSES OF m-NITRO-, 3-METHYL-4-METHOXY- AND 3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE AT 90.00°.

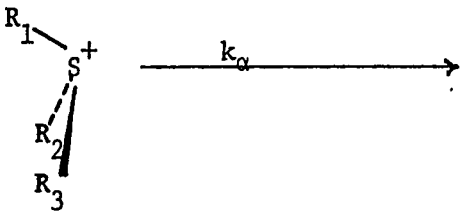
Run	[Salts] (M)	[2,6-Lutidine] (M)	Components	Rel. areas	Calcd. wt. in 4.93 ml. (g.)	Conc. (M)	mole %
III-151	m-nitro- 0.02354	0.07380	m-$NO_2ØCH_2OCH_3$ naphthalene H^+	0.72 1	0.1985	0.02409	102
						0.02210	94
III-162	3-CH_3-4-OCH_3- 0.2842	0	3-CH_3-4-$OCH_3ØCH_2OCH_3$ phenyl ether H^+	0.774 1	0.2262	0.02760	97
						0.02695	96
III-154	3,5-diCH_3-4-OCH_3 0.03081	0.09098	3,5-diCH_3-4-OCH_3-$ØCH_2OCH_3$ naphthalene H^+	0.9 1	0.2790	0.0314	102
						0.03121	101

DISCUSSION:

In the studies of the solvolysis and racemization of sulfonium salts, rate constants corresponding to the reactions shown in Equations 6, 7, 8 and 3 are encountered very often and are summarized at this point for convenience in the future discussion.

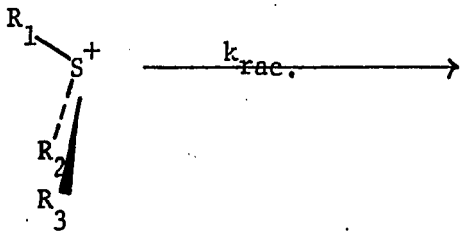


Eq. 6



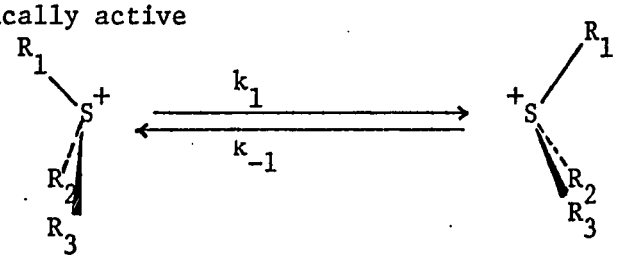
Eq. 7

optically active



Eq. 8

optically active



Eq. 3

where k_t=titrimetric rate constant.

k_α=polarimetric rate constant or rate constant for loss of

optical activity. This rate constant includes both decomposition and racemization of the active sulfonium salt.

$k_{rac.} = k_{\alpha} - k_t = 2k_1$ = racemization rate constant.

$k_1 = (k_{\alpha} - k_t)/2$ = rate constant for pyramidal inversion about the sulfur atom.

Comparison of racemization and solvolysis rates:

Two mechanisms which could explain the racemization of sulfonium salts are:

i). Heterolytic carbon-sulfur bond cleavage to form an ion-neutral molecule pair which can either return to sulfonium salt or react with the solvent to yield substitution and/or elimination products. (Eq. 5, Introduction).

ii) Pyramidal inversion about the sulfur atom. (Eq. 3).

The racemization of t-butylethylmethylsulfonium salts and a number of substituted systems in which a hydrogen of the t-butyl group was replaced by a substituent have been interpreted as proceeding via the second mechanism. This mechanism was also used to account for the racemization of benzylethylmethylsulfonium perchlorate(V) and p-nitrobenzylethylmethylsulfonium perchlorate(VI). The racemization rate constants, $k_{rac.}$, for V and VI were 6.3×10^{-6} sec.$^{-1}$ and 6.61×10^{-6} sec.$^{-1}$ respectively, in solvent methanol at 50.00°. The electronic effects of substituents which are directly attached to the central sulfur atom appear to be very small.

Markedly different behavior was found(32) for p-methoxybenzylethylmethylsulfonium perchlorate(VIII). For VIII, the rate constants for methanolysis, k_t, were 3.94×10^{-6} sec.$^{-1}$ and 203×10^{-6}

sec.$^{-1}$ at 25^{o} and 50^{o}, respectively. At the same temperatures in solvent methanol, the racemization rate constants, $k_{rac.}$, were 2.65 x 10^{-6} sec.$^{-1}$ and 105 x 10^{-6} sec.$^{-1}$, respectively. The ratio of k_{α}/k_{t} was 1.5 at 50^{o}. In methanol at 50^{o}, VIII underwent solvolysis three powers of ten faster and racemized 15 times faster than benzylethylmethylsulfonium perchlorate(V).

To distinguish between racemization by pyramidal inversion and by the heterolytic carbon-sulfur cleavage to form an ion-neutral molecule pair, p-methoxy-m-nitrobenzylethylmethylsulfonium perchlorate (VII) was prepared(32). If the racemization of p-methoxybenzylethylmethylsulfonium perchlorate(VIII) involved pyramidal inversion then there should be no significant difference in the values of $k_{rac.}$ for compounds VII and VIII since the electron withdrawing p-nitro group was shown to have no significant effect upon pyramidal inversion rates. The solvolysis of VIII should be ca. 10^{3} times faster than the solvolysis of VII. In contrast, if the C-S bond heterolytic cleavage mechanism best described the principal pathway for both solvolysis and racemization of VIII then both reactions by this pathway should be very much slower for VII than for VIII. The latter type of behavior was observed experimentally. The rate constant for racemization $k_{rac.}$, for VII at 50^{o} in solvent methanol was 6.87x 10^{-6} sec.$^{-1}$ which was very close to the $k_{rac.}$ values of 6.3x 10^{-6} sec.$^{-1}$ and 6.61x 10^{-6} sec.$^{-1}$ for V and VI, respectively, under the same conditions. At 90^{o}, the rate constant for methanolysis of VII was found to be 1.6 x 10^{-5} sec.$^{-1}$, comparable to the value of 2.45 x 10^{-5} sec.$^{-1}$ for methanolysis of V at 90^{o} obtained by extrapolation from data at lower temperatures.

While these data were taken as strong support for an ion-neutral molecule pair reaction, there remained the possibility that a m- and p-nitro substituent would not have the same type of electronic effects. For this reason, m-nitrobenzylethylmethylsulfonium perchlorate (IX) was synthesized and its racemization rate was studied. The rate constant for racemization, $k_{rac.}$, for IX is 6.5×10^{-6} sec.$^{-1}$ while $k_{rac.}$ for VI was found to be 6.61×10^{-6} sec.$^{-1}$ at 50° in methanol(32). This result shows that the m-nitro group exerts the same electronic effect as a p-nitro group. Hence, the conclusion that the acceleration of racemization rate of p-methoxybenzylethylmethylsulfonium perchlorate was caused by a mechanism other than inversion is further confirmed. The predominant pathway for racemization of p-methoxybenzylethylmethylsulfonium perchlorate involves the carbon-sulfur bond heterolysis mechanism.

The relative racemization rate constants, $k_{rac.}$, of m-nitrobenzylethylmethylsulfonium perchlorate(IX) and 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X) in solvent methanol, at 50°, compared to that of benzylethylmethylsulfonium perchlorate(V) are 0.96: 48:1(Table XIII). The rate of racemization of IX is comparable to that of V which suggests that IX also racemizes predominantly by the pyramidal inversion mechanism. Compound X racemizes very much faster. In anhydrous methanol at 50°, the racemization of X is $(328 \pm 48) \times 10^{-6}$ sec.$^{-1}$ as compared to a value of 105×10^{-6} sec.$^{-1}$ for p-methoxybenzylethylmethylsulfonium perchlorate(VIII). The ratio of polarimetric rate constant to titrimetric rate constant, k_α/k_t for X is 1.4 comparable to that for VIII which is 1.5. Therefore X and VIII undergo racemization by similar mechanisms and

TABLE XIII

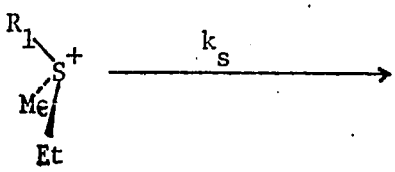
A COMPARISON OF RACEMIZATION RATES OF m-NITRO-, 3-METHYL-4-METHOXY- AND 3,5-DIMETHYL-4-METHOXY-BENZYLETHYLMETHYLSULFONIUM PERCHLORATES WITH BENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN ANHYDROUS METHANOL AT 50.00°.

R-C$_6$H$_4$-CH$_2$S$^+$(CH$_3$)CH$_2$CH$_3$ ClO$_4^-$	Run	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_1$ [c] ($sec.^{-1}$)	($k_{rac.}/k_{rac.}^V$) [d]
R=m-NO_2 (IX)	II-223	d1	0.02286	0.04835	0.0725			
	II-222	+	0.03020	0.05608		6.56±0.16	3.25±0.08	0.96
R=3-CH_3-4-OCH_3 (X)	III-3	+	0.03523	0.07468	768±16			
	III-5	+	0.03523	0.07468		1096±32	164±24	48
R=3,5-diCH_3-4-OCH_3 (XI)	III-262	+	0.03104	0.08898	12.7±0.3			
	III-264	+	0.03104	0.08898		24.9±0.6	6.1±0.5	1.79
R=H(V)					0.2	6.99	3.4	1

a). Titrimetric rate constant. b). polarimetric rate constant. c). $k_1=1/2(k_\alpha-k_t)$. d). racemization rate xonstant relative to that of benzylethylmethylsulfonium perchlorate. e). See Bibliography (32).

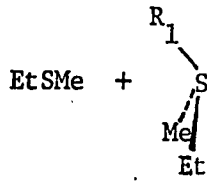
rule out pyramidal inversion as the principal pathway for racemization.

One other process which might account for the racemization of 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X) would involve nucleophilic displacement on the primary benzylic carbon by the ethyl methyl sulfide produced in the solvolytic reaction of compound X as shown in Equations 6 and 9:



$\xrightarrow{k_s}$ ROS + EtSMe + H^+ Eq. 6

optically active



$\xrightarrow{k_{exchange}}$ R-$\overset{+}{S}$(Et)-Me racemic Eq. 9

optically active

Run III-82 shows that under the conditions of solvolysis and racemization, i.e., in anhydrous methanol at 50.00°, 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate reacts with the added dimethyl sulfide to yield 3-methyl-4-methoxybenzyldimethylsulfonium perchlorate. This result indicates that the reaction sequence shown in Equations 6 and 9 could bring about racemization of the active sulfonium salt. In Run III-82, there was a large excess of added sulfide. The importance of such a sequence where the ethyl methyl sulfide is present in low concentration and is formed only on solvolysis of the sulfonium salt can be gauged by a kinetic analysis.

The average concentration of ethyl methyl sulfide at 50% loss of optical activity, $[EtSMe]_{avg.}$ was calculated using Equation

10 while the per cent racemization caused by exchange of ethyl methyl sulfide with starting material was calculated using Equation 11. Equations 10 and 11 are analogous to the equations used by Goering and Levy(36) in their studies of the mechanism of solvolysis of benzhydryl p-nitrobenzoate.

$$[EtSMe]_{avg.} = [Salt]_o[1 + 1/k_s t(e^{-k_s t} - 1)] + [EtSMe]_o \quad \text{Eq. 10}$$

where:

$[EtSMe]_{avg.}$ = average concentration of ethyl methyl sulfide from 0 to 50% loss of optical activity.

$[EtSMe]_o$ = concentration of ethyl methyl sulfide at the start of the reaction. This is equal to 0, since no ethyl methyl sulfide was present initially.

$[Salt]_o$ = molar concentration of the sulfonium salt at t=0.

k_s = solvolysis rate constant.

t = time at 50% loss of optical activity.

$$\% \text{ racemization by exchange} = 100[1-e^{-k_{exchange}(EtSMe)_{avg.}t}] \quad \text{Eq. 11}$$

where:

% racemization by exchange=% racemization caused by nucleophilic displacement of ethyl methyl sulfide formed on solvolysis on the primary benzilic carbon of the sulfonium salt.

$k_{exchange}$ = second order rate constant obtained from the slope of the straight line drawn when $k_{\alpha obs.}$ was plotted against the concentration of ethyl methyl sulfide.

t = time at 50% loss of optical activity.

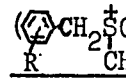
The second-order rate constant $k_{exchange}$ for the nucleophilic displacement on the primary benzylic carbon by ethyl methyl sulfide was obtained from the slope of the straight line shown in Figure VIII. This was calculated to be 2.03×10^{-5} mol.$^{-1}$ sec.$^{-1}$ for 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate.

The results calculated using Equations 10 and 11 are presented in Table XIV. At 50% loss of opitcal activity, the average concentration of ethyl methyl sulfide $[EtSMe]_{avg.}$ for the solvolysis of a 0.03 M solution of 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X) in methanol at 25° was found to be 0.0056 M. After 50% loss of optical activity, 25.5% of the sulfonium salt has undergone solvolysis. Of the unsolvolyzed salt, 31.6% must be racemic. Only about 0.4% of the unsolvolyzed salt could have racemized by the scheme shown in Equation 9. Therefore nucleophilic displacement on the primary benzylic carbon by ethyl methyl sulfide as shown in Equation 9 plays a very minor role on the racemization of 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X). The predominant pathway for the racemization of X involves carbon-sulfur bond heterolysis to yield an ion-neutral molecule pair which could either react to give solvolysis products or return to racemic sulfonium salts as shown in Eq. 5 (Introduction).

The replacement of a hydrogen ortho to the methoxy group in p-methoxybenzylethylmethylsulfonium perchlorate(VIII) by a methyl group accelerates the rates of solvolysis and racemization. At 50.00°, in solvent methanol, X solvolyzes 3.8 times faster and racemizes 3.6 times faster than VIII. These substituent effects are consistent with

TABLE XIV

% RACEMIZATION CAUSED BY EXCHANGE OF ETHYL METHYL SULFIDE IN THE SOLVOLYSIS OF SUBSTITUTED BENZYLETHYLMETHYLSULFONIUM SALTS IN METHANOL.

(
$CH_2\overset{+}{S}(CH_3)CH_2CH_3$ X^-)

R	X^-	Temp. (°C)	[salt] (M)	$[EtSMe]_{avg.}$ (M)	$k_{exchange}$ ($mol.^{-1}sec.^{-1}$)	% racemization by exchange
p-CH_3	ClO_4^-	50	0.027	0.00086	6.03×10^{-5}	0.5
3,5-diCH_3-4-OCH_3	ClO_4^-	50	0.03	0.0043	7.25×10^{-5}	0.9
3-CH_3-4-OCH_3	ClO_4^-	25	0.03	0.0056	2.21×10^{-5}	0.4
p-Cl	Br^-	50	0.032	0.0022	2.7×10^{-5}	0.3

a reaction involving a carbonium ion intermediate and provide further confirmation that both racemization and solvolysis are proceeding via similar reaction processes. It should be noted that pyrmidal inversion can still occur with these systems. Using the assumption that the rate constant for inversion of these salts are the same as the rate constants for inversion of benzylethylmethylsulfonium perchlorate, then less than 2% of the racemization of X occurs by way of pyramidal inversion.

By substituting both hydrogens ortho to the methoxy group of VIII by methyl groups, one might have expected a greater acceleration of both the solvolysis and racemization rates due to electronic effect. However, sterically, these two methyl substituents can hinder the p-methoxy group from becoming planar with the ring and prevent resonance stabilization of the carbonium ion. The study of the kinetics of solvolysis and racemization of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(XI) shows that the steric effect is more important than the electronic effect. Both the racemization and solvolysis rates of this compound are slower than those of p-methoxybenzylethylmethylsulfonium perchlorate(VIII) and 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X). At 50.00°, in solvent methanol, 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(XI) solvolyzes with a rate constant, k_t, equals to (12.7±0.3) x 10^{-6} $sec.^{-1}$ while the rate constant for racemization, $k_{rac.}$, is (12.2±0.9)x10^{-6} $sec.^{-1}$(see Table XIII). The relative rate constants of solvolysis of X : VIII : XI are 1 : 0.26 : 0.017 and their relative rate constants of racemization are 1 : 0.32 : 0.037.

Nucleophilic displacement by ethyl methyl sulfide on the primary benzylic carbon as shown in Equation 9 and Table XIV serves as a minor pathway of racemization for XI. At 50.00°, in solvent methanol, after 50% loss of optical activity, 33% of the sulfonium salt has

undergone solvolysis. Of the unsolvolyzed salt, 25.4% must be racemic. Only about 0.9% of the unsolvolyzed salt could have been racemized by the scheme shown in Equation 9.

These results obtained for the study of the racemization and solvolysis of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate (XI) provide unequivocal confirmation for the mechanism of racemization of p-methoxybenzylethylmethylsulfonium perchlorate(X). The only way in which the addition of the second methyl group could effect a lowering of the racemization and solvolysis rate constants would be by steric inhibition of resonance of the methoxy group with the aromatic ring. Hence, for VIII and X, a carbonium ion species must be formed.

This still leaves open the mechanism of racemization of XI. The racemization rate constant, $k_{rac.}$, of XI in solvent methanol at 50.00° is 1.79 times larger than that of benzylethylmethylsulfonium perchlorate (V). If one assumes that the rate constant for inversion k_1, is the same for V and XI, then one must invoke an additional pathway to account for about 45% of the racemization of XI. Conceivably, ion-neutral molecule pair formation and return accounts for the enhanced rate of racemization. However, one can not rule out a small substituent effect on racemization by inversion. At this stage, a final decision can not be made on the mechanism of racemization of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate(XI).

Solvent Effect

Table XI shows the rate constants for loss of optical activity, k_α, for 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate in a variety of solvents. The relative racemization rate

constants are as follows: anhydrous methanol(ε^{25}=32.63) : acetonitrile (ε^{25}=36.2) : methylene chloride(ε^{20}=9.08) are 1 : 1.1 : 2. The numbers in parentheses are the dielectric constants at the corresponding temperatures. The small increase in the racemization rates in less polar solvents like methylene chloride shows that the effect of dielectric constant of the solvent on the racemization rate is very small.

Temperature Effect

To determine the effect of temperature on the rate of solvolysis and racemization, the Arrhenius equation was employed(37):

$$k = Ae^{-E_a/RT} \qquad \text{Eq. 12}$$

For reactions in solution, the heat of activation(37) is given by Eq. 13:

$$\Delta H^{*}=E_a - RT = (E_a - 0.59) \text{ kcal./mole at } 25^{o}. \qquad \text{Eq. 13}$$

The entropy of activation, ΔS^*, is derived from the equation 14(37):

$$k = k_B(T/h) \cdot e^{\Delta S^*/R} \cdot e^{\Delta H^*/RT} \qquad \text{Eq. 14}$$

where k_B is Boltzman's constant and h is Plank's constant. Thus at 25^{o},

$$\Delta S^* = 4.576(\log k_{25}o - 12.79 + \Delta H^*/1.365) \text{ e. u.}$$

For racemization, the polarimetric rate constants were corrected to account for solvolysis occurring at the same time.

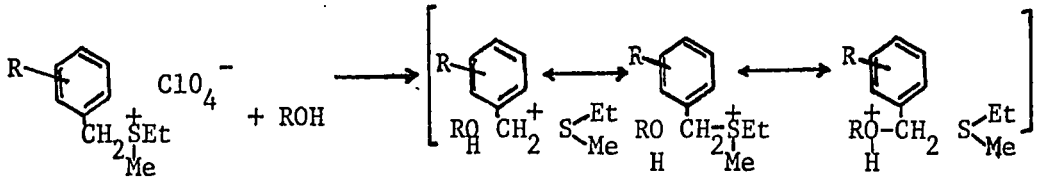
$$k_{rac.} = k_{\alpha} - k_t$$

where $k_{rac.}$ is the specific first-order rate constant for the racemization.

The values calculated for the enthalpy and entropy of activation for the racemization and solvolysis of the different salts in various solvents are presented in Table XV.

Table XV shows the activation parameters calculated for solvolysis of m-nitrobenzylethylmethylsuflonium perchlorate(IX), 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate(X) and 3,5-dimethyl4-methoxybenzylethylmethylsuflonium perchlorate(XI) at 25°. The energies of activation (E_a) and enthalpies(ΔH^*) for solvolysis, loss of optical activity and racemization of all three compounds are similar to each other.

One feature worth noting is that the solvolysis of m-nitrobenzylethylmethylsulfonium perchlorate(IX) in methanol gave a negative entropy value while a positive entropy value was calculated for 3-methyl-4-methoxybenzylethylmethylsuflonium perchlorate(X) and 3,5-dimethyl-4-methoxybenzylethylmethylsuflonium perchlorate(XI). For solvolysis of the sulfonium salts in methanol, there are three resonance structures that must be considered in representing the transition state. This is illustrated in Equation 15.



A' B' C'

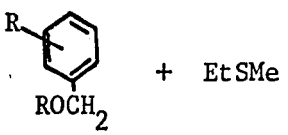
IX, R=m-NO_2

X , R=3-methyl-4-methoxy

XI, R=3,5-dimethyl-4-methoxy

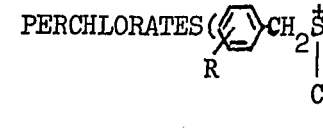
XII, R=p-Cl

XIII, R=p-CH_3



Eq. 15

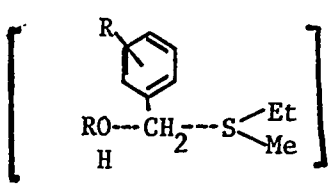
TABLE XV

ACTIVATION PARAMETERS FOR THE SOLVOLYSIS AND RACEMIZATION OF m-NITRO-, 3-METHYL-4-METHOXY- AND 3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATES() AT 25.00°.

R	Reaction	Solvent	E_a	ΔH*	ΔS*
m-NO_2	solvolysis	methanol	25.6±0.7	25.0±0.7	-18±7
	loss of optical activity	methanol	29.1±0.5	28.5±0.5	6±1
	racemization	methanol	29.1±0.5	28.6±0.5	6±1
3-CH_3-4-OCH_3	solvolysis	methanol	29.3±0.7	28.7±0.7	18±2
	loss of optical activity	methanol	29.3±0.4	28.7±0.7	17±1
	racemization	methanol	29.2±1.2	28.6±1.2	15±4
3,5-diCH_3-4-OCH_3	solvolysis	methanol	32.3±0.4	31.7±0.4	17±1
	loss of optical activity	methanol	29.6±0.5	29 ±0.5	10±1
	racemization	methanol	25.9±2.0	25.3±2.0	-3±6
	loss of optical activity	acetonitrile	30.8±0.6	30.2±0.6	14±2

For compounds X and XI, the resonance structure A' is important since the benzylic carbonium ion is stabilized by electron donating substituents on the aromatic ring, the methyl groups and the methoxy group. On solvolysis, compounds X and XI will attain a transition state resembling A'. This is a limiting case in Winstein's terminology(38) and represents a system where a discrete carbonium ion is formed as an intermediate in the reaction. A greater degree of freedom is attained in the transition state than in the ground state. This accounts for the positive entropies of activation for X and XI.

For compound IX, the electron withdrawing nitro group will render structure A' less important. The transition state for solvolysis of this compound in methanol would best be described by structure D', which is the combined form of resonance structures A', B' and C'. This reaction would be classed as a 'nucleophilic' process in Winstein's terminology and there would be considerable nucleophilic character to the solvent assistance at the transition state. A decrease in the degrees of freedom at the transition state compared to the ground state could give rise to the observed negative entropy value.



D'

\+ IX, R=m-NO_2

XII, R=p-Cl

XIII, R=p-CH_3

CHAPTER II

THE PYRAMIDAL INVERSION MECHANISM

A more detailed description of racemization of sulfonium salts by the pyramidal inversion mechanism about the sulfur atom is presented in this chapter. The following sulfonium salts were synthesized and resolved into their optical isomers: p-chlorobenzylethylmethylsulfonium perchlorate(XII), p-methylbenzylethylmethylsulfonium perchlorate(XIII) and p-chlorobenzylethylmethylsulfonium bromide(XIV).

The kinetics of racemization and solvolysis of XII and XIII as well as the results of product analyses are given and compared with the kinetics of racemization and solvolysis of XIV.

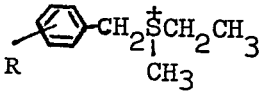
SYNTHESIS AND RESOLUTION

p-Chlorobenzylethylmethylsulfonium perchlorate(XIV) and p-methylbenzylethylmethylsulfonium perchlorate(XV).

The route followed for the syntheses of compounds XII and XIII is illustrated in Figure I(Chapter I) where R is p-chloro- or p-methyl-for XII and XIII, respectively. p-Chlorobenzaldehyde and p-methylbenzaldehyde were reduced to the corresponding alcohols with sodium borohydride. p-Chlorobenzyl bromide and p-methylbenzyl bromide were obtained by bubbling hydrogen bromide gas through benzene solutions of the corresponding alcohols. p-Chlorobenzylethylmethylsulfonium bromide and p-methylbenzylethylmethylsulfonium bromide were obtained by treating p-chlorobenzyl bromide and p-methylbenzyl bromide, respectively,

TABLE XVI

PROPERTIES OF SOME p-CHLORO- AND p-METHYLBENZYLETHYLMETHYLSULFONIUM SALTS

( X^-).

R	X⁻					
	Br^-	$CH_3SO_4^-$	dBT(1) (-)	dBT(1) (+)	ClO_4^- (-)	ClO_4^- (+)	ClO_4^- (dl)
p-Cl-	(dl) m.p.96-97°	oil	m.p.131-132°		m.p.88°		m.p.88°
	(+) m.p.92°		$[\alpha]_{589}^{25}$=-69.6		$[\alpha]_{436}^{25}$=-31.5		
	$[\alpha]_{436}^{25}$=24.2		$[\alpha]_{436}^{25}$=-166		$[\alpha]_{365}^{25}$=-56.2		
	$[\alpha]_{365}^{25}$=43.8		(c 1.599, MeOH)		(c 1.3159, MeOH)		
	(c 0.9244, MeOH)						
p-CH_3-	oil	oil	m.p.135°		m.p.101°		m.p.103°
			$[\alpha]_{589}^{25}$=-77.3		$[\alpha]_{589}^{25}$=-0.7		$[\alpha]_{589}^{25}$=13.6
			$[\alpha]_{436}^{25}$=-182		$[\alpha]_{365}^{25}$=-3.6		$[\alpha]_{436}^{25}$=53.8
			(c 0.489, MeOH)		(c 0.1224, MeOH)		(c 0.7459, MeOH)

(1) Dibenzoylhydrogentartrate.

with ethyl methyl sulfide. Other salts were obtained by the conversion of the sulfonium bromide into the hydroxide using a Dowex 1-x8 anion exchange resin in its hydroxide form, followed by neutralization of the basic eluent with the appropriate acid. The optically active perchlorates were obtained by resolution of the 2R, 3R-dibenzoylhydrogentartrates followed by replacement of the dibenzoylhydrogentartrate anion by perchlorate. Details of the procedure are presented in the Experimental section and some of the properties of the sulfonium salts are listed in Table XVI.

RESULTS

The rates of racemization and solvolysis of p-chlorobenzylethylmethylsulfonium perchlorate(XII), p-methylbenzylethylmethylsulfonium perchlorate(XIII) and p-chlorobenzylethylmethylsulfonium bromide (XIV) were measured in a variety of solvents in the same manner as was employed for m-nitrobenzylethylmethylsulfonium perchlorate(IX), described in Chapter I. All rates were followed to ca. 85% completion. Good straight lines were obtained when $\log(V_\infty - V_t)$ or $\log(\alpha_\infty - \alpha_t)$ were plotted against time. Typical examples of rate runs for solvolysis and racemization reactions are presented in Tables XVII, XVIII, XIX and XX. The corresponding plots of $\log(V_\infty - V_t)$ and $\log(\alpha_\infty - \alpha_t)$ against time are shown clearly in Figures X, XI, XII and XIII.

Tables XXI, XXII and XXIII summarize the titrimetric rate constants, k_t, polarimetric rate constants, k_α, and inversion rate constants, k_1, found for p-chlorobenzylethylmethylsulfonium perchlorate

TABLE XVII

SOLVOLYSIS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE (0.03476 M) WITH ADDED 2,6-LUTIDINE (0.04335 M) IN ANHYDROUS METHANOL AT 90.00°. RUN III-171.

Aliquot:4.93 ml. Titrant:$NaOCH_3$, 0.03186 M. Indicator:Phenophthalein. Theoretical infinity titer:5.38 ml.

Time (sec.)	Titer (ml.)	$\log(V_\infty - V_t)$	$10^4 k_t$ ($sec.^{-1}$)
0	0.61	0.6902	
840	1.21	0.6335	1.55
1560	1.73	0.5775	1.66
2460	2.25	0.5132	1.66
3720	2.89	0.4183	1.68
5280	3.69	0.2601	1.88
7080	4.13	0.1399	1.79
12000	4.92	$\bar{1}$.7709	1.76
97860	5.51	Average	1.71±0.08

V_∞ =5.51 ml., 102% of the theoretical infinity.

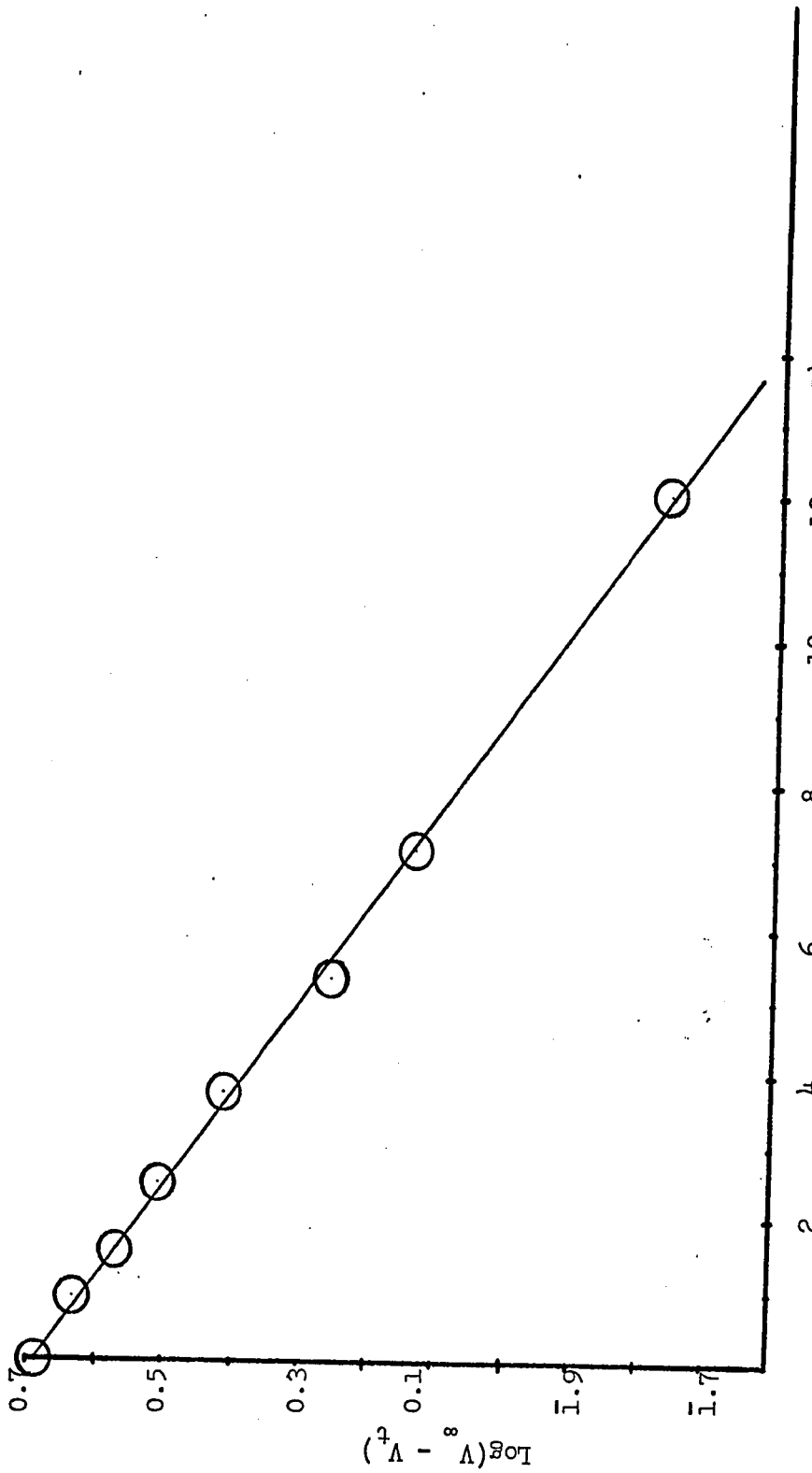


Figure X. $\log(V_\infty - V_t)$ vs. time for the solvolysis of p-chlorobenzylethylmethylsulfonium bromide(0.03476 M) with added 2,6-lutidine(0.04335 M) in anhydrous methanol at 90.00°. Run III-171.

TABLE XVIII

RACEMIZATION OF (+)-p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE (0.03282 M) WITH ADDED 2,6-LUTIDINE(0.04241 M) IN ANHYDROUS METHANOL AT 50.00°. RUN IV-66.

Time (sec.)	$\alpha^{25}_{436m\mu}$	$\alpha^{25}_{365m\mu}$	$\log(\alpha_\infty - \alpha_t)$	$\log(\alpha_\infty - \alpha_t)$	$10^5 k_{\alpha 436m\mu}$ (sec.$^{-1}$)	$10^5 k_{\alpha 365m\mu}$ (sec.$^{-1}$)
0	0.224	0.405	$\bar{1}.3502$	$\bar{1}.6075$		
7200	0.205	0.368	$\bar{1}.3118$	$\bar{1}.5658$	1.23	1.33
15660	0.183	0.331	$\bar{1}.2625$	$\bar{1}.5198$	1.29	1.29
26460	0.163	0.292	$\bar{1}.2122$	$\bar{1}.4654$	1.20	1.24
35220	0.140	0.252	$\bar{1}.1461$	$\bar{1}.4014$	1.33	1.34
64800	0.092	0.169	$\bar{2}.9690$	$\bar{1}.2279$	1.35	1.35
85980	0.068	0.123	$\bar{2}.8325$	$\bar{1}.0899$	1.39	1.39
540000	0			Average	1.30±0.06	1.32±0.04

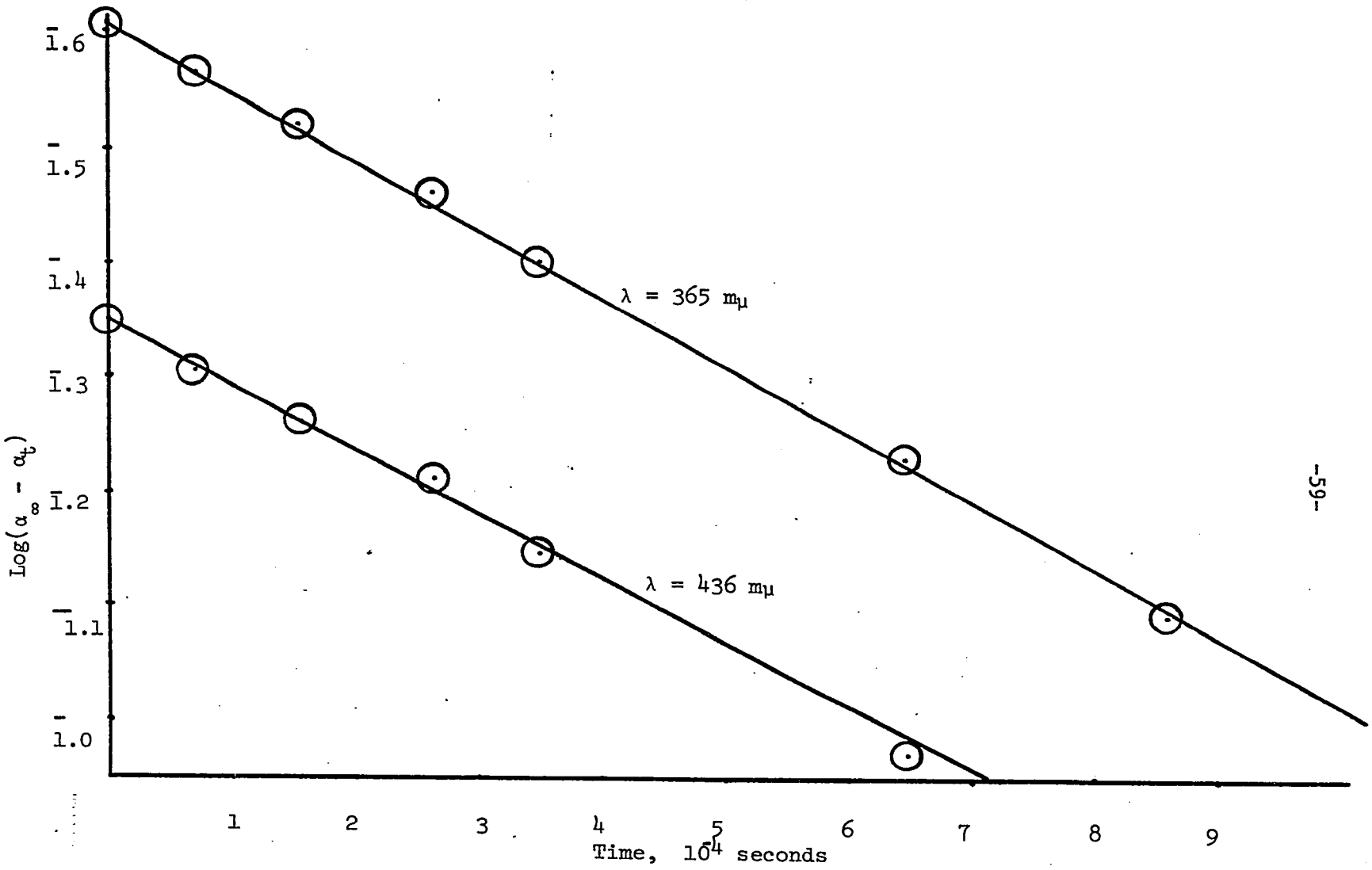


Figure XI. $\text{Log}(\alpha_\infty - \alpha_t)$ vs. time for the racemization of(+)-p-chlorobenzylethylmethylsulfonium bromide(0.03282 M) with added 2,6-lutidine(0.04241 M) in anhydrous methanol at 50.00°. Run IV-66.

TABLE XIX

SOLVOLYSIS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE (0.02202 M) WITH ADDED 2,6-LUTIDINE(0.03088 M) IN ANHYDROUS METHANOL AT 70.00°. RUN II-280.

Aliquot:5 ml. Titrant:$NaOCH_3$, 0.03186 M. Indicator:Phenolphthalein. Theoretical infinity titer:5.38 ml.

Time (sec.)	Titer (ml.)	$\log(V_\infty - V_t)$	$10^6 k_t$ ($sec.^{-1}$)
0	0.08		
79500	0.545	0.0622	1.80
190560	1.125	0.1550	1.87
268200	1.475	0.2225	1.91
440400	2.03	0.3570	1.87
529800	2.25	0.4242	1.84
687600	2.585	0.5525	1.85
855360	2.85	0.6965	1.88
604738[a]	3.56[b]	Average	1.86±0.03

a). At 90.00°. b). V_∞ = 3.56 ml., 103% of the theoretical infinity.

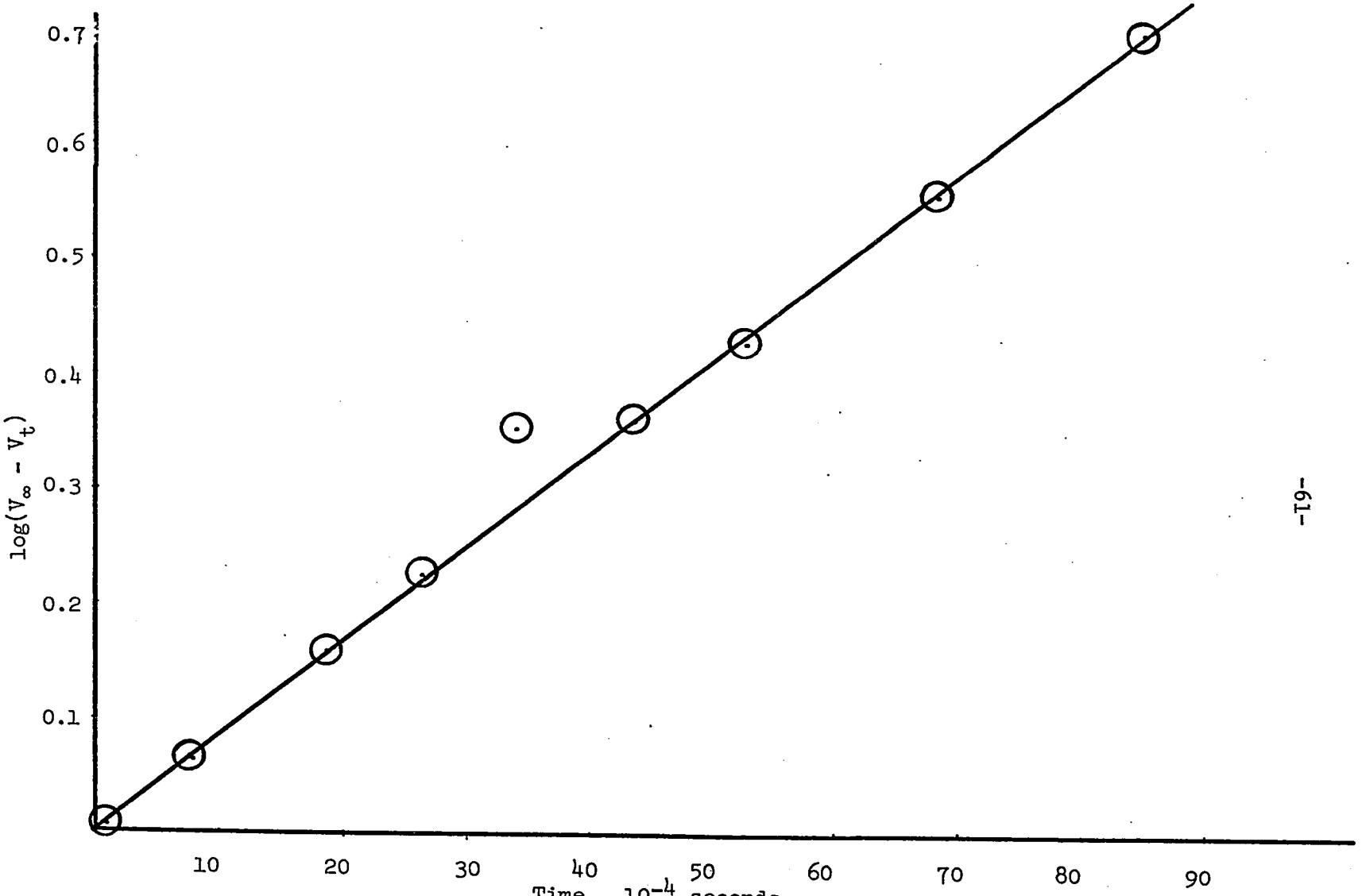


Figure XII. $\text{Log}(V_\infty - V_t)$ vs. time for the solvolysis of p-chlorobenzylethylmethylsulfonium perchlorate(0.02200 M) with added 2,6-lutidine(0.03088 M) in anhydrous methanol at 70.00°. Run II-280.

TABLE XX

RACEMIZATION OF (-)-p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE (0.04369 M) WITH ADDED 2,6-LUTIDINE (0.0693 M) IN ANHYDROUS METHANOL AT 50.00°. RUN II-266.

Time (sec.)	$\alpha^{25}_{365m\mu}$	$\log(\alpha_\infty - \alpha_t)$	$10^6 k_\alpha$ [a] (sec.$^{-1}$)
0	-0.710	$\bar{1}.8513$	
6000	-0.683	$\bar{1}.8344$	6.49
9600	-0.667	$\bar{1}.8241$	6.53
13200	-0.650	$\bar{1}.8129$	6.7
16920	-0.636	$\bar{1}.8035$	6.51
24660	-0.603	$\bar{1}.7803$	6.63
28140	-0.589	$\bar{1}.7701$	6.65
35340	-0.557	$\bar{1}.7459$	6.87
40680	-0.541	$\bar{1}.7332$	6.69
45780	-0.526	$\bar{1}.7210$	6.55
80220	-0.423	$\bar{1}.6263$	6.46
91860	-0.391	$\bar{1}.5922$	6.5
105000	-0.350	$\bar{1}.5441$	6.74
115320	-0.334	$\bar{1}.5237$	6.54
168300	-0.236	$\bar{1}.3729$	6.55
86400 [b]	0	Average	6.60±0.09

a). Polarimetric rate constant. b). at 90.00°.

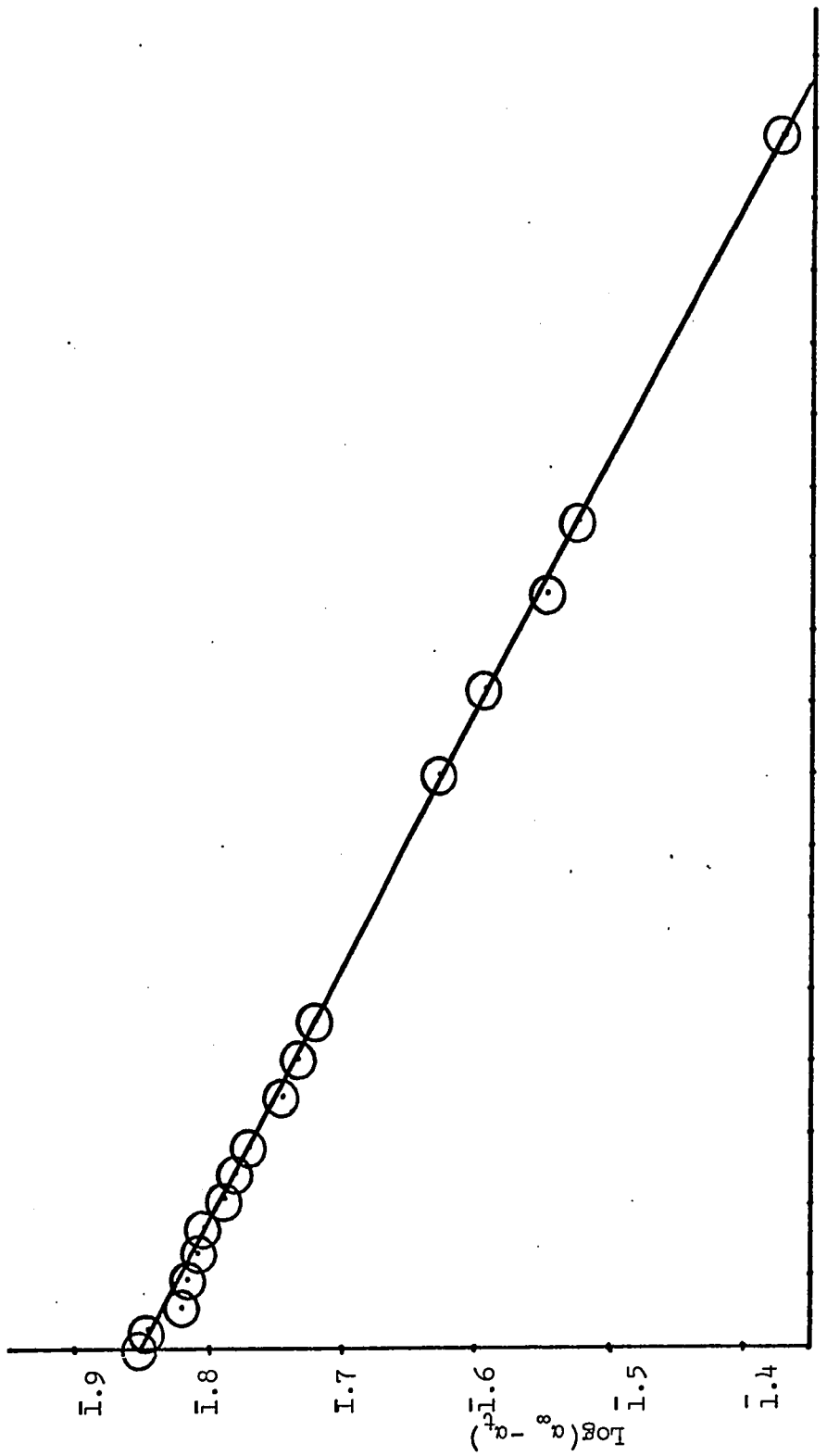


Figure XIII. Log($\alpha_\infty - \alpha_t$) vs. time for the racemization of(-)-p-chlorobenzylethylmethylsulfonium perchlorate(0.04369 M) with added 2,6-lutidine(0.0693 M) in anhydrous methanol at 50.00°. Run II-266.

TABLE XXI

SOLVOLYSIS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN A VARIETY OF SOLVENTS

Run	Temp. (°C)	Isomer	Solvent	[Salt] (M)	[2,6-Lutidine] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_1$ [c] ($sec.^{-1}$)
II-289	90	dl	MeOH	0.02200	0.03088	16.3±1.3		
II-280	70	dl	MeOH	0.02200	0.03088	1.86±0.03		
III-210	70	+	MeOH	0.03508	0.04164		96.6±0.6	49.2±0.3
II-279	50	dl	MeOH	0.02200	0.03088	0.15±0.01		
II-266	50	-	MeOH	0.04369	0.0693		6.60±0.09	3.23±0.05
III-15	50	-	CH_2Cl_2	0.03244	0.0645		9.34±0.47	
III-183	50	-	Acetone	0.02633	0.06122		6.74±0.29	
III-184	50	-	Acetone	0.02666	0		6.67±0.16	
III-185	50	-	Acetone	0.02900	0.1599		6.57±0.26	
III-217-A [d]	50	+	CH_3CN	0.03445	0.06297		8.53±0.11	
III-217-B	50	+	CH_3CN	0.03445	0.06297		8.68±0.15	
III-218-A [d]	70	+	CH_3CN	0.02804	0.09769		127±4	
III-218-B	70	+	CH_3CN	0.02804	0.09769		128±2	
III-115	50	-	80%H_2O-Acetone	0.02675	0.05058		6.69±0.06	

a). Titrimetric rate constant. b). polarimetric rate constant using Method I with λ=365mμ unless otherwise stated. c). $k_1=1/2(k_\alpha-k_t)$. d). polarimetric rate constant using Method I with λ=436mμ.

TABLE XXII

SOLVOLYSIS OF p-METHYLBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN METHANOL

Run	Temp. °C	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	[EtSMe] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_1$ [c] ($sec.^{-1}$)
III-275	90	dl	0.01782	0.02913	0	64.3±3.7		
III-67	90	dl	0.0337	0.0495	0	60.3±1		
II-276	70	dl	0.01782	0.02913	0	8.2±0.24		
III-215	70	-	0.03817	0.1025	0		113.9±1.9	52.9±1.1
II-277	50	dl	0.01782	0.02913	0	0.65±0.02		
II-267 [d]	50	+	0.02660	0.06329	0		7.4±0.17	3.38±0.1
III-44	90	-	0.03332	0.05206	0.05326	60.9±1.6		
III-47 [d]	50	+	0.03281	0.0507	0.06166		11.1±0.29	
III-63	50	+	0.03279	0.05239	0.1362		15.62±0.24	

a). Titrimetric rate constant. b). polarimetric rate constant. Both runs were done by Method I. λ=365mμ. c). $k_1=1/2(k_\alpha-k_t)$. d). From these runs, the $k_{\alpha obs.}$ was plotted against[EtSMe], from the slope of the straight line drawn was obtained $k_2=6.03 \times 10^{-5}$ $mol.^{-1}sec.^{-1}$

TABLE XXIII

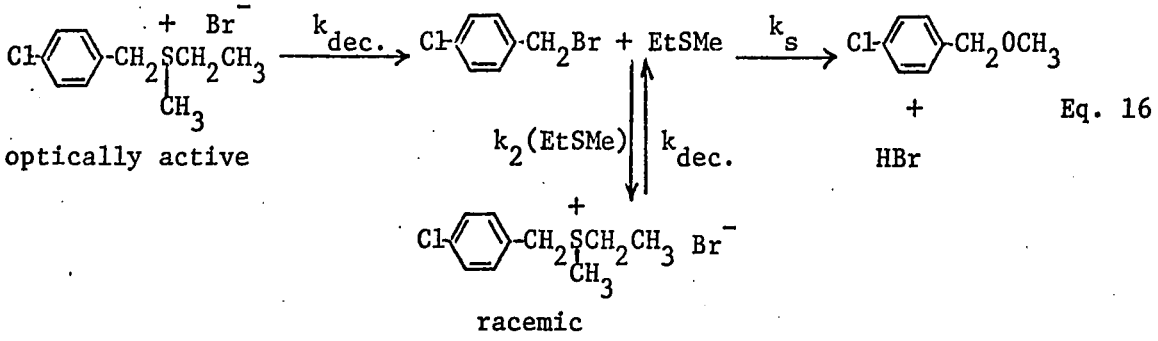
SOLVOLYSIS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE IN METHANOL WITH ADDED 2,6-LUTIDINE AT VARIOUS TEMPERATURES.

Run	Temp. °C	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	$10^6 k_{t1}$[a] (sec.$^{-1}$)	$10^6 k_{\alpha 1}$[b] (sec.$^{-1}$)	$10^6(k_{\alpha 1}-k_t)/2$[c] (sec.$^{-1}$)
III-168	90	±	0.02698	0.06042	192±10		
III-171	90	±	0.03476	0.04335	171±8		
III-170	50	±	0.03476	0.04335	2.91±0.08		
III-107	50	±	0.03286	0.04451	2.77±0.23		
III-172-A[d]	50	+	0.02519	0.08221		13.1±1.3	5.1±0.7
III-172-B[e]	50	+	0.02519	0.08221		12.9±0.54	5.0±0.3
III-105-A[d]	50	+	0.02616	0.08277		13.4±1.1	5.3±0.6
III-105-B[e]	50	+	0.02616	0.08277		13.6±0.2	5.4±0.1

a). Titrimetric rate constant. b). polarimetric rate constant. c). This term is not equal to the inversion rate constant, k_1. d). polarimetric rate constant obtained using λ=365 mμ . e) polarimetric rate constant obtained using λ=436 mμ.

(XII), p-methylbenzylethylmethylsulfonium perchlorate(XIII) and p-chlorobenzylethylmethylsulfonium bromide(XIV) in methanol. Compounds XII and XIII racemize with rates comparable to each other while XIV racemizes 1.18 times faster than XII and 1.24 times than XIII.

For compounds XIV, the bromide ion concentration was determined by the Volhard method described in detail in the experimental section. Table XXIV shows the result obtained when bromide ion concentration in the solvolysis of p-chlorobenzylethylmethylsulfonium bromide in methanol at 25° was determined by the Volhard method. There is first a very slight decrease in the amount of bromide ion in the solution and then an increase in bromide ion concentration until the titer is equivalent to that used for the first point. This result can be explained by the scheme shown in Equation 16:



Eq. 16

The solvolysis of p-chlorobenzylethylmethylsulfonium bromide (XIV) results in the formation of p-chlorobenzyl bromide which can react with the solvent methanol, to give p-chlorobenzyl methyl ether and hydrobromic acid. The p-chlorobenzyl bromide may also react with the ethyl methyl sulfide formed in the reaction to give starting material which is racemic with a rate constant k_2.

The pseudo-first-order rate constant observed for the solvolysis of p-chlorobenzyl bromide with various concentration of ethyl methyl sulfide,

TABLE XXIV

SOLVOLYSIS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE IN ANHYDROUS METHANOL(DETERMINATION OF BROMIDE ION CONCENTRATION BY VOLHARD METHOD) AT 50.00°. RUN IV-11.

Aliquot:4.93 ml. Titrant: $AgNO_3$, 0.03024 M, KSCN, 0.03074 M. Indicator: Ferric Alum. Theoretical Infinity Titer: 4.96 ml. of $AgNO_3$ calculated in terms of ml. of KSCN.

Time (sec.)	Volume of $AgNO_3$ (ml.)	Volume of $AgNO_3$ calcd. in terms of KSCN (ml.)	KSCN (ml.)	Net ml. of $AgNO_3$ calcd. in terms of KSCN (ml.)
0	10	9.84	5.04	4.80
			5.00	4.84
600	10	9.84	4.89	4.95
2580	10	9.84	5.10	4.74
6060	5	4.92	0.23	4.69
9300	5	4.92	0.22	4.70
19560	5	4.92	0.46	4.46
25980	5	4.92	0.54	4.38
35640	10	9.84	5.7	4.14
63120	5	4.92	0.75	4.17
			0.75	4.17
84180	5	4.92	0.7	4.22
188460	5	4.92	0.52	4.40
341640	5	4.92	0.28	4.64
446520	5	4.92	0.24	4.68
451020	5	4.92	0.15	4.77
517860	5	4.92	0.2	4.72
			0.17	4.75*

* V_∞ = 96% of the theoretical infinity titer.

TABLE XXV

SOLVOLYSIS OF p-CHLOROBENZYL BROMIDE IN METHANOL AT 50.00°.

Run	[p-ClØCH$_2$Br] (M)	[2,6-Lutidine] (M)	[EtSMe] (M)	k_{obs} x10^5 (sec.$^{-1}$)
IV-13	0.0359	0.05297	0	1.87±0.19
IV-18	0.03577	0.03380	0	1.74±0.06
IV-12	0.03575	0.04084	0.008211	2.85±0.22
IV-16	0.03576	0.04838	0.01757	3.38±0.34
IV-17	0.03576	0.04802	0.02880	4.60±0.23
IV-6	0.03642	0.0511	0.03659	4.64±0.19
IV-9	0.03574	0.05088	0.04943	7.10±0.44
IV-19	0.0359	0.04067	0.06366	9.55±0.20
IV-10	0.03595	0.05476	0.07668	12.2 ±0.4
IV-15	0.03578	0.04470	0.07680	10.6±0.5
IV-20	0.03578	0.04128	0.04013	5.97±0.32

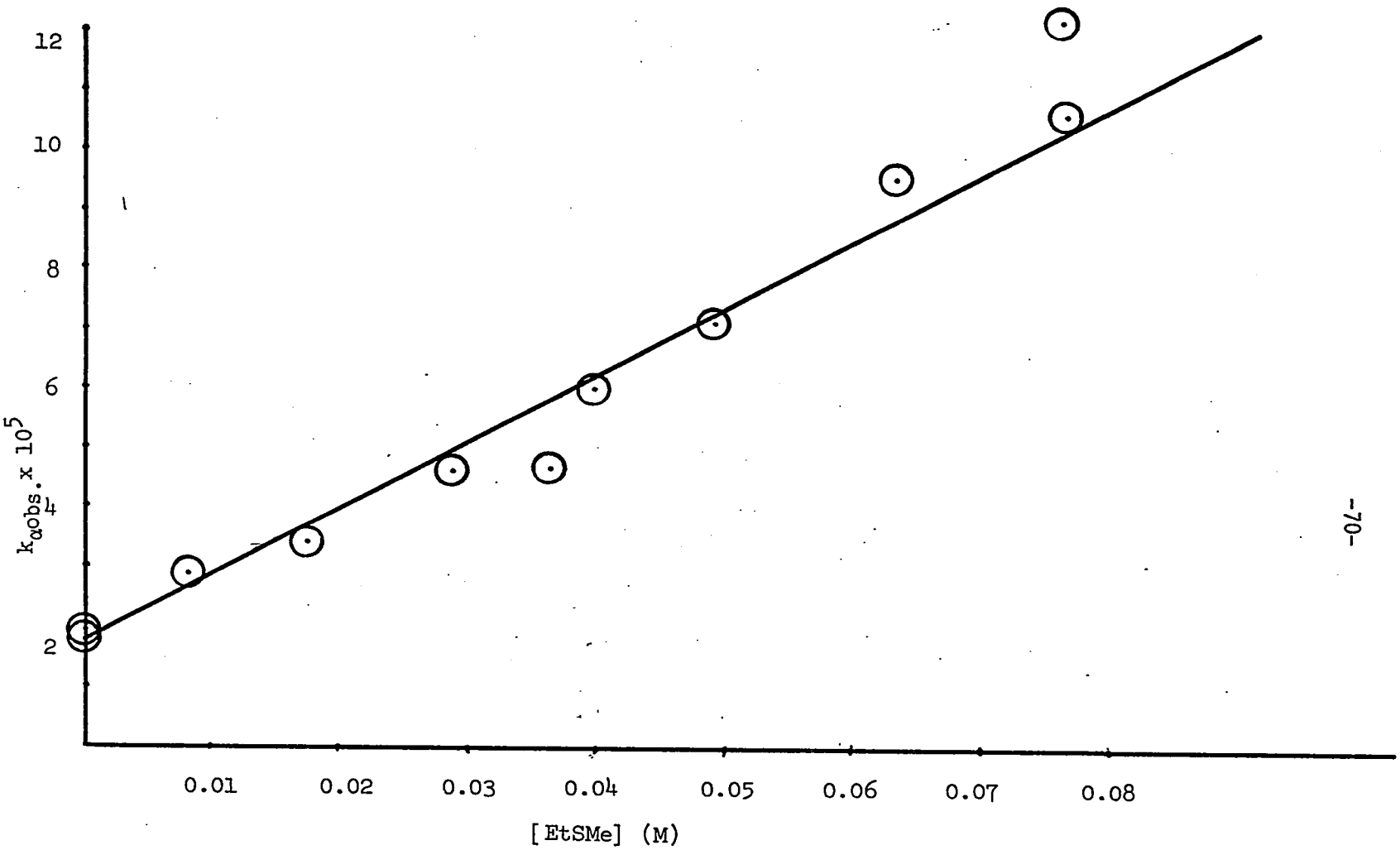


Figure XIV. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the solvolysis of p-chlorobenzylbromide (0.035-0.036M) in anhydrous methanol at 50.00°. Runs IV-13, IV-18, IV-12, IV-16, IV-17, IV-6, IV-9, IV-19, IV-10, IV-15, IV-20.

$k_{obs.}$, was determined by the Volhard method. The results obtained are tabulated in Table XXV. The corresponding plot of $k_{obs.}$ vs. concentration of the ethyl methyl sulfide is shown in Figure XIV. The second-order rate constant k_2, was obtained from the slope of the straight line shown in Figure XIV and was found to be 1.08×10^{-3} 1. $mole^{-1} sec.^{-1}$. The intercept corresponds to the rate of solvolysis of p-chlorobenzyl bromide in the absence of ethyl methyl sulfide. A typical rate run for the solvolysis of p-chlorobenzyl bromide in methanol at 50.00° is illustrated in Table XXXI. The corresponding plot of $\log(V_\infty - V_t)$ vs. time is shown in Figure XVII.

The observed rate constants for loss of optical activity, $k_{\alpha obs.}$, of p-chlorobenzylethylmethylsulfonium bromide(XIV) and p-methylbenzylethylmethylsulfonium perchlorate(XIII) increase with increasing concentrations of added ethyl methyl sulfide as shown in Tables XXII and XXVI. The corresponding plots of $k_{\alpha obs.}$ vs. concentration of ethyl methyl sulfide are shown in Figures XV and XVI. The second-order rate constants $k_{exchange}$ for the nucleophilic displacement by ethyl methyl sulfide on the primary benzylic carbon of XIII and XIV as shown in Equation 9 in Chapter I were obtained from the slope of the straight line and were found to be 6.03×10^{-5} 1. $mole^{-1} sec.^{-1}$ for XIII and 2.7×10^{-5} 1. $mole^{-1} sec.^{-1}$ for XIV.

In acetonitrile, the rate constant for decomposition of p-chlorobenzylethylmethylsulfonium bromide(XIV) was determined by the Volhard method. The results are tabulated in Table XXVII. The first three runs show that the decomposition of XIV in acetonitrile is comparable to its rate constant for loss of optical activity. The average decomposition rate constant for the first three runs is 4.47×10^{-5} 1. $mole^{-1} sec.^{-1}$. The last three runs listed in Table XXVII were the first experiments

TABLE XXVI

RATE OF LOSS OF OPTICAL ACTIVITY OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE IN PRESENCE OF ETHYL METHYL SULFIDE AT 50.00° IN ANHYDROUS METHANOL.

Run	[Salt] (M)	[2,6-Lutidine] (M)	[EtSMe] (M)	$k_{\alpha obs.} \times 10^5$ (sec.$^{-1}$)
IV-66	0.03282	0.04241	0	1.32± 0.04
IV-23	0.03302	0.04696	0.06945	1.51± 0.04
IV-24	0.03289	0.04290	0.09439	1.53± 0.08
IV-69	0.03285	0.05553	0.194	1.85± 0.05

TABLE XXVII

DECOMPOSITION RATE CONSTANTS AND RACEMIZATION RATE CONSTANTS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE IN ACETONITRILE AT 25.00°.

Run	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	$10^5 k_t$ [a] (sec.$^{-1}$)	$10^5 k_\alpha$ [b] (sec.$^{-1}$)
IV-7	±	0.01522	0.05613	4.25± 0.12	
IV-22	±	0.01524	0.05773	4.95± 0.27	
IV-65	±	0.01525	0.05465	4.67± 0.4	$(4.07\pm 0.19)_{436m\mu}$
III-278	±	0.02288	0.06081	5.42± 0.20	$(4.09\pm 0.16)_{365m\mu}$
III-292	+	0.01501	0.05516		$(3.50\pm 0.13)_{365m\mu}$
III-294	±	0.02996	0.06367	5.50± 0.17	

a). Titrimetric rate constant. b). polarimetric rate constant.

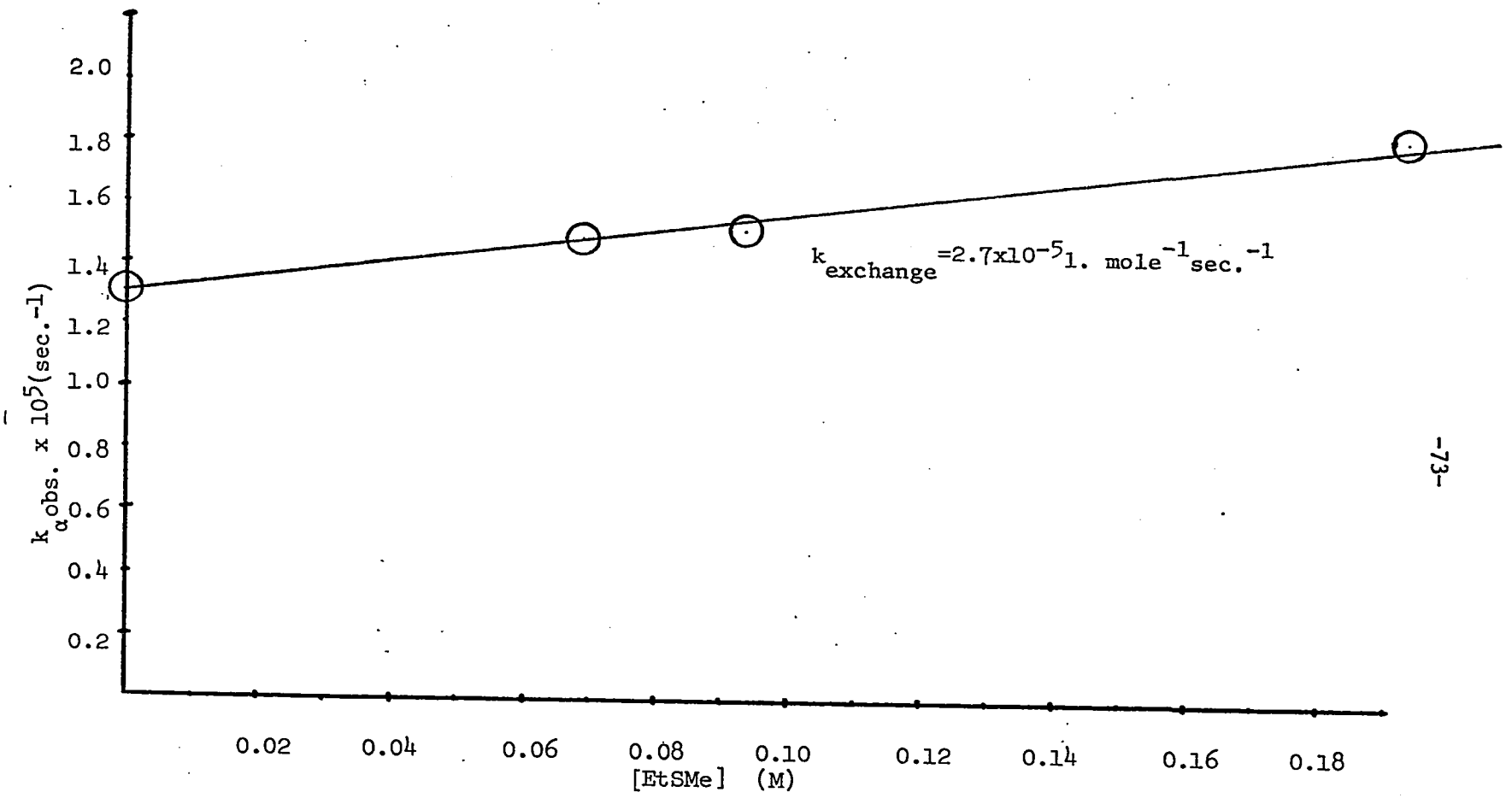


Figure XV. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the racemization of p-chlorobenzylethylmethylsulfonium bromide(0.032-0.033 M) with added 2,6-lutidine in anhydrous methanol at 50.00°. Runs IV-66, IV-23, IV-24 and IV-69.

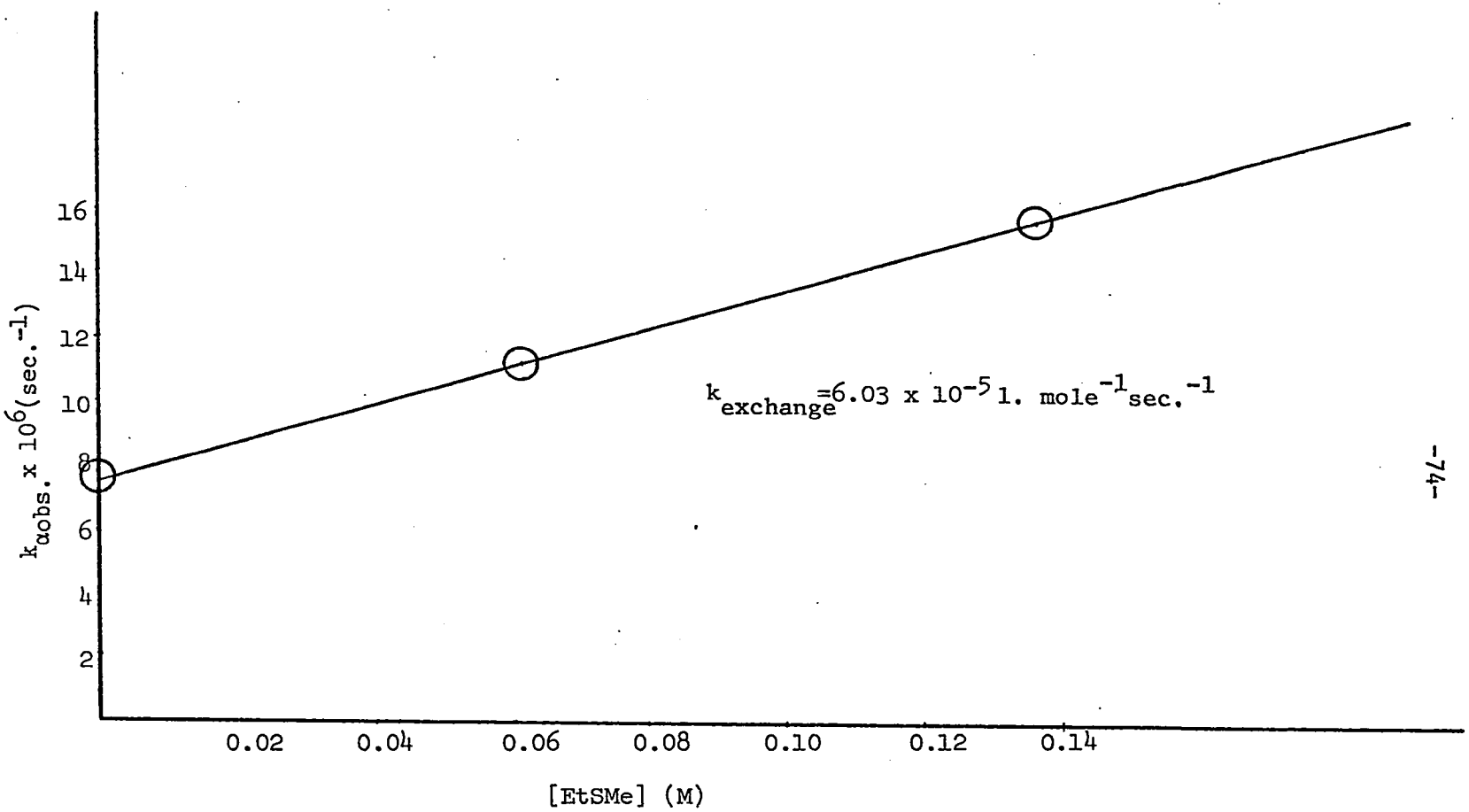


Figure XVI. Plot of $k_{\alpha obs.}$ vs. [EtSMe] for the racemization of p-methylbenzylethylmethylsulfonium perchlorate(0.027 M) with added 2,6-lutidine in anhydrous methanol at 50.00°. Runs II-267, III-47 and III-63.

carried out in this solvent. It is not possible for the decomposition of p-chlorobenzylethylmethylsulfonium bromide(XIV) to be faster than its loss of optical activity. The results probably reflect large experimental errors when first developing the technique for halide analysis. While the data are not of high precision, it appears that the decomposition and racemization rates are identical for the reaction.

Tables XXVIII and XIX summarize the racemization rate constants for reaction of p-chlorobenzylethylmethylsulfonium perchlorate in 80% water-acetone at 50° in the presence of sodium fluoride and sodium perchlorate, respectively. The results given in Table XXVIII show that the presence of fluoride ions in the solution does not affect the rate of racemization of p-chlorobenzylethylmethylsulfonium perchlorate. The data in Table XXIX show that increasing the ionic strength by adding an inert salt such as sodium perchlorate has a small effect on the rate of racemization of p-chlorobenzylethylmethylsulfonium perchlorate. The rate constant for racemization in the presence of 0.1271 M of sodium perchlorate is $(5.78\pm0.36)\times10^{-5}$ sec.$^{-1}$ compared to $(6.69\pm0.06)\times10^{-6}$ sec.$^{-1}$ in the absence of sodium perchlorate.

The analyses of the products of methanolysis of p-chlorobenzylethylmethylsulofnium perchlorate (XII) and p-methylbenzylethylmethylsulfonium perchlorate(XIII) were carried out using gas chromatography. The results are tabulated in Table XXX. The calculated mole per cent of each product is 98 to 102 per cent of the theoretical value.

TABLE XXVIII

RACEMIZATION RATE CONSTANTS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN 80% WATER-ACETONE AT 50.00° IN PRESENCE OF SODIUM FLUORIDE.

Run	Isomer	[Salt] (M)	[NaF] (M)	[2,6-Lutidine] (M)	$10^6 k\alpha^a$ (sec.$^{-1}$)
III-176	-	0.02613	0.02877	0.04885	6.46±0.16
III-177	-	0.02736	0.05158	0.05452	5.92±0.20
III-114	-	0.02626	0.102	0.0744	6.46±0.44
III-178	-	0.02587	0.1284	0.1232	6.64±0.08

a). Polarimetric rate constant.

TABLE XXIX

RACEMIZATION RATE CONSTANTS OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN 80% WATER-ACETONE AT 50.00° IN PRESENCE OF SODIUM PERCHLORATE.

Run	Isomer	[Salt] (M)	[$NaClO_4$] (M)	[2,6-Lutidine] (M)	$10^6 k\alpha^a$ (sec.$^{-1}$)
III-181	-	0.02679	0.02891	0.05794	6.66±0.50
III-179	-	0.02735	0.05105	0.05389	6.34±0.15
III-180	-	0.02716	0.1040	0.05439	6.63±0.19
III-182	-	0.02676	0.1271	0.05279	5.78±0.36

a). Polarimetric rate constant.

TABLE XXX

THE ANALYSES OF THE PRODUCTS OF METHANOLYSIS OF p-METHYL- AND p-CHLOROBENZYLETHYLMETHYL-SULFONIUM PERCHLORATE AT 90.00°.

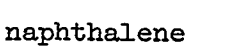
Sample	[Salts] (M)	[2,6-Lutidine] (M)	Components	Rel. Areas	Calcd. wt. in 4.93 ml.(g)	Conc. (M)	mole %
III-152	p-CH_3 0.03212	0.06529		0.799	0.2130	0.03172	99
			naphthalene	1			
			H^+			0.03251	101
III-149	p-Cl 0.03389	0.05331		0.928	0.2617	0.0331	98
			naphthalene	1			
			H^+			0.03470	102

TABLE XXXI

SOLVOLYSIS OF p-CHLOROBENZYL BROMIDE IN ANHYDROUS METHANOL AT 50.00° (USING THE VOLHARD METHOD FOR DETERMINING BROMIDE ION CONCENTRATION) IN THE PRESENCE OF ETHYL METHYL SULFIDE(0.0768 M) AND 2,6-LUTIDINE(0.04470 M). RUN IV-15.

Aliquot: 4.93 ml. Titrant: $AgNO_3$, 0.05195 M; KSCN, 0.03020 M

Indicator: Ferric alum Theoretical titer: 3.15 ml. of $AgNO_3$.

Time	$AgNO_3$ (ml.)	KSCN (ml)	KSCN calcd. in terms of $AgNO_3$ (ml.)	Net $AgNO_3$ (ml.)	$\log(V_\infty - V_t)$	$k_s \times 10^4$ ($sec.^{-1}$)
0	5	7.78	4.52	0.48	0.4265	
600	5	7.8	4.53	0.47	0.4298	
1200	5	7.42	4.31	0.69	0.3909	0.683
2100	5	6.92	4.02	0.98	0.3365	0.987
3000	5	6.56	3.81	1.19	0.2923	1.03
5280	5	5.84	3.40	1.60	0.1903	1.03
7680	5	5.17	3.01	1.99	0.0645	1.09
10080	5	4.76	2.77	2.23	$\bar{1}$.9638	1.06
13320	5	4.23	2.46	2.54	$\bar{1}$.7853	1.11
17280	5	3.92	2.28	2.72	$\bar{1}$.6335	1.06
24360	5	3.47	2.02	2.98	$\bar{1}$.2304	1.13
29280	5	3.40	1.98	3.02	$\bar{1}$.1139	1.03
87300	5	3.19	1.85	3.15[a]		
					Average[b]	1.06±0.05

a). V_∞ = 93% of the theoretical infinity titer. b). the first rate constant(0.683×10^{-4} $sec.^{-1}$) was discarded in calculating the average rate constant.

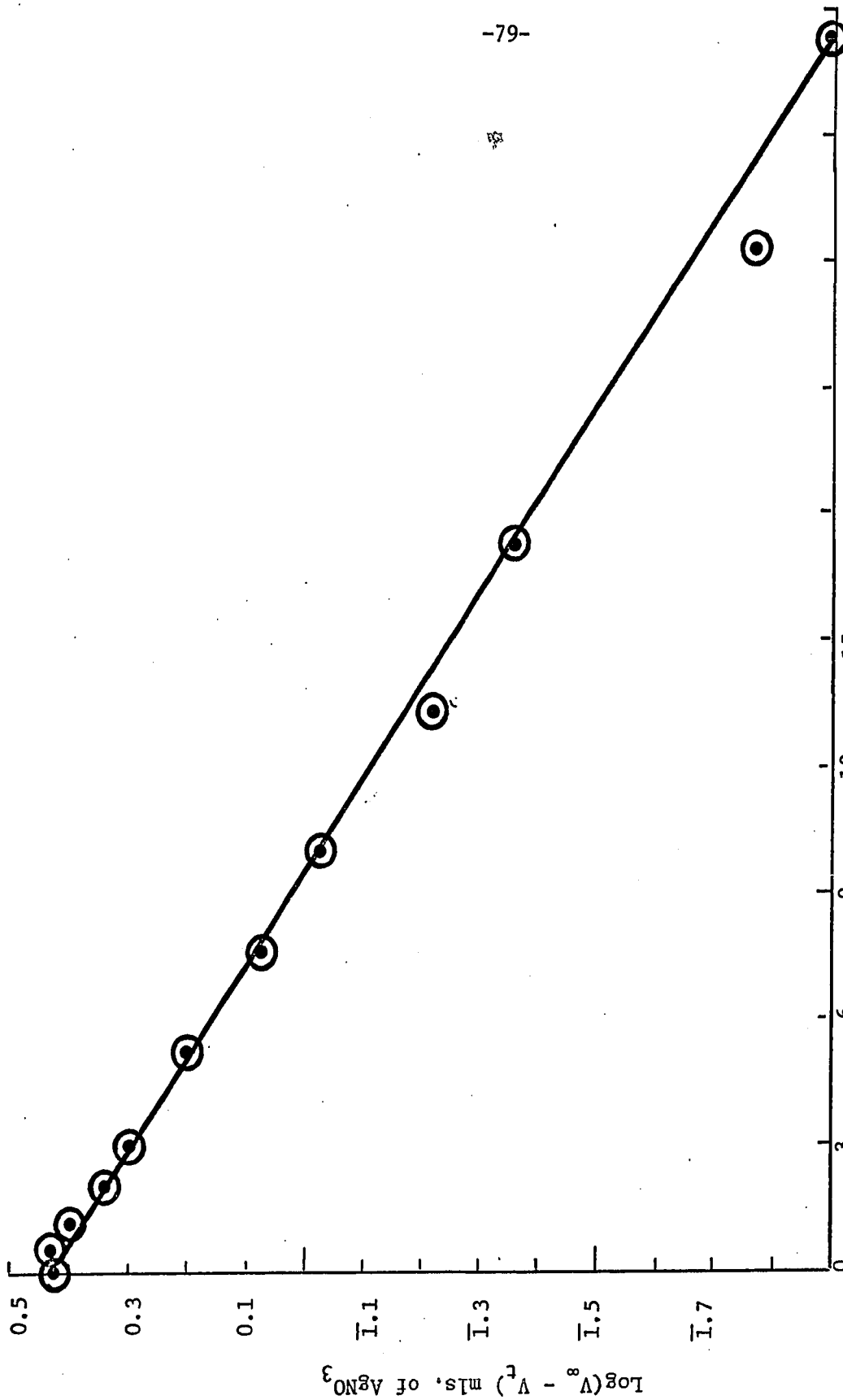


Figure XVII. Plot of $\text{Log}(V_\infty - V_t)$ vs. time for the solvolysis of p-chlorobenzyl bromide in anhydrous methanol at 50.00° (using the Volhard method) in the presence of ethyl methyl sulfide (0.0768 M) and 2,6-lutidine (0.04470 M). Run IV-15.

DISCUSSION

Comparison of racemization and solvolysis rates

It was shown in Chapter I that two mechanisms which can account for the racemization of sulfonium salts are:

i). A heterolytic carbon-sulfur cleavage to form an ion-neutral molecule pair which can either return to sulfonium salt or react with solvent to yield substitution and/or elimination products.

ii). A pyramidal inversion about the sulfur atom analogous to the inversion of the ammonia molecule.

By studying the substituent effect, one can distinguish between the two mechanisms. In methanol at 50°, the relative rate constants of racemization of p-nitrobenzylethylmethylsulfonium perchlorate (VI)(32), p-methoxy-m-nitrobenzylethylmethylsulfonium perchlorate(VII) (32) and m-nitrobenzylethylmethylsulfonium perchlorate(IX) compared to benzylethylmethylsulfonium perchlorate(V) are 0.98 : 1.05 : 0.99 : 1. The second mechanism was suggested to explain the results obtained.

In methanol at 50°, the relative rate constants of racemization of p-chlorobenzylethylmethylsulfonium perchlorate(XII) and p-methylbenzylethylmethylsulfonium perchlorate(XIII) compared to benzylethylmethylsulfonium perchlorate(V) are 0.95 : 0.99 : 1(Table XXXII). Compounds XII and XIII racemize with rates comparable to V. Since V was found to racemize by the pyramidal inversion about the sulfur atom, it follows that XII and XIII also racemize by the same mechanism.

Nucleophilic displacement of ethyl methyl sulfide produced in solvolysis on the primary benzylic carbon as shown in Equation 9 and Table XVI(Chapter I), accounts for only a small amount of

TABLE XXXII

A COMPARISON OF RACEMIZATION RATES OF SUBSTITUTED BENZYLETHYLMETHYLSULFONIUM SALTS WITH BENZYLETHYLMETHYLSULFONIUM PERCHLORATE ($R\text{-}C_6H_4CH_2\overset{+}{S}(CH_3)CH_2CH_3\ X^-$) IN ANHYDROUS METHANOL AT 50.00°.

R	X^-	Run	Isomer	[Salt] (M)	[2,6-Lutidine] (M)	$10^6 k_t$ [a] ($sec.^{-1}$)	$10^6 k_\alpha$ [b] ($sec.^{-1}$)	$10^6 k_1$ [c] ($sec.^{-1}$)	V [d] ($k_{rac.}/k_{rac.}$)
p-Cl	ClO_4^-	II-279	d1	0.02200	0.03088	0.15±0.01			
		II-266	-	0.04369	0.0693		6.60±0.09	3.23±0.05	0.95
p-CH_3	ClO_4^-	II-277	d1	0.01782	0.02913	0.65±0.02			
		II-267	+	0.02660	0.06329		7.4±0.17	3.38±0.1	0.99
p-Cl	Br^-	III-170	d1	0.03476	0.04335	2.91±0.08			
		III-172-A	+	0.02519	0.08221		13.1±1.3	3.8[e]	1.12
m-NO_2	ClO_4^-	II-223	d1	0.02286	0.04835	0.06[f]			
		II-222	+	0.03020	0.05608		6.56±0.16	3.25±0.08	0.96
3-CH_3-Cl	ClO_4^-	III-3	+	0.03523	0.07468	768±16			
4-OCH_3		III-5	+	0.03523	0.07468		1096±32		48
3,5-diCH_3-	ClO_4^-	III-262	+	0.03104	0.08898	12.7±0.3			
4-OCH_3		III-264	+	0.03104	0.08898		24.9±0.6		1.79
Hg	ClO_4^-					0.2	6.99	3.4	1

a). Titrimetric rate constant. b). polarimetric rate constant. c). racemization rate constant, $k_{rac.\alpha} = k_{\alpha} - k_t$ except for p-chlorobenzylethylmethylsulfonium bromide where $k_{rac.\alpha} = k_{\alpha} - k_{dec.}$ d). racemization rate constant relative to that of benzylethylmethylsulfonium perchlorate. e). $k_{rac.\alpha} = k_{\alpha} - k_{dec.}$ Rate constant for decomposition of p-chlorobenzylethylmethylsulfonium bromide, $k_{dec} = 5.6 \times 10^{-6}$ sec.$^{-1}$. f). extrapolated value. g). See Bibliography, (33).

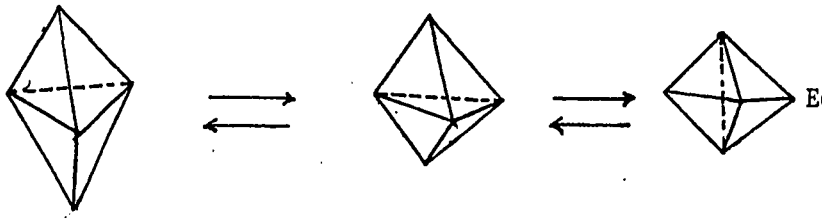
racemization of p-methylbenzylethylmethylsulfonium perchlorate(XIII). Using the value of $k_{exchange}$, the titrimetric and polarimetric rate constants, the following conclusions can be reached. After 50% loss of optical activity, 4.4% of XIII has undergone solvolysis, of the unsolvolyzed salt, 47.7% must be racemic. Only ca. 0.5% of the unsolvolyzed salt could have been racemized by the scheme shown in Equation 9.

An alternative pathway for racemization

The kinetic results obtained from studies of the solvolysis and racemization of p-chlorobenzylethylmethylsulfonium perchlorate(XII) and p-methylbenzylethylmethylsulfonium perchlorate(XIII) clearly indicate that racemization takes place without cleavage of any of the carbon-sulfur bonds. The major pathway for racemization of XII and XIII was suggested to be the pyramidal inversion mechanism in analogy to the well-known inversion of ammonia and amines. However, an alternative pathway for racemization of sulfonium salts involving pseudorotation must be considered. This alternative mechanism will be discussed in detail in the following section.

Pseudorotation(39) of compounds in which the central atom is pentacovalently bonded is defined as the intramolecular process where a trigonal bipyramidal molecule is transformed by deforming bond angles in such a way that it appears to have been rotated by 90^{o} about one of the interatomic bonds. Thus, as shown in Equation 17, the substituent that is toward the viewer remains fixed, while the vertical(apical)substituents are pushed backward and the horizontal(equatorial)substituents are pulled forward so as to produce a tetragonal pyramid where the fixed substituent

is at the apex. A continuation of the process leads to the second trigonal bipyramid, which appears to have been produced by rotating the first about the bond from the fixed substituent(the 'pivot') to the central atom.



Eq. 17

Tetravalent sulfur species may be considered to be approximately trigonal bipyramidal in geometry with the electron pair on sulfur occupying one of the equatorial positions. A minimum of five pseudorotations of an optically active tetracovalent sulfur species are required to convert it to its mirror image. It is conceivable that racemization of sulfonium salts without breaking any C-S bond could occur by addition of a nucleophile to the central sulfur atom to form a tetravalent sulfur species. After the appropriate pseudorotations and loss of the nucleophile, the mirror image of the original sulfonium salt would be formed. If this alternative process were to account for the racemization of sulfonium salts, then the presence of nucleophiles which could add to the sulfur should greatly accelerate the process. Therefore, optically active p-chlorobenzylethylmethylsulfonium bromide was synthesized and the kinetics of its racemization and solvolysis were studied. Attempts to isolate p-chlorobenzylethylmethylsulfonium fluoride failed.

Compounds containing quadrivalent sulfur atoms are not unknown in the literature of organosulfur chemistry(40-43). Some examples of known compounds include SF_4 and alkyl- and arylsulfur trichlorides and

trifluorides. Tetravalent sulfur intermediates have also been proposed in the chlorinolysis of both thioethers and arenesulfenyl chlorides (44-45).

As shown in Tables XXI and XXIII, p-chlorobenzylethylmethylsulfonium bromide losses optical activity about twice as fast as p-chlorobenzylethylmethylsulfonium perchlorate in solvent methanol at 50.00°. To compare the racemization of the bromide and perchlorate salts, the polarimetric rate constants must be corrected for solvolysis of the sulfonium salts. In methanol at 50.00°, the rate constant for the solvolysis of p-chlorobenzylethylmethylsulfonium bromide(XIV) and p-chlorobenzylethylmethylsulfonium perchlorate(XII) are $(2.91\pm0.08)\times10^{-6}$ sec.$^{-1}$(Table XXIII, Run III-170) and $(1.48\pm0.14)\times10^{-7}$ sec.$^{-1}$(Table XXI, Run II-279), respectively. Compound XIV solvolyzes about 20 times faster than XII. Using these values, the apparent rate constants for racemization k_α-k_t, of XII and XIV are 6.45×10^{-6}sec.$^{-1}$ and 10.2×10^{-6} sec.$^{-1}$, respectively. The apparent rate constant for racemization of XIV is 60% larger that for XII. This result indicates that there is not a large difference in racemization rates for the two salts. The nucleophilic bromide ion does not have a profound influence on the racemization process.

The estimate of the relative rates of racemization is subject to further correction. The rate constant k_t for p-chlorobenzylethylmethylsulfonium bromide XIV, does not measure the rate of decomposition of the optically acitve salt. The solvolysis of XIV involves the sequence of reaction shown in Equation 16. The rate constant k_t measures the rate of formation of solvolysis products, p-chlorobenzyl methyl ether, ethyl

sulfide and hydrobromic acid. It was shown that during the course of the reaction, a finite amount of p-chlorobenzyl bromide is formed. Therefore, the rate constants, k_s and k_2(EtSMe) are not very much larger than $k_{dec.}$'

As far as we are aware, an exact mathematical solution for the evaluation of $k_{dec.}$ for a reaction of this type has never been obtained. If the steady state approximation could be applied to this reaction, then an exact solution would be obtained. The application of the steady state approximation would require taking the rate of change of concentration of p-chlorobenzyl bromide with changes in time, $d[ClC_6H_4CH_2Br]/dt$, to be equal to zero. This is not a valid assumption in our case. It was shown that during the course of solvolysis of p-chlorobenzylethylmethylsulfonium bromide, a small but finite amount of p-chlorobenzyl bromide is formed. The maximum amount of this present in the solution corresponds to ca. 15% of the initial concentration of the sulfonium bromide.

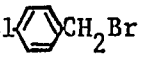
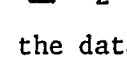
For Equation 16, the kinetic expression shown by Equation 18 which gives the rate of change of concentration of the p-chlorobenzyl bromide with changes in time can be written.

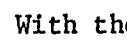
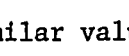
$$\frac{d[ClC_6H_4CH_2Br]}{dt} = k_{dec.}[d\text{-}Br] + k_{dec.}[dl\text{-}Br] - k_2[EtSMe][ClC_6H_4CH_2Br] - k_s[ClC_6H_4CH_2Br] \qquad \text{Eq. 18}$$

$$= k_{dec.}[Salt] - k_2[EtSMe][ClC_6H_4CH_2Br] - k_s[ClC_6H_4CH_2Br]$$

where d-Br represents the optically active sulfonium bromide and dl-Br represents the racemic sulfonium bromide.

From the data in Table XXIV, a plot of the concentration of p-chlorobenzyl bromide vs. time can be made. Such a plot is shown in Figure XVIII. $d[ClC_6H_4CH_2Br]/dt$ is the slope of the tangent to this

curve at any point. For the specific case of the point corresponding to maximum on the curve, the slope d[Cl  CH_2Br]/dt is by definition equal to zero. Hence, $k_{dec.} = \{k_2[EtSMe][Cl$  $CH_2Br] + k_s[Cl$  $CH_2Br]\}$ / [Salt].

From a visual inspection of the data, two limiting curves as shown in Figure XVIII can be drawn, each of which would give rise to a different point as the maximum. With the data from these curves, rate constant $k_{dec.}$ which were of similar values were obtained. From curve I, $k_{dec.} = 5.05 \times 10^{-6}$ sec.$^{-1}$ and from curve II, $k_{dec.} = 5.58 \times 10^{-6}$ sec.$^{-1}$. These numbers vary by only 10% from one another and set reasonable limits on the value of $k_{dec.}$. To check these two values, tangents to the curve at other points were drawn. The slope of the tangents gave the values of d[p-ClØCH_2Br]/dt and the values of $k_{dec.}$ were obtained using Equation 18 where $k_{dec.} = \{d[Cl$  $CH_2Br]/dt + k_2[EtSMe][Cl$  $CH_2Br] + k_s[Cl$  $CH_2Br]\}$ / [Salt].

Using curve I, tangents at points O and A were drawn and the values of $k_{dec.}$ obtained were 6.10×10^{-6} sec.$^{-1}$ and 5.65×10^{-6} sec.$^{-1}$, respectively. Using curve II, tangents at points B and C were drawn, the respective values of $k_{dec.}$ obtained were 6.03×10^{-6} sec.$^{-1}$ and 5.08×10^{-6} sec.$^{-1}$. The average of the rate constants, $k_{dec.}$, obtained from curve I was 5.60×10^{-6} sec.$^{-1}$, whereas from curve II, an average of 5.56×10^{-6} sec.$^{-1}$ for $k_{dec.}$ was obtained. The two sets of rate constants gave values which are very close to each other. It is clear from these calculations that a value close to 5.6×10^{-6} sec.$^{-1}$ is a good estimation of $k_{dec.}$ and will not be significantly altered using a best fit curve of the data.

The racemization rate constants, $k_{rac} = k_\alpha - k_{dec.}$ of p-chlorobenzylethylmethylsulfonium bromide are $(1.31 \times 10^{-5}) - (5.60 \times 10^{-6}) = 7.5 \times 10^{-6}$ sec.$^{-1}$ and $(1.31 \times 10^{-5}) - (5.56 \times 10^{-6}) = 7.6 \times 10^{-6}$ sec.$^{-1}$ using the

two values of $k_{dec.}$, The inversion rate constants, $k_1=k_\alpha-k_{dec.}/2$, are 3.75×10^{-6} sec.$^{-1}$ and 3.77×10^{-6} sec.$^{-1}$, respectively. These numbers may both be represented as 3.8×10^{-6} sec.$^{-1}$ within the experimental errors.

Under the same conditions, the rate constant for inversion k_1, was found to be $(3.23 \pm 0.05) \times 10^{-6}$ sec.$^{-1}$ for p-chlorobenzylethylmethylsulfonium perchlorate(XII). The relative rates of racemization of p-chlorobenzylethylmethylsulfonium bromide compared to the corresponding perchlorate salt are 1.18 : 1 using k_1^{XIV} equal to 3.8×10^{-6} sec.$^{-1}$. The results show that changing the anion from a non-nucleophilic perchlorate to a nucleophilic bromide did not markedly influence the rate of racemization. In fact, considering the inherent errors in the calculation, the rate constant of inversion, k_1, for the sulfonium bromide may be the same as for the corresponding perchlorate salt.

It should be noted that p-chlorobenzylethylmethylsulfonium bromide can also undergo racemization by a process involving nucleophilic displacement by ethyl methyl sulfide produced in the solvolysis on the primary benzylic carbon as shown in Equation 9 in Chapter I. The second-order rate constant $k_{exchange}$, for nucleophilic displacement by ethyl methyl sulfide on the primary benzylic carbon of XIV was obtained from the slope of the straight line shown in Figure XV. This figure was obtained by plotting the data shown in Table XXVI. Using $k_{exchange}$, k_t and k_α, the following conclusion was derived. After 50% loss of optical activity, 21.1% of XIV has undergone solvolysis, of the unsolvolyzed salt, 36.6% must be racemic. Only ca. 0.3% of the unsolvolyzed salt could have been racemized by the scheme shown in Equation 9. Therefore, a negligible amount of racemization of p-chlorobenzylethylmethylsulfonium

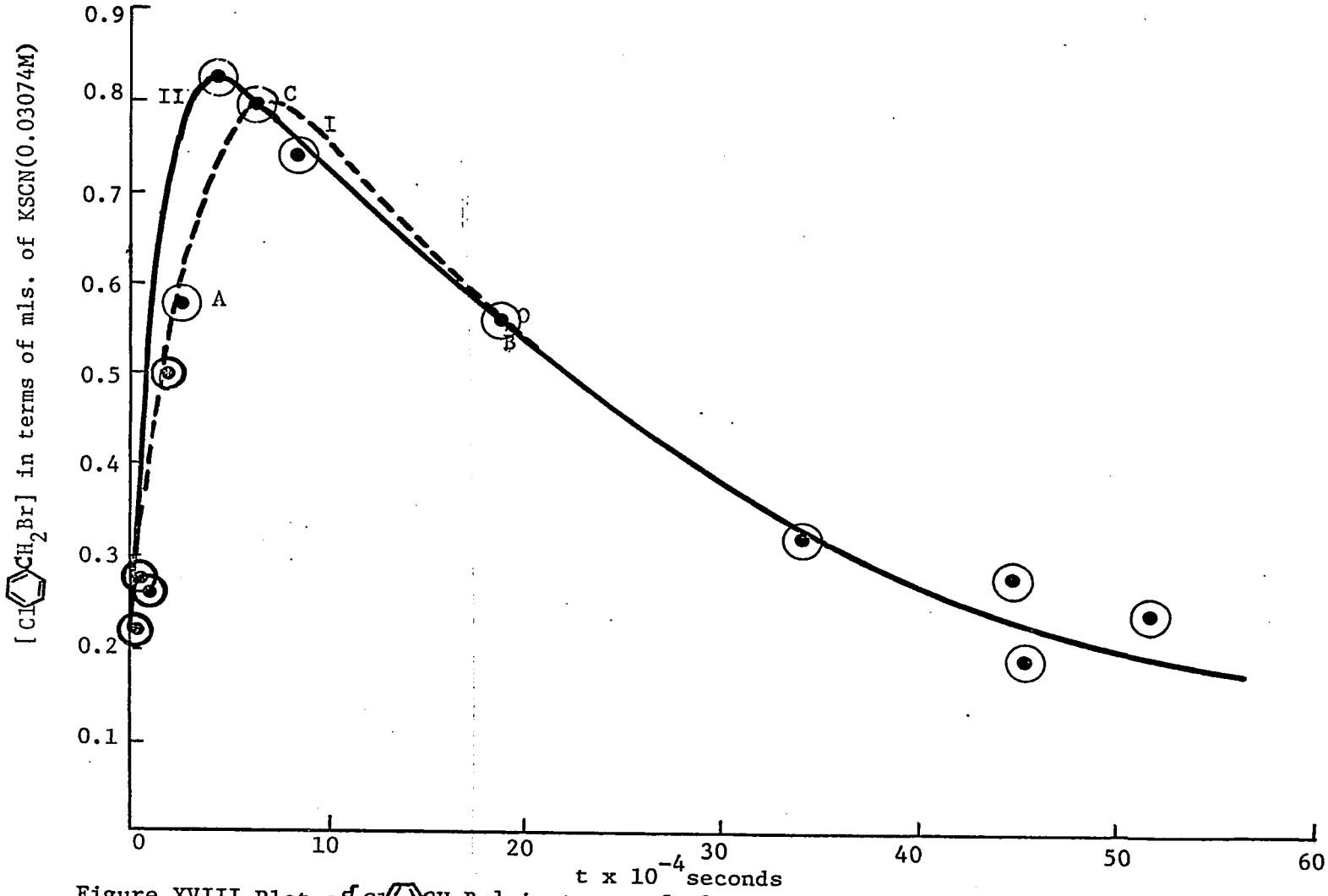


Figure XVIII.Plot of [ClC$_6$H$_4$CH$_2$Br] in terms of mls. of KSCN vs. time for the solvolysis of p-chlorobenzylethylmethylsulfonium bromide (0.03094 M) in anhydrous methanol at 50.00° in the presence of 2,6-lutidine(0.04082 M). Run IV-11.

bromide(XIV) is caused by this process and it has not been accounted for in calculating the polarimetric rate constants.

The predominant pathway for racemization of p-chlorobenzylethylmethylsulfonium bromide and perchlorate must be the same. While it is not possible to unequivocally rule out a small amount of racemization via an addition, pseudorotation, elimination process in the case of the sulfonium bromide, we have not found any evidence that such a process is a major pathway for the racemization of sulfonium salts. The major pathway for racemization of these sulfonium salts must involve pyramidal inversion.

Solvent Effect

For the solvolysis of p-chlorobenzylethylmethylsulfonium perchlorate(XII), increasing the ionic strength by adding inert salt has a very small effect on the rate constants for racemization. Table XXIX shows that in the presence of 0.1271 M of sodium perchlorate the rate constant for racemization of XII is $(5.78\pm0.36)\times10^{-5}$ sec.$^{-1}$ compared to $(6.69\pm0.06)\times10^{-6}$ sec.$^{-1}$ in the absence of sodium perchlorate. In non-hydroxylic solvents like methylene chloride, acetonitrile and acetone, the production of acid is so slow that the solvolysis rates could not be determined by titration with standard sodium methoxide solution.

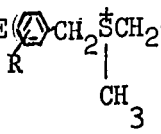
Table XXI shows that in acetone, $\varepsilon^{25}=20.7$, the rate of loss of optical activity for p-chlorobenzylethylmethylsulfonium perchlorate (XII) is very similar to the rate in anhydrous methanol, $\varepsilon^{25}=32.63$. Racemization rates in methylene chloride, $\varepsilon^{20}=9.08$ and in acetonitrile

ε^{25}=36.2, are faster than the rates in anhydrous methanol. Relative rate constants of loss of optical activity for p-chlorobenzylethylmethylsulfonium perchlorate(XII) are 1.36 : 1.30 : 1.00 : 1.00 in methylene chloride, acetonitrile, acetone and methanol, respectively. The small increase in the racemization rates in less polar solvents like methylene chloride and acetonitrile shows that the effect of dielectric constant of the solvent on the racemization rate is very small.

Temperature Effect

The activation parameters for the solvolysis, racemization and loss of optical activity of compounds XII, XIII and XIV are tabulated in Table XXXIII. E_a, ΔH^*, ΔS^* were calculated using Equations 12, 13 and 14 presented in Chapter I. For the solvolysis reactions of p-chlorobenzylethylmethylsulfonium perchlorate(XII), p-methylbenzylethylmethylsulfonium perchlorate(XIII) and p-chlorobenzylethylmethylsulfonium bromide(XIV) negative entropies of activation were obtained and the values are similar to the value for the solvolysis of m-nitrobenzylethylmethylsulfonium perchlorate. Again, structure D'(see page 52) would best described the transition state of solvolysis of compounds XII, XIII and XIV. The decrease in the degree of freedom in the transition state compared to the ground state can account for the observed negative entropies.

TABLE XXXIII

ACTIVATION PARAMETERS FOR THE SOLVOLYSIS AND RACEMIZATION OF p-METHYL-p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE AND p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE () AT 25.00°.

R	X^-	Reaction	Solvent	E_a	ΔH*	ΔS*
p-CH_3	ClO_4	solvolysis	methanol	25.9±0.1	24.8±0.1	-10±4
		loss of optical activity	methanol	30.00±0.4	29.4±0.4	9±1
		racemization	methanol	30.13±0.6	29.5±0.6	9±2
		loss of optical activity	acetonitrile	28.82±0.8	28.2±0.8	6±2
p-Cl	ClO_4	solvolysis	methanol	26.9±1.0	26.3±1.0	-9±3
		loss of optical activity	methanol	29.4±0.2	28.9±0.2	7±1
		racemization	methanol	29.5±0.2	29 ± 0.2	7±1
		loss of optical activity	acetonitrile	29.5±0.4	28.9±0.4	8±1
p-Cl	Br^-	solvolysis	methanol	23.6±0.4	23.1±0.4	-13±1

Effect of the presence of fluoride ions in the solvolysis of p-chlorobenzylethylmethylsulfonium perchlorate

Racemization rate constants of p-chlorobenzylethylmethylsulfonium perchlorate in 80% water-acetone at 50.00° in presence of sodium fluoride were measured and summarized in Table XXVIII. The rate constants observed for loss of optical activity, $k_{\alpha obs.}$, remained essentially the same with change in concentration of sodium fluoride. Since the presence of the fluoride ions does not affect the rate of racemization of p-chlorobenzylethylmethylsulfonium perchlorate, the suggestion that racemization by way of the formation of a tetracovalent intermediate which may undergo pseudorotation may be discarded in this case as well as for the reaction in the presence of bromide ion. The racemization of p-chlorobenzylethylmethylsulfonium salts are not affected by the nature or nucleophilicity of the associated anion. Racemization is predominantly by the inversion mechanism.

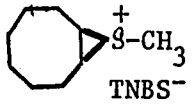
CHAPTER III

NMR STUDIES ON SOME SULFONIUM AND AMMONIUM COMPOUNDS

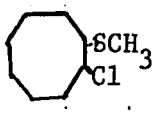
Two recent papers have suggested the intermediacy of tetracovalent sulfur species based on nmr studies.

Helmkamp, Owsley and Rettig(33) studied the reaction of cyclooctene-S-methylepisulfonium 2,4,6-trinitrobenzenesulfonate(XV) with a variety of nucleophilic reagents. The reaction of XV with chloride ion in the presence of cyclohexene gave a quantitative yield of cyclooctene and 1-chloro-2(methylthio)cyclohexene. When equivalent amounts of 0.25 M solutions of XV and tetraphenylarsonium chloride in deuterated nitromethane were mixed at room temperature in an nmr tube, the 60-MHz nmr spectrum, which was immediately recorded at 37°, showed two clearly defined singlets at 122 and 128 Hz downfield from TMS. The upfield singlet was the stronger in intensity immediately after mixing. Seven minutes after mixing, the intensities of the two signals were approximately equal. After 15 minutes, the signal at 122 Hz had disappeared and the resulting spectrum was superimposable on that of 1-chloro-2-(methylthio)cyclooctane(XVI). During the reaction period, signals at 158 Hz corresponding to the methyl group of XV and at 171 Hz for methanesulfenyl chloride could not be detected. Furthermore, no signal could be detected in the olefinic region of the spectrum, a fact which indicates the absence of cyclooctene. When the solution was kept at -5°, the signal at 122 Hz remained for at least 30 minutes. However, the signal disappeared when more chloride ion was added to the solution at -5° or when the solution was warmed to room temperature. The signal at 122 Hz was attributed to the presence of the

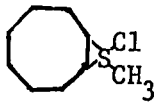
intermediate, 9-chloro-9-methyl-9-thiabicyclo(6. 1. 0)nonane, XVII.



XV

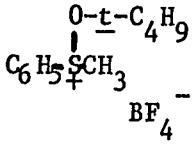


XVI

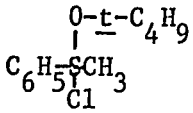


XVII

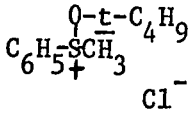
C. R. Johnson and Juan J. Rigau(34) studied the t-butyl hypochlorite oxidation of sulfides to sulfoxides. In the oxidation of methyl phenyl sulfide with t-butyl hypochlorite, a product was obtained whose nmr spectrum differs with the spectrum of methyphenyl-t-butoxy-sulfonium fluoroborate, XVIII. They proposed structure XIX, a tetra-valent sulfur species, rather than XX, an ionic species, for the product. The nmr data are summarized in Table XXXIV.



XVIII



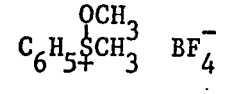
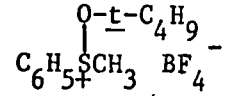
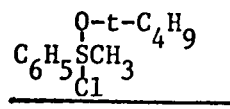
XIX



XX

TABLE XXXIV

NMR SPECTRA OF SOME ALKOXYSULFONIUM SALTS IN CD_2Cl_2.

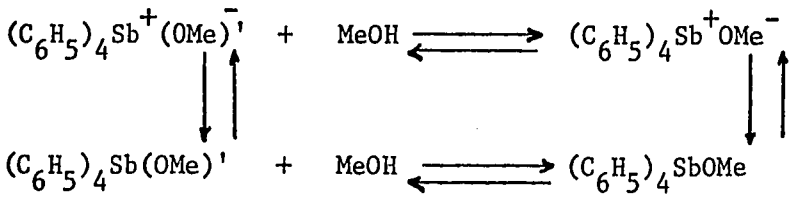
Compound	Temp. °C	δ values, ppm		
		Aryl	S-Methyl	Alkoxy
	37	7.85(m)	3.43	3.86
	-46	8.05(2H, m) 7.75(3H, m)	3.42	1.54
	-46	8.25(2H, m) 7.70(3H, m)	3.78	1.49

The δ values of the S-methyl groups of methylphenyl-t-butoxysulfonium fluoroborate(XVIII) and the proposed intermediate(XIX) differ by 0.36 ppm. Johnson et al.(34) suggested that the differences could not be entirely accounted for by ion pairing phenomena and hence must be due to the formation of stable tetracovalent sulfur species, XIX, rather than the ionic species, XX. However, no experimental justification was given for their assumption that ion pairing phenomena would not account for the difference in the chemical shifts.

Helmkamp et al.(33) concluded using simple Huckel calculations that there is more electron density on the methyl group of the proposed intermediate, 9-chloro-9-methyl-9-thiabicyclo(6.1.0)nonane(XVII) than on the methyl group of cyclooctene-S-methylepisulfonium 2,4,6-trinitrobenzenesulfonate(XV). The S-methyl signal of XVII is 36 Hz(0.6 ppm) upfield from the S-methyl signal of XV which appears at 158 Hz. In contrast, Johnson's data summarized in Table XXXIV show a downfield shift of 0.36 ppm of the S-methyl signal of the proposed intermediate compared to that of methylphenyl-t-butoxysulfonium fluoroborate(XVIII).

A naive approach would predict an upfield shift of the signals if a tetracovalent sulfur species was formed. This prediction is based on the fact that as the charge on the sulfur is changed from a positive value to 0, there is an increase in the electron density around the sulfur atom.

W. E. McEwen et al.(46) studied the reactions of tetraarylstibonium salts with sodium alkoxides. Treatment of tetraphenylstibonium bromide with sodium methoxide in solvent methanol gives methoxytetraphenylantimony which was suggested to be in equilibrium with tetraphenylstibonium methoxide. The equilibria are shown in Equation 19.



Eq. 19

Methoxytetraphenylantimony was isolated as a crystalline compound and had nmr signals associated with the aromatic protons centered at 7.38 ppm and 7.60 ppm. These signals were shifted upfield by 0.57 ppm and 0.35 ppm relative to tetraphenylantimony cation(7.95 ppm). McEwen's data agree with the naive assumption that the signals will be shifted upfield when the charge on the central atom is decreased. However, Johnson's data shown in Table XXXIV are contrary to this assumption. Although the result obtained for the pentavalent antimony compound may not necessary apply to the sulfur compound, it is suggestive that the interpretation advanced by Johnson et al. may not be completely valid.

Previous workers observed ion-pairing phenomena in the reactions of sulfonium salts in solvents of dielectric constants lower than 25. Swain and Kaiser(47) have suggested the participation of ion pairs in the rate determining step in the solvolysis of dimethyl-t-butylsulfonium halides in solvents of low dielectric constant. However, in solvents of dielectric constant $\geq$ 25, ion-pairing phenomena become less important. Conductimetric measurements on the sulfonium salts in 90% acetone-water mixture(ε=25) was carried out by Swain and Kaiser(51) in order to check the possibility of such ion-pairing. They concluded that the agreement between the measured equivalent conductances and those calculated by Onsager equation for strong electrolytes were sufficiently close to preclude the presence of a significant degree of ion-pairing. Jacobsen and Hyne(21) have repeated the conductance study for trimethylsulfonium

iodide in various ethanol-water mixtures using the modified Fuoss method of analysis to determine the degree of ion pairing involved. They concluded that below a dielectric constant of 30, ion pairing was sufficiently significant to be observable as a kinetic effect if the ion pairs participate in a rate-determining step.

Smith et al.(48) studied the nmr spectra of tetra-n-butylammonium chloride, bromide, iodide, perchlorate and picrate in nitrobenzene over the salt concentration range, 0.005-0.25 M. The position of the resonance of the α-methylene protons of the cation was found to be sensitive to the concentration and the nature of the anion. They interpreted the data in terms of ion association and estimated the ion pair dissociation constants for the halide salts from their nmr data. Hence, with these salts, ion pairs formation can cause shifts in the position of the various groups. In solvent nitrobenzene, the positions of resonance of the α-methylene absorption are different for tetra-n-butylammonium bromide and tetra-n-butylammonium perchlorate. Tetra-n-butylammonium bromide with a concentration of 0.23 M has its α-methylene absorption at 220.5 cps(τ6.32) compared with 210.6 cps(τ6.49) of that of a 0.168 M solution of tetra-n-butylammonium perchlorate. The difference in the chemical shifts between the two salts is 0.17 ppm. This chemical shift difference must be associated with ion pairing phenomena and cannot be associated with the formation of neutral addition product since nitrogen cannot expand its octet and become pentavalent.

In this chapter, the nmr spectra of several sulfonium and ammonium salts in a variety of solvents are presented. The effect of changes of temperature, changes of the anion and concentrations of the solution on these nmr spectra are discussed.

Our results will be discussed in the light of the suggestion that tetracovalent sulfur species formed from sulfonium salts may be relatively stable as well as in terms of ion pairing phenomena influencing the nmr spectra of the salts.

RESULTS AND DISCUSSION

Effect of changes of anion in nmr spectra of sulfonium salts

Tables XXXV and XXXVI present the nmr data for p-chlorobenzylethylmethylsulfonium perchlorate and bromide, respectively, in various solvents at the temperature of the probe. In Table XXXVII, a comparison is made between the nmr data for p-chlorobenzylethylmethylsulfonium perchlorate and p-chlorobenzylethylmethylsulfonium bromide. Table XXXVIII shows the differences between the different groups of protons in 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate and bromide.

In Table XXXIX, the nmr data for p-chlorobenzylethylmethylsulfonium perchlorate, fluoroborate and bromide salts are presented. The first two salts show no significant differences in their nmr spectra. However, their nmr spectra are different from that of the sulfonium bromide.

In CD_2Cl_2, the δ values for the $S-CH_3$ protons in the p-chlorobenzylethylmethylsulfonium perchlorate differs by 0.38 ppm from that of the $S-CH_3$ protons in p-chlorobenzylethylmethylsulfonium bromide. For the methylene protons of the ethyl groups, the difference is 0.44 ppm. The greatest difference occurs in the methylene protons of the benzyl groups, a difference of 0.83 ppm. The midpoint of the multiplet corresponding to the aromatic protons of the bromide salt appears at τ2.41 while the

TABLE XXXV

NMR SPECTRA OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE IN A VARIETY OF SOLVENTS AT THE TEMPERATURE OF THE PROBE.

Run	Solvent	ε[a]	solvent	τ values -C-CH_3 (t, J=7.5cps)	S-CH_3 (s)	S-CH_2-C (q, J=7.5cps)	ArCH_2- (s)	Aromatic protons
IV-111-A-1	CD_2Cl_2	9.08(20)[48]	4.59-4.68(m)	8.52	7.13	6.61	5.28	2.54(s)
IV-111-A-2	CD_3NO_2	35.9(30)[49]	5.55-5.75(m)	8.48	7.13	6.62	5.34	2.46(s)
IV-52-B-1	CD_3CN	36.2(25)[49]	7.95-8.18(m) 7.75(s)	8.63	7.29	6.76	5.46	2.53(s)
IV-51-A-1	90%CD_3COCD_3 - D_2O	25.3(25)[50]	8.28-8.54(m) 6.78(s)	8.98	7.52	7.0	5.64	2.58-3.08(m)
II-260-A-Nmr-422	DMSO-d_6	46.6(25)[49]	7.36-7.62(m) 6.68(s)	8.65	7.2	6.72	5.3	2.42(s)

a). Dielectric constant, the number in parenthesis is the temperature for the quoted dielectric constant. The dielectric constants are for undeuterated solvents.

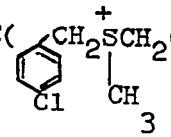
TABLE XXXVI

NMR SPECTRA OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE IN A VARIETY OF SOLVENTS AT THE TEMPERATURE OF THE PROBE.

Run	Solvent	ε[a]	Solvent	τ values				
				$-C-CH_3$ (t,J=7.5cps)	$S-CH_3$ (s)	$S-CH_2-C$ (q,J=7.5cps)	$ArCH_2$ (s)	Aromatic protons
III-165-A -Nmr-476	$CDCl_3$	4.8(20)[48]	none	8.53	6.77	6.15	4.51	2.08-2.75(m)
IV-110-A-2	CD_2Cl_2	9.08(20)[48]	4.58-4.67(m)	8.58	6.75	6.17	4.45	2.07-2.75(m)
IV-110-A-4	CD_3NO_2	35.9(30)[49]	5.49-5.74(m)	8.51	6.9	6.31	4.76	2.05-2.64(m)
IV-52-A-1 (0.51 M)	CD_3CN	36.2(25)[49]	7.85-8.16(m) 7.45(s)	8.62	7.02	6.44	4.89	2.17-2.42(m)
IV-51-B-1 (0.52 M)	90%CD_3COCD_3-D_2O	25.3(25)[50]	8.25-8.45(m) 6.67(s)	8.96	7.24	6.80	5.33	2.46-3.04(m)
III-252-Nmr-517	DMSO-d_6	46.6(25)[49]	7.4-7.62(m) 6.75(s)	8.68	7.17	6.71	5.22	2.34-2.6(m)
III-250-Nmr-501 (external standard)	D_2O	78.25(25)[48]	5.42(s)	8.57	7.3	6.8	5.46	2.6(s)

a). Dielectric constant, the number in parenthesis is the temperature for the quoted dielectric constant. The dielectric constants are for undeuterated solvents except for D_2O.

TABLE XXXVII

A COMPARISON OF THE NMR SPECTRA OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE AND BROMIDE( X-) IN A VARIETY OF SOLVENTS AT THE TEMPERATURE OF THE PROBE.

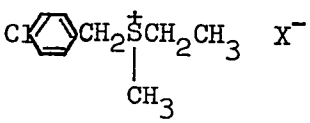
Run	Solvent	X^-	τ values: Solvent peak	S-C-CH_3 (t,J=7.5cps)	S-CH_3 (s)	S-CH_2-C (q,J=7.5cps)	ArCH_2- (s)	Aromatic protons
IV-110-A-2	CD_2Cl_2	Br	4.58-4.67(m)	8.58	6.75	6.17	4.45	2.07-2.75(m)
IV-111-A-1	CD_2Cl_2	ClO_4	4.59-4.68(m)	8.52	7.13	6.61	5.28	2.54(s)
IV-52-A-1	CD_3CN (0.51 M)	Br	7.85-8.16(m) 7.45(s)	8.62	7.02	6.44	4.89	2.17-2.42(m)
IV-52-B-1	CD_3CN (0.50 M)	ClO_4	7.95-8.18(m) 7.75(s)	8.63	7.29	6.76	5.46	2.53(s)
IV-51-B-1	90%CD_3COCD_3 -D_2O (0.52 M)	Br	8.25-8.45(m) 6.67(s)	8.96	7.24	6.80	5.33	2.46-3.04(m)
IV-51-A-1	90% CD_3COCD_3 -D_2O (0.51 M)	ClO_4	8.28-8.54(m) 6.78(s)	8.98	7.52	7.0	5.64	2.58-3.08(m)
III-252-Nmr -517	DMSO-d_6	Br	7.4-7.62(m) 6.75(s)	8.68	7.17	6.71	5.22	2.34-2.6(m)
II-260-A -Nmr-422	DMSO-d_6	ClO_4	7.36-7.62(m) 6.68(s)	8.65	7.2	6.72	5.3	2.42(s)
IV-110-A-4	CD_3NO_2	Br	5.49-5.74(m)	8.51	6.9	6.31	4.76	2.05-2.64(m)
IV-111-A-2	CD_3NO_2	ClO_4	5.55-5.75(m)	8.48	7.13	6.62	5.34	2.46(s)

TABLE XXXVIII

A COMPARISON OF THE NMR SPECTRA OF 3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE AND BROMIDE($3,5\text{-di}CH_3\text{-}4\text{-}OCH_3C_6H_2CH_2\overset{+}{S}(CH_3)CH_2CH_3\ X^-$) IN A VARIETY OF SOLVENTS AT THE TEMPERATURE OF THE PROBE.

Run	Solvent	X^-	τ values						
			Solvent peak	$S\text{-}C\text{-}CH_3$ (t,J=7.5cps)	$ArCH_3$ (s)	$S\text{-}CH_3$ (s)	$S\text{-}CH_2\text{-}C$ (q,J=7.5cps)	$O\text{-}CH_3$ (s)	$ArCH_2$ (s)	Aromatic protons
III-77-Nmr-519	$CDCl_3$	Br	none	8.53	7.74	6.8	6.18	6.27	4.75	2.58-2.76(m)
II-240-Nmr-412	$CDCl_3$	ClO_4	none	8.53	7.73	7.13	6.6	6.27	5.4	2.8(s)
IV-112-A-1	CD_2Cl_2	Br	4.64-4.74(m)	8.57	7.75	6.85	6.29	6.3	4.82	2.75(s)
IV-113-A-1	CD_2Cl_2	ClO_4	4.65-4.74(m)	8.56	7.75	7.2	6.67	6.31	5.44	2.85(s)
III-77-Nmr-520	DMSO-d_6	Br	7.41-7.63(m)	8.67	7.76	7.14	6.63	6.34	5.26	2.8(s)
III-80-Nmr-518	DMSO-d_6	ClO_4	7.42-7.59(m)	8.67	7.75	7.23	6.75	6.33	5.45	2.85(s)

TABLE XXXIX

A COMPARISON OF THE NMR SPECTRA OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM BROMIDE, FLUOROBORATE, AND PERCHLORATE( X^-) IN CD_2Cl_2 AT -40°.

Run	[Salt] (M)	X^-	τ values: CD_2Cl_2 (m)	S-C-CH_3 (t, J=7.5cps)	S-CH_3 (s)	S-CH_2-C (q, J=7.5cps)	ArCH_2 (s)	Aromatic protons
IV-81-A	0.25	Br	4.57[a]	8.57	6.77	6.19	4.44	2.05-2.77(m)
IV-87-A	0.19	BF_4	4.52-4.65	8.55	7.19	6.7	5.34	2.52(s)
IV-89-A	0.38	ClO_4	4.51-4.67	8.52	7.14	6.64	5.29	2.5(s)

a). The CD_2Cl_2 peak overlaps with the methylene protons of the benzyl group, therefore the τ value at the midpoint of the multiplet is given.

singlet for the aromatic protons of the perchlorate salt is at τ2.54, the difference is 0.13 ppm. The smallest difference is observed in the methyl protons of the ethyl groups attached to the sulfur, they differ by 0.06 ppm.

In CD_3NO_2, the same trend is observed, but the difference in chemical shifts are smaller: $ArCH_2$(0.58) > S-CH_2-C(0.31) > S-CH_3(0.23) > aromatic protons(0.11) > S-CH_3(0.01). The numbers in the parentheses are the differences in ppm between the perchlorate and bromide salts. The signals for the bromide salt appear at lower field. Hereafter, all differences in ppm will be represented by numbers in parentheses. The dielectric constant of nitromethane is 35.9 at 30° compared to 9.08 at 20° for methylene chloride. It is clear that increasing the dielectric constants which should increase the dissociation constants reduces the chemical shift differences.

In CD_3CN, the same trend of differences between the nmr spectra of the perchlorate and bromide salts is again observed: $ArCH_2$(0.57) > S-CH_2-C(0.32) > S-CH_3(0.27) > aromatic protons(0.23) > S-CH_3(0.01). The chemical shifts differences between the signals for the perchlorate and the bromide salts have almost the same values as in CD_3NO_2. In agreement with this observation, the dielectric constant of acetonitrile is 36.2 at 25° compared to 35.9 at 30° for nitromethane.

In 90% CD_3COCD_3-D_2O, the differences between the nmr spectra of the perchlorate and the bromide salt are as follows: $ArCH_2$(0.31) > S-CH_3(0.28) > S-CH_2-C(0.2) > aromatic protons(0.08) > S-C-CH_3(0.02). In this solvent, the difference is greater between the S-CH_3 protons than between the S-CH_2-C protons.

As the dielectric constant of the solvent becomes much larger,

the differences of the chemical shifts of the signals corresponding to the perchlorate and the bromide salts become very small. This can be seen in the runs in DMSO-d_6: III-252-Nmr-517 and II-260-A-Nmr-422 in Table XXXVII, where the largest chemical shift difference is less than 0.1 ppm.

The chemical shifts of the different groups of protons in 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate also differ from the 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium bromide as shown in Table XXXVIII. No significant differences are observed in the groups not attached directly to the sulfur atom. The two aromatic methyl groups and the methoxy group in both salts show chemical shifts which are the same within experimental errors. However, large chemical shifts differences are observed in groups attached to the asymmetric center, namely: $ArCH_2$-S, S-CH_2-C and S-CH_3.

In $CDCl_3$, the greatest difference in chemical shifts between 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate and bromide is again observed in the methylene protons of the benzyl groups. The difference is 0.65 ppm. The methylene protons of the ethyl groups differ by 0.42 ppm. The S-CH_3 groups differ by 0.33 ppm. The midpoint of the multiplet peak corresponding to the aromatic protons of the bromide appears at τ2.67 while the singlet peak for the aromatic protons of the perchlorate is at τ2.8, the difference is 0.13 ppm.

In CD_2Cl_2, the differences in chemical shifts between the 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate and bromide are as follows: $ArCH_2$(0.62) > S-CH_3(0.45) > S-CH_2-C(0.38) > aromatic protons(0.10). In contrast to $CDCl_3$, the difference between the S-CH_3 groups in this solvent is greater than the difference between the S-CH_2-C groups.

In DMSO-d_6, small differences in the chemical shifts can

still be observed: $ArCH_2$(0.19) > S-CH_3(0.09) > S-CH_2-C(0.08) > aromatic protons(0.05).

Once again, the differences in the chemical shifts was found to become greater as the dielectric constant of the solvent decreases, this is consistent with a greater degree of association of the ions.

Whenever there is a difference in the chemical shift, the signal for the protons in bromide salts always occur at a lower field than those for the perchlorate salts. It is clear from these data that the sulfonium salts behave in a manner quite analogous to that observed by Johnson et al.(34).

Smith et al.(48) have studied the nmr spectra of various tetra-n-butylammonium salts. They interpreted their results in terms of ion association and estimated the ion pair dissociation constants for the halide salts.

In the next section, results of studies of various quaternary ammonium salts will be discussed.

Effect of changes of anion on the nmr spectra of some quaternary ammonium salts.

In Table XL, a summary of the nmr data for a number of tetra-n-butylammonium salts in solvent methylene chloride is presented. The differences in chemical shifts between the perchlorate and the trinitrobenzenesulfonate salts are very small, the largest difference in the chemical shifts is less than 0.1 ppm. However, the nmr spectra of these two compounds differ from that of the bromide. The following differences between the perchlorate and the bromide are observed: C-C-C-CH_2-N(0.15) > $CH_3CH_2CH_2$-C-N(0.04). The differences are smaller than those for the sulfonium salts. Under the same conditions, the chemical shift difference

TABLE XL

NMR SPECTRA OF TETRA-n-BUTYLAMMONIUM SALTS[$(CH_3CH_2CH_2CH_2)_4N^+ X^-$] IN CD_2Cl_2 AT THE TEMPERATURE OF THE PROBE.

Run	[Salt] (M)	X^-	τ values: $CH_3CH_2CH_2C$-N- (m)	τ values: C-C-C-CH_2-N (m)	τ values: Solvent peak (m)
IV-34-A-1	0.44	ClO_4	8.0-9.22	6.55-7.0	4.62-4.71
IV-34-A-2	0.27	TNB	8.05-9.26	6.58-7.03	4.58-4.62
IV-34-A-3	0.47	Br	7.92-9.21	6.35-6.9	4.55-4.65

between the S-CH_2-C groups in p-chlorobenzylethylmethylsulfonium perchlorate and bromide is 0.44 ppm which is about three times larger than the chemical shift difference between the C-C-C-CH_2-N groups in tetra-n-butylammonium perchlorate and bromide. One factor which will tend to make the chemical shifts differences between the quaternary ammonium salts smaller is that the negative ion is sterically hindered from getting close to the four bulky n-butyl groups. It cannot be in equidistant from all of them at the same time. The values of the chemical shifts of the different groups of protons of tetra-n-butylammonium bromide are the average values resulting from tumbling of the two ions with respect to one another.

Benzyltrimethylammonium halides also show differences in their nmr spectra compared to benzyltrimethylammonium perchlorate. Table XLI gives the comparison between the nmr spectra of the benzyltrimethylammonium salts in several solvents at the temperature of the probe. The δ values of the benzyl methylene protons of the chloride and the perchlorate salts in CD_3NO_2 differ by 0.29 ppm whereas for the bromide and the perchlorate salts in 90% CD_3COCD_3-D_2O, the difference is 0.15 ppm.

As with the bromide and perchlorate salts of the sulfonium compounds, differences in nmr spectra were found for the halide and perchlorate salts of tetra-n-butylammonium and benzyltrimethylammonium compounds. In the case of the quaternary ammonium salts, these differences cannot be attributed to the formation of the covalent N-X bond, since ammonium compounds are not capable of forming pentacovalent intermediates. However, the ammonium salts can exist as ion pairs in solution. Since a quantitative but not a qualitative difference between the sulfonium and ammonium salts was found, ion pairing phenomena cannot be ruled out *a priori* in accounting for the nmr spectra of sulfonium salts.

TABLE XLI

A COMPARISON OF NMR DATA OF BENZYLTRIMETHYLAMMONIUM SALTS IN A VARIETY OF SOLVENTS AT THE TEMPERATURE OF THE PROBE. ($\phi CH_2\overset{+}{N}(CH_3)_3\ X^-$)

Run	X^-	[Salt] (M)	Solvent	τ values: Solvent peak	$\overset{+}{N}(CH_3)_3$ (s)	$-CH_2-\overset{+}{N}$ (s)	Aromatic protons
IV-117-A	ClO_4	0.35	CD_3NO_2	5.59-5.79(m)	6.84	5.47	2.43(s)
IV-117-B	Cl	0.17	CD_3NO_2	5.69(m)	6.74	5.18	2.25-2.59(m)
IV-46-A-2	Br	0.52	90%CD_3COCD_3 -D_2O	7.89(m, CD_3COCD_3)		5.12	2.03-2.62(m)
				6.22(s, D_2O)	6.66		
IV-46-B-2	ClO_4	0.52	90%CD_3COCD_3 -D_2O	7.9(m, CD_3COCD_3)	6.73	5.27	2.35(broad singlet with small splittings).
				6.3(s, D_2O)			

The question of whether sulfonium salts exist as tetracovalent species or as ion pairs in solution was further investigated by studying the nmr spectra of mixtures of various sulfonium salts.

Nmr spectra of mixtures of the sulfonium salts

Mixtures of p-chlorobenzylethylmethylsulfonium perchlorate and bromide and of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate and bromide were prepared. The nmr data obtained for these mixtures are presented in Tables XLII and XLIII.

Each mixture gave only one set of signals corresponding to a value intermediate between those of the two components. Each set of signal was shifted upfield with respect to the signals for the bromide and downfield with respect to the signals for the perchlorate salt. These results are consistent with rapid exchange between the ions resulting in new resonance signals with the values of the chemical shifts intermediate between those of the two components.

If the sulfonium bromide is best represented by the tetravalent sulfur species, XXI, then the downfield shift of the signals for p-chlorobenzylethylmethylsulfonium perchlorate and the upfield shift of the signals for p-chlorobenzylethylmethylsulfonium bromide can be rationalized only if the tetracovalent intermediate, XXI, undergoes exchange with the p-chlorobenzylethylmethylsulfonium perchlorate faster than the time average of nuclear relaxation as illustrated in the scheme shown in Equation 20. Alternatively, the tetravalent species must undergo rapid reversible ionization to yield ionic species which then undergo exchange with the sulfonium perchlorate.

TABLE XLII

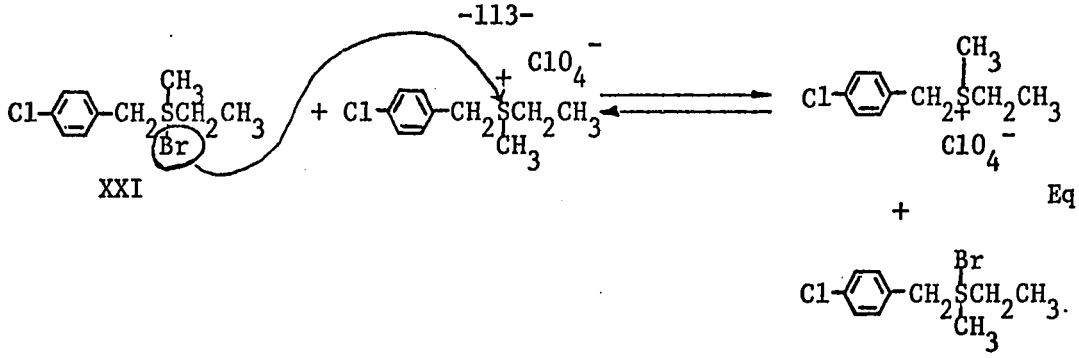
NMR SPECTRA OF MIXTURES OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM PERCHLORATE AND BROMIDE AT THE TEMPERATURE OF THE PROBE IN A VARIETY OF SOLVENTS.

Run	Solvent	[Sulfonium perchlorate] (M)	[Sulfonium bromide] (M)	τ values					
				Solvent peak	$S-C-CH_3$ (t, J =7.5cps)	$S-CH_3$ (s)	$S-CH_2-C$ (q, J =7.5cps)	$ArCH_2-$ (s)	Aromatic protons
IV-32-B	CD_2Cl_2	0.24	0.3	4.62-4.73(m)	8.58	7.0	6.45	4.92	2.25-2.76
IV-32-A	CD_3CN	0.25	0.26	7.92-8.2(m) 7.59(s)	8.64	7.16	6.6	5.17	2.25-2.67

TABLE XLIII

NMR SPECTRA OF MIXTURES OF 3,5-DIMETHYL-4-METHOXYBENZYLETHYLMETHYLSULFONIUM PERCHLORATE AND BROMIDE AT THE TEMPERATURE OF THE PROBE IN A VARIETY OF SOLVENTS.

Run	Solvent	[Sulfonium perchlorate] (M)	[Sulfonium bromide] (M)	τ values							
				Solvent peak	$-C-CH_3$ (t, J =7.5cps)	$ArCH_3$ (s)	$S-CH_3$ (s)	$-CH_2-C$ (q, J =7.5 cps)	$O-CH_3$ (s)	$ArCH_2$ (s)	Aromatic protons
IV-33-A	CD_2Cl_2	0.22	0.23	4.65-4.73(m)	8.58	7.77	7.05	6.49	6.32	5.15	2.8
IV-33-B	CD_3CN	0.22	0.22	7.89-8.17(m)	8.63	7.75	7.21	6.66	6.32	5.36	2.8



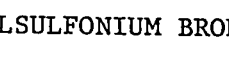
XXI

Eq. 20

The nmr studies of mixtures of benzylmethylethoxysulfonium fluoroborate and p-chlorobenzylethylmethylsulfonium bromide showed that they behave in the same manner as the mixture of p-chlorobenzylethylmethylsulfonium perchlorate and bromide.

Table XLIV summarizes the nmr data of mixtures of benzylmethylethoxysulfonium fluoroborate and p-chlorobenzylethylmethylsulfonium bromide in CD_2Cl_2 at -40°. For this mixture, the chemical shifts of the different groups of protons corresponding to the p-chlorobenzylethylmethylsulfonium salts were compared with Run IV-81-A in Table XXXIX which gives the nmr spectrum of pure p-chlorobenzylethylmethylsulfonium bromide in the same solvent and at the same temperature. The nmr spectra of the mixtures had signals corresponding to the methylene groups and S-CH_3 group of the sulfonium salt which were shifted upfield relative to the nmr spectra of the pure p-chlorobenzylethylmethylsulfonium bromide. The amount of upfield shift is inversely proportional to the mole per cent of the p-chlorobenzylethylmethylsulfonium bromide in the various mixtures. The mole per cent of sulfonium bromide in the mixtures recorded in Table XLIV are as follows: IV-82-A(36%) < IV-85-A(50%) < IV-82-B(66%). The signals for the methylene protons of the benzyl group in p-chlorobenzylethylmethylsulfonium bromide in the mixture is shifted upfield as follows: IV-82-A(0.67) > IV-85-A(0.52) > IV-82-B(0.45). The signals for the S-CH_3 protons in the mixture is also shifted as follows: IV-82-A(0.37) > IV-85-A(0.26) > IV-82-B(0.17). The numbers in parentheses

TABLE XLIV

NMR SPECTRA OF MIXTURES OF BENZYLMETHYLETHOXYSULFONIUM FLUOROBORATE($\phi CH_2\overset{+}{S}(OCH_2CH_3)CH_3\ BF_4^-$) and p-CHLORO-BENZYLETHYLMETHYLSULFONIUM BROMIDE() IN CD_2Cl_2 AT VARIOUS TEMPERATURES.

Run	$\phi CH_2\overset{+}{S}(OCH_2CH_3)CH_3\ BF_4^-$ (M)	Br^- (M)	Temp (°C)	CD_2Cl_2	τ values: O-C-CH_3 (t, J=7cps)	-C-CH_3 (t, J=7cps)	p-Cl S-CH_3 (s)	S-CH_3 (s)	-O-CH_2-C (m)	ϕCH_2 (d, J=14cps)	p-Cl ϕCH_2- (s)	Aromatic protons (m)
IV-82-A	0.25	0.14	-40	4.59	8.82	8.53	7.09	6.51	5.49-6.84			
										5.31	4.51	5.11 2.15-2.77
IV-82-A_2[a]	0.25	0.14	25	4.66	8.78	8.56	7.12	6.62	5.57-6.8			
										5.29	4.65	5.18 2.22-2.79
IV-82-B	0.13	0.25	-40	4.59	8.86	8.55	6.94	6.39	5.54-6.66			
										5.27	4.22	4.89 2.05-2.73
IV-85-A	0.19	0.19	-40	4.6	8.86	8.57	7.03	6.47	5.53-6.77			
										5.31	4.37	4.97 2.13-2.75
IV-62-D	0.23	0.25	-40	4.57	8.82	8.54	7.0	6.44	5.52-6.79			
										5.28	4.35	4.96 2.11-2.69
IV-62-D_2[b]	0.23	0.25	25	4.69	8.8	8.58,8.37	7.15	6.68	5.43-6.6			
									8		4.72	5.24 2.32-2.79

a). This run was taken after allowing the solution for Run IV-82-A to stand at room temperature for about a day, nmr for this run shows extra peaks at τ7.54 and 7.99 compared to Run IV-82-A. b). This run was taken after allowing the solution for Run IV-62-D_2 to stand at room temperature for about a day, nmr for this run shows extra peaks at τ7.55 and 7.99.

are the upfield shifts in ppm.

For benzylmethylethoxysulfonium salts in the mixtures, the different groups of protons are shifted downfield as compared to Run IV-80-B(Table XLV) which gives the nmr data for benzylmethylethoxysulfonium fluoroborate in the same solvent at the same temperature. The amount of the downfield shift is inversely proportional to the mole per cent of benzylmethylethoxysulfonium fluoroborate in the different mixtures. The mole per cent of benzylmethylethoxysulfonium fluoroborate are as follows: IV-82-B(34%) < IV-85-A(50%) < IV-82-A(64%). The signal for the S-CH_3 protons is shifted downfield as follows: IV-82-B(0.37) > IV-85-A(0.29) > IV-82-A(0.25). The doublets corresponding to the methylene protons of the benzyl groups are shifted downfield in a similar manner: IV-82-B (0.14, 0.73) > IV-85-A(0.10, 0.58) > IV-82-A(0.10, 0.44).

The validity of the scheme represented by Equation 20 was investigated by studying the nmr spectra of mixtures of quaternary ammonium and sulfonium salts. Since the quaternary ammonium salts can not form pentacovalent intermediates, studying the nmr spectra of a mixture of sulfonium bromide and quaternary ammonium perchlorate will indicate whether Equation 20 holds or not. If the sulfonium bromide forms a stable tetracovalent sulfur species which gives exchange only by the type of process shown in Equation 20, then no exchange should be observed when the sulfonium bromide and quaternary ammonium perchlorate are mixed. Exchange could occur on mixing sulfonium perchlorate and quaternary ammonium bromide.

Nmr spectra of mixtures of quaternary ammonium salts with sulfonium salts

Table XLV shows a comparison of the nmr spectra for mixtures of p-chlorobenzylethylmethylsulfonium salts and tetra-n-butylammonium

TABLE XLV

NMR SPECTRA OF MIXTURES OF p-CHLOROBENZYLETHYLMETHYLSULFONIUM SALTS(Cl-C$_6$H$_4$-CH$_2$-$\overset{+}{S}$(CH$_3$)-CH$_2$CH$_3$ X^-, 0.19 M) AND TETRA-n-BUTYLAMMONIUM SALTS[$(CH_3CH_2CH_2CH_2)_4\overset{+}{N}$ Y^-, 0.19 M) IN CD_2Cl_2 AT -40°.

Run	X^-	Y^-	CD_2Cl_2 (m)	τ values: $CH_3CH_2CH_2$-C-N (m)	CH_3-C-C-CH_2-N (m)	$S-CH_2C$ (q)	$ArCH_2$ (s)	Aromatic protons (m)
IV-86-B	Br	ClO_4	4.60	7.99-9.49	6.52-7.19	6.29 (J=7.5cps)	4.7	2.14-2.74
IV-88-A	Br	ClO_4	4.55	8.01-9.48	6.54-7.11	6.27 (J=7.5cps)	4.68	2.08-2.74
IV-86-A	ClO_4	Br	4.63	8.07-9.49	6.56-7.16	6.36 (J=8cps)	4.73	2.13-2.74

a). The τ values given for the solvent peak are those of the center of the multiplets, the whole ranges of the multiplets could not be taken, since they overlap with the methylene protons of the benzyl groups.

salts. Runs IV-86-B and IV-88-A contain mixtures of p-chlorobenzylethylmethylsulfonium bromide with tetra-n-butylammonium perchlorate. The signals corresponding to the sulfonium salts in the mixture were compared with Run IV-81-A in Table XXXIX which gives the nmr spectrum of p-chlorobenzylethylmethylsulfonium bromide in CD_2Cl_2 at -40°. Relative to Run IV-81-A, the methylene protons of the benzyl groups are shifted upfield by 0.23 ppm and 0.26 ppm in Runs IV-86-B and IV-88-A respectively. The methylene protons of the ethyl groups were shifted upfield by 0.07 ppm and 0.1 ppm, respectively. Run IV-86-A in Table XLV shows the nmr spectra of a mixture of p-chlorobenzylethylmethylsulfonium perchlorate and tetra-n-butylammonium bromide. The signals for the sulfonium salts in the mixture were compared with Run IV-89-A in Table XXXIX which gives the nmr spectrum of pure p-chlorobenzylethylmethylsulfonium perchlorate. A downfield shift of 0.61ppm(using TMS as standard) or 0.65 ppm(using the solvent as standard) for the methylene protons of the benzyl group was observed. The signals for the methylene protons of the ethyl group are also shifted downfield by 0.24 ppm(using TMS as standard) or 0.28 ppm(using the solvent as standard). The C-C-C-CH_2-N signal for tetra-n-butylammonium bromide which overlaps with S-CH_3 signal for the sulfonium perchlorate appears at τ6.56-7.16. This is shifted upfield compared to Run IV-34-A-3 (Table XL) where C-C-C-CH_2-N signal appears at τ6.35-6.9.

The δ values of the chemical shifts of $ArCH_2$-S and S-CH_2-C protons clearly show that in the mixture of p-chlorobenzylethylmethylsulfonium bromide with tetra-n-butylammonium perchlorate, there is an upfield shift of the set of signals relative to pure p-chlorobenzylethylmethylsulfonium bromide. This behavior is analogous to what was observed for mixtures of sulfonium bromide and perchlorate and for mixtures of sulfonium bromide and alkoxysulfonium fluoroborate. The nmr

spectra of samples prepared from either p-chlorobenzylethylmethylsulfonium bromide and tetra-n-butylammonium perchlorate or from p-chlorobenzylethylmethylsulfonium perchlorate and tetra-n-butylammonium bromide are identical within the accuracy of the measurements. An identical mixture must be produced in the solution regardless of which pair of salts was used to prepare the mixture. Exchange by the type of process shown in Equation 20 could be observed on mixing sulfonium perchlorate and quaternary ammonium bromide. Such an exchange process can not occur with the quaternary ammonium perchlorate and sulfonium bromide. Since identical behavior was observed with both mixtures, this rules out the scheme where a tetravalent sulfur intermediate is formed and undergoes rapid exchange with the perchlorate salt as shown in Equation 20.

The results are consistent with rapid exchange of ion pairs formed in the solution. If a covalent intermediate is present in the solution, it must be in rapid reversible equilibrium with the ion pairs which can undergo exchange.

Effect of concentration on the nmr spectra of sulfonium salts

Table XLVI presents the nmr spectra of various sulfonium perchlorates and bromides in a variety of solvents at the temperature of the probe. For the perchlorate salts, over a ten-fold change in concentration from 0.5 M to 0.05 M in solvents CD_2Cl_2 and CD_3CN, the nmr spectra show no significant differences as can be seen by comparing the first three runs in Table XLVII with Run IV-113-A-1 in Table XXXVIII, Run IV-111-A-1 in Table XXXV and Run IV-52-B-1 in Table XXXVI, respectively.

TABLE XLVI

NMR SPECTRA OF DILUTE SOLUTIONS OF SULFONIUM PERCHLORATES AND BROMIDES IN A VARIETY OF SOLVENTS AT THE TEMPERATURE OF THE PROBE.

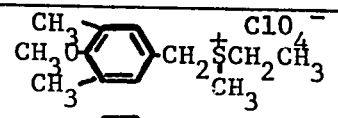
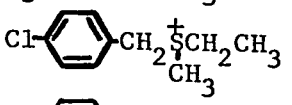
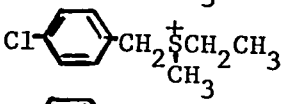
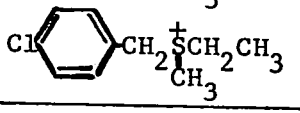
Run	Solvent	Compound	Concentration (M)	Solvent peak	τ values S-C-CH_3 (t, J =7.5cps)	S-CH_3 (s)	S-CH_2-C (q, J =7.5cps)	$ArCH_2$	Aromatic protons
IV-38-B	CD_2Cl_2		0.05	4.62-4.69(m)	8.51	7.16	6.66	5.43(s)	2.84(s)
IV-38-A-1'	CD_2Cl_2		0.05	4.65-4.72(m)	8.56	7.17	6.65	5.3 (s)	2.53(s)
IV-38-A-2	CD_3CN		0.05	8.02-8.22(m) 7.94(s)	8.64	7.36	6.83	5.53 (split s)	2.51 (split s)
IV-38-B-3	CD_3CN		0.05	7.92-8.19(m) 7.89(s)	8.66	7.11	6.6	5.1(s)	2.3-2.63(m)

TABLE XLVII

NMR SPECTRA OF BENZYLMETHYLETHOXYSULFONIUM FLUOROBORATE(0.25 M) IN CD_2Cl_2 AT VARIOUS TEMPERATURES.

Run	Temp. (°C)	CD_2Cl_2 (m)	τ values O-C-CH_3 (t, J=7cps)	S-CH_3 (s)	S-CH_2-C (m)	ϕCH_2 (d, J=14cps)		Aromatic protons (s)
IV-80-A	+42	4.57-4.72	8.78	6.77	5.56-6.11	5.4	4.95	2.49
IV-80-B	-40	4.52-4.67	8.83	6.76	5.61-6.18	5.41	4.95	2.49
IV-80-C	-80	4.46-4.71	8.86	6.73	5.61-6.26	5.42	4.94	2.46

For the bromide salts, a ten-fold decrease in concentration in solvent CD_3CN, shifted the signal corresponding to the methylene protons of the benzyl group by 0.21 ppm upfield. The $S-CH_2-C$ signal was shifted upfield by 0.16 ppm and the signal for the $S-CH_3$ group was shifted upfield by 0.09 ppm. The upfield shifts were calculated by comparing Runs IV-52-A-1(Table XXXVI) and IV-38-B-3(Table XLVI). The concentrations of p-chlorobenzylethylmethylsulfonium bromide for these two runs were 0.5M and 0.05M, respectively.

As shown in Runs IV-38-A-2 and IV-38-B-3 in Table XLVI, the benzyl methylene group in p-chlorobenzylethylmethylsulfonium bromide has its chemical shift 0.43 ppm downfield from the corresponding group in the perchlorate salt at 0.05 M concentration, whereas this difference is 0.85 ppm at 0.5 M concentration (Runs IV-81-A and IV-89-A in Table XXXIX). These data indicate that as the concentration of the salts is lowered, the differences between the spectra of the sulfonium bromide and perchlorate become smaller.

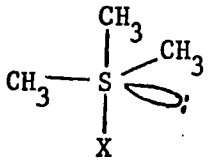
Effect of temperature on the nmr spectra of sulfonium salts

In Table XLVII are reported nmr data of benzylmethylethoxysulfonium fluoroborate in CD_2Cl_2 at various temperatures. No significant differences in the nmr spectra was observed with changes of temperature from -80^o to -40^o to the temperature of the probe which is about 40^o. Similar behavior was found for p-chlorobenzylethylmethylsulfonium bromide and perchlorate as can be seen by comparing the data summarized for Runs IV-81-A and IV-89-A in Table XXXIX with Runs IV-110-A-2 and IV-111-A-1

in Table XXXVII.

Nmr spectra of trimethylsulfonium salts

Attempts to investigate the formation of tetracovalent sulfur species,XXII, were made by studying the nmr spectra of trimethylsulfonium bromide and perchlorate in a variety of solvents at 0°, -40° and $-80^{\circ}C$. If a tetracovalent sulfur species were formed, two signals in the nmr spectra corresponding to the apical and equatorial methyl groups should be observed by freezing the salt in one conformation and stop pseudorotation. This may be achieved by taking the nmr spectra at a low enough temperature. Only one signal for the three methyl groups, a singlet at $\tau 7.5$ was observed at ambient temperature. For only one signal to be observed means that either of three situations prevail: (i). Both equatorial and apical groups show the same chemical shift. (ii). Pseudorotation is rapid and equilibrates the groups. (iii). The salt is not best described as a stable tetravalent sulfur species. The nmr spectra of the salt in liquid SO_2 at 0°, -40° and $-80^{\circ}C$ showed only one signal for the methyl groups.



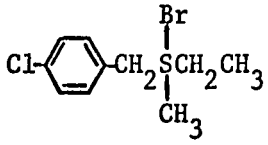
XXII

CONCLUSION

Quaternary ammonium salts have been shown to exhibit specificities in their nmr spectra as the negative ion is changed in a manner analogous to the specificities observed with sulfonium salts. Since these changes must be associated with ion pair phenomena for the quaternary ammonium salts, similar phenomena could account for the behavior of sulfonium salts.

Formation of a tetracovalent sulfur intermediate, XXI, which may then undergo rapid exchange with the perchlorate salt as shown in Equation 20 was ruled out. The basis for ruling out the scheme shown in Equation 20 was the analogous behavior exhibited by mixtures of tetra-n-butylammonium perchlorate and p-chlorobenzylethylmethylsulfonium bromide compared with mixtures of tetra-n-butylammonium bromide and p-chlorobenzylethylmethylsulfonium perchlorate. Analogous behavior was also exhibited by mixtures of sulfonium bromide and perchlorate as well as mixtures of alkoxysulfonium fluoroborate and sulfonium bromide.

Our results are consistent with the formation of ion pairs in solution, which can then undergo rapid exchange. If a tetracovalent intermediate were present in solution, it must be in rapid reversible equilibrium with the ion pairs which can then undergo rapid exchange.



XXI

EXPERIMENTAL

Physical measurements:

All melting points were obtained using a Hershberg type melting point apparatus with a set of Anschutz thermometers. All values are uncorrected.

Refractive indices were obtained on a Bausch and Lomb Abbe 3L Refractometer thermostated at 25°.

Nuclear magnetic resonance spectra were recorded using Varian Analytical Nmr Spectrophotometers, Model A-60 with a probe temperature of 33° and A-56-60-A with a probe temperature of 42°. The latter model was also used for low temperature runs. A Varian Analytical Spectrophotometer Model HA-100 was used for recording nmr spectra of solutions of low concentration.

Infrared spectra were recorded on a Perkin-Elmer Grating Infrared Spectrophotometer Model 421.

Ultraviolet spectra were recorded on a Perkin-Elmer Ultraviolet-Visible Spectrophotometer Model 202 and Cary Recording Spectrophotometer Model 14 M.

Optical rotation measurements were obtained using a Perkin-Elmer Polarimeter, Model 141. Kinetic analyses were carried out using incident light having wavelengths of 436 and 365 mμ.

Gas chromatographic analyses were made using a Perkin-Elmer Model 154D Vapor Fractometer modified with a high temperature filament detector 154-0370, an Aerograph A-90-P3 and a Honeywell Disc Chart Integrator Model 201 B.

Elemental Analyses were performed by Mrs. D. Mahlow and Mrs. A. Dunn.

Solvents:

Anhydrous methanol

Anhydrous methanol was prepared from commercially available methyl hydrate by treatment with magnesium methoxide and distilled as described by Fieser(52).

Anhydrous acetone

Shawinigan reagent grade acetone was allowed to percolate through a 60 cm. column packed with Linde type 4A molecular sieves. A small amount of molecular sieves was added to the eluent before it was distilled through a 70 cm. Vigreux column. The water content of the acetone was determined by a Karl Fisher titration using anhydrous pyridine as solvent as suggested by Smith, Fainberg and Winstein(53). The purified acetone was not stored, but rather a fresh batch was prepared each time the solvent was required.

Methylene chloride

Methylene chloride was prepared using the procedure described by R. Tomilson(54).

Acetonitrile(55)

Reagent grade acetonitrile(about 2 liters) was distilled

from about 10 g. of phosphorous pentoxide. It was then refluxed over 30 g. of potassium carbonate for 5 hours and then again distilled from 10 g. of phosphorous pentoxide. B. p. $_{706\ mm.}$ 78.5°.

Reagents and Materials:

2,6-Lutidine

This reagent was kindly supplied by M. A. Armour. It was prepared as follows: Eastman practical grade 2,6-lutidine was dried over potassium hydroxide for several days, followed by refluxing and distillation from barium oxide as described by Fieser for the preparation of anhydrous pyridine(56). The center cut was treated with boron trifluoride and distilled as described by Brown et al.(57).

Standard sodium methoxide

A solution of sodium methoxide in methanol was prepared by the addition of a weighed amount of freshly cleaned sodium to one gallon of Fisher certified anhydrous methanol. The resulting solution was standardized with Fisher certified primary standard potassium hydrogen phthalate in water using phenolphthalein as indicator. Restandardization showed the solution to be stable for at least two years when it is stored in a tightly stoppered dark bottle.

Ferric alum indicator

Ferric alum indicator was prepared by dissolving 10 g. of

ferric ammonium sulfate in a boiling solution of 20 ml. of 6N HNO_3 and 80 ml. of distilled water.

Standard silver nitrate solution

Standard sodium chloride solutions were prepared by dissolving accurately weighed sodium chloride crystals in the required volumes of water. Known aliquots of the sodium chloride solutions were transferred to 50 ml. Erlenmayer flasks using a 5 ml. pipette. Silver nitrate solutions prepared by dissolving the approximately weighed crystals in the required volume of water was then added in excess. The excess silver nitrate solution was back titrated with standard potassium thiocynate solution prepared as described in the next section. The net ml. of silver nitrate solution can then be calculated and the solution standardized by comparing with the known concentrations of the sodium chloride solutions.

Standard potassium thiocynate solution

Approximately weighed potassium thiocynate crystals were dissolved in the required volume of water. This solution was then standardized against silver nitrate solution.

(-)-2R, 3R-Dibenzoyltartaric acid monohydrate

(-)-2R, 3R-Dibenzoyltartaric acid monohydrate was prepared from 200 g. (1.3 moles) of (+)-2R, 3R-tartaric acid as described by Butler(58). Yield;335 g. (72%). M.p. 88-89°(reported:88-89°(58),

88-90°(59)], $[\alpha]_D^{25}$; -116.0°[reported; $[\alpha]_D^{25}$; -116.0(58), $[\alpha]_D^{18}$; -115.78 (59), $[\alpha]_D^{25}$; -114.8(60)]. Nmr($CDCl_3$): τ4.07(s, 2H), τ2.8-2.4(m, 6H), τ2.2-1.8(m, 4H), τ1.17(s, 4H). Ir($CDCl_3$): 3600-2500, 1738, 1604, 1586, 1493, 1450, 1260, 1115, 880, 727 and 706 $cm.^{-1}$

Anal. Calcd. for $C_{18}H_{16}O_9$: C, 57.45; H, 4.29.
Found: C, 57.80; H, 4.32.

m-Nitrobenzyl alcohol(61)

A 500 ml. three-necked flask, equipped with a mechanical stirrer, a thermometer and a dropping funnel was placed in an ice bath. A solution of 30.2 g.(0.2 mole) of m-nitrobenzaldehyde in 200 ml. of methanol was poured into the flask and while stirring, a solution of 4 g. (0.1 mole) of sodium borohydride in 50 ml. of water was added dropwise. The temperature of the reaction was kept at 18-25°. When about 3/4 of the sodium borohydride solution had been added, there was no further tendency for the temperature to rise and the addition was stopped. A small portion of the reaction mixture was treated with dilute sulfuric acid and hydrogen was evolved as bubbles.

Most of the methanol was removed by means of rotary evaporator and the residue was diluted with 200 ml. of water. The mixture was extracted with ether, the ether layer was washed with water and dried with anhydrous magnesium sulfate. The ether was removed using a rotary evaporator. The residual pale yellow oil was distilled under reduced pressure to yield 26 g.(85%) of m-nitrobenzyl alcohol, $b.p._{5mm}$ 160°. [reported(61): $b.p._{3mm}$ 175-180°, $b.p._{17mm}$ 183-185°]. Nmr($CDCl_3$): τ6.8(s, 1H), τ5.2(s, 2H), τ1.67-2.75(m, 4H).

m-Nitrobenzyl bromide

Hydrogen bromide was bubbled into a solution of 6,2 g. of m-nitrobenzyl alcohol in 20 ml. of benzene for 30 minutes. The water which formed was separated from the benzene solution. The benzene solution was washed with a small amount of water and the benzene was removed using a rotary evaporator. The residue was recrystallized from 95% ethanol to yield 7 g.(80%) of m-nitrobenzyl bromide, m.p. 54-55° (reported(62): 58-59°). Nmr($CDCl_3$): τ5.42(s, 2H), τ1.62-2.7(m, 4H).

m-Nitrobenzyl ethyl sulfide(63)

A 24,8 g.(0,4 mole) quantity of ethyl mercaptan dissolved in 50 ml. of methanol was added to an ice cooled sodium methoxide solution prepared by dissolving 9.2 g.(0,4 mole) of sodium in 400 cc. of methanol. An 80 g.(0.37 mole) quantity of m-nitrobenzyl bromide in 200 ml. of methanol was added. The mixture was refluxed on steam bath for 2 hours. The methanol was removed using a rotary evaporator. Ether was added and the solution was washed once with 10% sodium hydroxide solution and then twice with distilled water. The ether layer was dried with magnesium sulfate and the ether was removed using a rotary evaporator. The residue was distilled at reduced pressure, $b.p._{4mm.}$ 149-150°, to yield 56 g.(77%) of m-nitrobenzyl ethyl sulfide. Nmr(CCl_4): τ8.78(t, J=7.5cps, 3H), τ7.58(q, J=7.5cps, 2H), τ6,24(s, 2H), τ1.75-2.75(m, 4H).

m-Nitrobenzylethylmethylsulfonium methylsulfate

To a solution of 25,4 g.(0,13 mole) of m-nitrobenzyl ethyl

sulfide in 30 ml. acetonitrile was added excess dimethyl sulfate (18.9 g., 0.15 mole). The mixture was allowed to stand at room temperature overnight. The salt solidified when ether was added. The solid was filtered and recrystallized from a solution of methanol and ether to yield 32 g. (76%) of m-nitrobenzylethylmethylsulfonium methylsulfate, m.p. 76-78°, Nmr(D_2O): τ8.56(t, J=7.5cps, 3H), τ7.17(s, 3H), τ6.18(q, J=7.5cps, 2H), τ6.31(s, 3H), τ5.25(s, 2H), τ1.5-2.5(m, 4H).

Racemic m-Nitrobenzylethylmethylsulfonium perchlorate

A 7 g.(0.022 mole) quantity of m-nitrobenzylethylmethylsulfonium methylsulfate dissolved in 150 ml. of anhydrous methanol was passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with dilute perchloric acid. The solvent was removed and the residue was recrystallized twice from methanol and had m.p. 72°. The nmr(DMSO-D_6) of this material showed a signal at τ6.65 which could not be attributed to the sulfonium salt. This impurity was not eliminated by recrystallizing the sulfonium perchlorate from acetone nor by drying in an Aberhalden drying apparatus heated by refluxing acetone. However, this impurity was eliminated by drying the compound overnight in an Aberhalden drying apparatus heated by refluxing ethanol. The compound was dried by putting the drying boat away from the direct heat of the refluxing ethanol to avoid melting the compound which had m.p. 76° and was obtained in 12% yield(0.8 g.). Ir(nujol): 2920, 2850, 1535, 1460, 1430, 1354, 810, 700 $cm.^{-1}$ Nmr(CD_3COCD_3): τ8.44(t, J=7.5 cps, 3H), τ6.9(s, 3H), τ6.35(q, J=7.5cps, 2H), τ4.92(s, 2H), τ1.43-2.36(m, 4H).

Anal. Calcd. for $C_{10}H_{14}SClO_6N$: C, 38.53; H, 4.53; Cl, 11.37; S, 10.29; N, 4.49.

Found: C, 38.28, 38.15; H, 4.53, 4.43; Cl, 11.54, 11.74; S, 10.39, 10.20; N, 3.98, 4.04.

Optically active m-nitrobenzylethylmethylsulfonium perchlorate

A 28 g.(0.087 mole) quantity of m-nitrobenzylethylmethylsulfonium methylsulfate dissolved in methanol was passed through a column containing Dowex 1-x8 (50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with 32.7 g. (0.087 mole) of d(+)-dibenzoyltartaric acid. The solvent was removed using a rotary evaporator and the solid was recrystallized from methanol four times to yield 19.2 g. (38%) of m-nitrobenzylethylmethylsulfonium dibenzoylhydrogentartrate, m.p. 165°. The salt was only slightly soluble in methanol, acetone, water, chloroform and in all solvents tested. It had a negative rotation, but the exact rotation could not be determined because of its slight solubility in all solvents tested.

The dibenzoylhydrogentartrate salt dissolved in a large quantity of methanol (4 g. in 3 liters of methanol), was passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with dilute perchloric acid. The methanol was removed using a rotary evaporator. The residue was recrystallized twice from methanol and dried in an Aberhalden drying apparatus to yield 1.9 g. (7%) of optically active m-nitrobenzylethylmethylsulfonium perchlorate, m.p.78-79°. $[\alpha]_D^{25}=13.9$, $[\alpha]_{436}^{25}=31.7$(c 0.05046, MeOH). The ir and nmr spectra were superimposable with those of the racemic

compound.

Anal. Calcd. for $C_{10}H_{14}SClO_4N$: C, 38.53; H, 4.53; Cl, 11.37; S, 10.29; N, 4.49.

Found: C, 38.17, 38.27; H, 4.52, 4.54; Cl, 11.31, 11.04; S, 10.42, 10.07; N, 4.26, 4.42.

3,5-Dimethyl-4-hydroxybenzyl alcohol(61)

To 86.4 g.(0.71 mole) of 2,6-dimethylphenol in 700 cc. of 5% sodium hydroxide solution was added 46 cc. of 40% formaldehyde solution. The mixture was stirred using a magnetic stirrer for 4 days at room temperature. On acidification with acetic acid, an oil was formed which was extracted with ether. The ether was removed using a rotary evaporator. The residue was recrystallized from benzene-methanol mixture to yield 41 g. (38%) of 3,5-dimethyl-4-hydroxybenzyl alcohol, m.p. 103-104°(reported(61): 104.5-105). Nmr(CD_3COCD_3): τ7.8(s, 6H), τ5.53(s, 2H), τ3.06(s, 2H).

3,5-Dimethyl-4-methoxybenzyl alcohol(64)

To 29 g.(0.19 mole) of 3,5-dimethyl-4-hydroxybenzyl alcohol contained in a three-necked flask equipped with a refluxing condenser, a mechanical stirrer and a dropping funnel was added 8.3 g.(0.2 mole) of sodium hydroxide in 83 ml. of water. The warm mixture was stirred with a magnetic stirrer and then cooled by immersing the reaction vessel in an ice bath. A 23.9 g.(0.19 mole) quantity of dimethyl sulfate was added dropwise while the mixture was being stirred. The mixture was refluxed for 2 more hours after all the methyl sulfate had been added to insure complete reaction. The mixture was allowed to cool and water was added. The

solution was transferred to a separatory funnel, ether was added and the lower layer was discarded. The upper layer which contained the desired compound and ether was washed successively with water, two portions of sulfuric acid and again with water until the water washings were neutral to litmus. Some sodium chloride was added to each washing as this will facilitate the separation of the two layers. The ether solution was dried with magnesium sulfate, the ether was removed using a rotary evaporator and the residue was distilled at reduced pressure, b.p.$_{9mm.}$ 139-147°, to yield 19.1 g.(60%) of 3,5-dimethyl-4-methoxybenzyl alcohol. Nmr($CDCl_3$): τ7.76(s, 6H), τ6.32(s, 3H), τ5.5(s, 2H), τ3.04(s, 2H).

3,5-Dimethyl-4-methoxybenzyl bromide

Hydrogen bromide was bubbled through a solution of 11.9 g. (0.07 mole) of 3,5-dimethyl-4-methoxybenzyl alcohol in 30 ml. benzene for 10 minutes. The water formed was separated from the benzene solution. The benzene solution was washed with a small amount of water and then dried with potassium carbonate. The potassium carbonate was removed by filtration and the benzene was removed using a rotary evaporator. The residue was distilled at reduced pressure, b.p.$_{9mm.}$ 132-133.5°, b.p.$_{6mm.}$ 124-125°, to yield 13 g.(79%) of 3,5-dimethyl-4-methoxybenzyl bromide. n_D^{25}: 1.5563. Nmr($CDCl_3$): τ7.75(s, 4H), τ6.3(s, 3H), τ5.59(s, 2H), τ2.95(s, 2H).

3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium bromide

To 2 g.(0.009 mole) of 3,5-dimethyl-4-methoxybenzyl bromide

in acetone was added excess ethyl methyl sulfide(0,8 g., 0,01 mole). The mixture was allowed to stand at room temperature overnight. Ether was added to induce precipitation. The solid which precipitated out was filtered and recrystallized from acetone-methanol mixture to yield 0.75 g. (28%) of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium bromide, m.p. 106-107°. The compound was soluble in water, methanol, moderately soluble in acetone and insoluble in chloroform, carbon tetrachloride. Nmr(D_2O): τ8.64(t, J=7.5 cps, 3H), τ7.8(s, 6H), τ7.3(s, 3H), τ6.84(q, J=7.5cps, 2H), τ6.32(s, 3H), τ5.55(s, 2H), τ2.88(s, 2H).

Racemic 3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate

A 3 g.(0,01 mole) quantity of 3,5-dimethyl-4-methoxybenzyl-ethylmethylsulfonium bromide was dissolved in methanol and passed through a column containing Dowex 1-x8 (50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was carefully neutralized with dilute perchloric acid. The solvent was removed using a rotary evaporator. The residue was recrystallized twice from methanol and dried overnight in an Aberhalden drying apparatus heated with refluxing ethanol to yield 1 g.(31%) of racemic 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate, m.p.115°. The salt was soluble in acetone, chloroform, moderately soluble in methanol and insoluble in ether. Nmr($CDCl_3$): τ8.53(t, J=7.5cps, 3H), τ7.73(s, 6H), τ7.13(s, 3H), τ6.6(q, J=7.5 cps, 2H), τ6.27(s, 3H), τ5.4(s, 2H), τ2.8(s, 2H). Ir(Nujol): 1220, 886, 860 $cm.^{-1}$

Anal. Calcd. for $C_{13}H_{21}ClO_5S$: C, 48,07; H, 6,52; Cl, 10,91.

Found: C, 48.04, 48,22; H, 6.73, 6,55; Cl, 11.05, 10.85.

Optically active 3,5-Dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate

A 29.4 g. (0.096 mole) quantity of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium bromide was dissolved in methanol and passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with d(+)-dibenzoyl tartaric acid. The methanol was removed using a rotary evaporator. The residue was recrystallized twice from methanol to yield 9.2 g.(16%) of 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium dibenzoyl tartrate, m.p. 134-135°. $[\alpha]^{25}_{589}$: -67.4; $[\alpha]^{25}_{578}$: -71.9; $[\alpha]^{25}_{546}$:-81.2; $[\alpha]^{25}_{436}$: -162.4(c 0.257, methanol). Nmr(DMSO-D_6): τ8.7(t, J=7.5 cps, 3H), τ7.76(s, 6H), τ7.3(s, 3H), τ6.75(q, J=7.5 cps, 2H), τ6.32 (s, 3H), τ5.42(s, 2H), τ4.31(s, 2H), τ1.91-2.9(m, 12H).

The dibenzoyl tartrate salt obtained was dissolved in methanol and passed through the column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was carefully neutralized with dilute perchloric acid. The solvent was removed using a rotary evaporator. The residue was recrystallized from methanol-ether mixture and dried overnight in an Aberhalden drying apparatus heated with refluxing ethanol to yield 3.3 g.(11% based on the bromide salt) of optically active 3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate, m.p. 111-112°, $[\alpha]^{25}_{589}$; 14.1; $[\alpha]^{25}_{436}$:32.1(c 0.6108, MeOH). Nmr and ir of this compound were superimposable with those of the racemic compound.

Anal. Calcd. for $C_{13}H_{21}ClO_5S$: C, 48.07; H, 6.52; Cl, 10.91.

Found; C, 48.09, 47.81; H, 6.68, 6.36; Cl, 11.58, 10.89.

The dibenzoyl tartrate salt which did not crystallized from methanol was changed to the perchlorate salt using the procedure described in the previous section. After recrystallizing three times from methanol and dried in an Aberhalden drying apparatus, the yield of the (-)-3,5-dimethyl-4-methoxybenzylethylmethylsulfonium perchlorate was 2.5 g.(8%), m.p. 114.5°, $[\alpha]_{365}^{25}$; -1.7(c 0.599, methanol). Nmr ($CDCl_3$) and ir (Nujol) of this compound were superimposable with those of the racemic compound.

Anal. Calcd. for $C_{13}H_{21}ClO_5S$: C, 48.07; H, 6.52; Cl, 10.91; S, 9.87.

Found: C, 47.98, 47.75; H, 6.49, 6.60; Cl, 11.01, 10.87; S, 10.02.

p-Chlorobenzyl alcohol

A 150 g.(1.08 mole) quantity of p-chlorobenzaldehyde was treated with 10.8 g.(0.27 mole) of sodium borohydride using the procedure described for the preparation of m-nitrobenzyl alcohol. The solid obtained was recrystallized from ligroin-benzene mixture to yield 68 g. (45%) of p-chlorobenzyl alcohol, m.p. 68-69°(reported(65): 75°). Nmr ($CDCl_3$): τ7.68(s, 1H), τ5.38(s, 2H), τ2.68(s, 4H).

p-Chlorobenzyl bromide

A 68 g.(0.33 mole) quantity of p-chlorobenzyl alcohol was converted to p-chlorobenzyl bromide using the procedure described for the conversion of m-nitrobenzyl alcohol to m-nitrobenzyl bromide. The

solid was recrystallized from ligroin to yield 69 g.(70%) of p-chlorobenzyl bromide, m.p. 48-49° (reported(66):51°). Nmr($CDCl_3$): τ5.57(s, 2H), τ2.7(s, 4H).

p-Chlorobenzylethylmethylsulfonium bromide

To 2.08 g.(0.012 mole) of p-chlorobenzyl bromide dissolved in 5 ml. acetone was added 1.23 g.(0.016 mole) of ethyl methyl sulfide. The solution was allowed to stand at room temperature overnight. Ether was added and p-chlorobenzylethylmethylsulfonium bromide oiled out which then solidified after several washings with ether and cooling in dry ice-acetone bath with scratching. The solid was recrystallized from methanol-ether mixture and dried in an Aberhalden drying apparatus for 3 hours at room temperature to yield 1.45 g.(43%) of p-chlorobenzylethylmethylsulfonium bromide, m.p. 96-97°. Uv($CHCl_3$): $\lambda_{max.}$=242 mμ(ε=8677), (CH_3CN): $\lambda_{max.}$=223 mμ(ε=3332). Nmr(D_2O): τ8.62(t, J=7.5 cps, 3H), τ7.26(s, 3H), τ6.78(q, J=7.5 cps, 2H), τ5.34(s, overlapping with D_2O signal), τ2.56(s, 4H).

Anal. Calcd. for $C_{10}H_{14}SBrCl$: C, 42.65; H, 5.01; Br+Cl, 25.18; S, 11.38.

Found: C, 42.95, 42.75; H, 4.79, 4.95; Br+Cl, 25.51; S, 11.46, 11.35.

p-Chlorobenzyl ethyl sulfide

A 67 g.(0.33 mole) quantity of p-chlorobenzyl bromide was converted to p-chlorobenzyl ethyl sulfide by treatment with 21.1 g.(0.34 mole) of ethyl mercaptan and 7.8 g.(0.38 mole) of sodium using the

procedure described for the preparation of m-nitrobenzyl ethyl sulfide. The residue was distilled at reduced pressure, b.p.$_{7\,mm.}$ 120-122°, b.p.$_{14\,mm.}$ 132° to yield 46.5 g.(76%) of p-chlorobenzyl ethyl sulfide, Nmr($CDCl_3$): τ8.34(t, J=7.5 cps, 3H), τ7.61(q, J=7.5 cps, 2H), τ6.35(s, 2H), τ2.75(s, 4H).

p-Chlorobenzylethylmethylsulfonium methylsulfate

To 2.86 g.(0.015 mole) of p-chlorobenzyl ethyl sulfide in 5 ml. of acetonitrile was added excess dimethyl sulfate (2.44 g., 0.019 mole). The mixture was allowed to stand at room temperature for three hours. Ether was added and p-chlorobenzylethylmethylsulfonium methylsulfate oiled out, it did not solidified on cooling in dry ice-acetone bath. The solvents were removed as much as possible using a rotary evaporator, the residue was again cooled down to dry ice-acetone temperature, but still no solid precipitate was formed. Nmr of the glassy residue corresponds to that of p-chlorobenzylethylmethylsulfonium methylsulfate. Nmr($CDCl_3$): τ8.58(t, J=7.5 cps, 3H), τ7.04(s, 3H), τ6.48(q, J=7.5 cps, 2H), τ6.27(s, 3H), τ5.05(s, 2H), τ2.47(m, 4H).

Racemic p-chlorobenzylethylmethylsulfonium perchlorate

p-Chlorobenzylethylmethylsulfonium methylsulfate was dissolved in methanol and passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form, the basic eluent was neutralized with dilute perchloric acid and the solvent was removed using a rotary evaporator. The residue was recrystallized twice from methanol and dried in an Aberhalden drying apparatus which was heated

with refluxing ethanol to yield 0.5 g.(11%, based on the p-chlorobenzyl ethyl sulfide), m.p. 88°. Uv($CHCl_3$): $\lambda_{max.}$=241 mμ(ε=3836), (CH_3CN): $\lambda_{max.}$=227 mμ(ε=13380). Ir(Nujol): 840, 803 $cm.^{-1}$ Nmr(DMSO-D_6): τ8.65(t, J=7.5 cps, 3H), τ7.2(s, 3H), τ6.72(q, J=7.5 cps, 3H), τ5.3(s, 2H), τ2.42(s, 4H).

Anal. Calcd. for $C_{10}H_{14}Cl_2O_4S$: C, 39.87; H, 4.69; Cl, 23.54.
Found: C, 39.89, 39.66; H, 4.31, 4.49; Cl, 23.07, 23.06.

A better method for the preparation of p-chlorobenzylethylmethylsulfonium perchlorate was using p-chlorobenzylethylmethylsulfonium bromide in place of p-chlorobenzylethylmethylsulfonium methylsulfate. The rest of the procedure was the same as that described above. The yield of the p-chlorobenzylethylmethylsulfonium perchlorate using p-chlorobenzylethylmethylsulfonium bromide as starting material was 61%.

Optically active p-Chlorobenzylethylmethylsulfonium perchlorate

p-Chlorobenzylethylmethylsulfonium methylsulfate was dissolved in methanol and passed through a column containing Dowex 1-x8 (50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with d(+)-dibenzoyl tartaric acid. The solvent was removed on a rotary evaporator. The residue was recrystallized twice from methanol-acetone mixture to yield 8 g.(5% based on the p-chlorobenzyl ethyl sulfide) of p-chlorobenzylethylmethylsulfonium dibenzoyl tartrate, m.p.131-132°, $[\alpha]^{25}_{589}$: -69.6; $[\alpha]^{25}_{578}$: -72.9; $[\alpha]^{25}_{546}$: -84.8; $[\alpha]^{25}_{436}$: -166(c 1.599, methanol).

The dibenzoyl tartrate salt was dissolved in methanol and passed through a column of Dowex 1-x8(50-100 mesh) anion exchange resin

in its hydroxide form. The basic eluent was carefully neutralized with dilute perchloric acid. The residue was recrystallized from methanol and dried overnight in an Aberhalden drying apparatus which was heated with refluxing ethanol to yield 8 g.(5% based on the p-chlorobenzyl ethyl sulfide used to prepare p-chlorobenzylethylmethylsulfonium perchlorate) of optically active p-chlorobenzylethylmethylsulfonium perchlorate, m.p. 88°. Nmr and ir were superimposable with those of the racemic compound, $[\alpha]_{436}^{25}$: -31.5; $[\alpha]_{365}^{25}$: -56.2.

Anal. Calcd. for $C_{10}H_{14}Cl_2O_4S$: C, 39.87; H, 4.69; Cl, 23.54.
Found: C, 40.11, 40.31; H, 4.39, 4.63; Cl, 23.38, 23.35.

p-Methylbenzyl alcohol

A 98 g.(0.82 mole) quantity of practical grade p-methylbenzaldehyde(p-tolualdehyde) was treated with 8.4 g.(0.21 mole) of sodium borohydride using the procedure described for the reduction of m-nitrobenzaldehyde. The residue was recrystallized from heptane to yield 75 g. (75%) of p-methylbenzyl alcohol, m.p.58.5(reported(66): 60°). Nmr ($CDCl_3$): τ7.75 + τ7.68(two overlapping singlets, 4H), τ5.44(s, 2H), τ2.92(m, 4H).

p-Methylbenzyl bromide

A 48.6 g.(0.398 mole) of p-methylbenzyl alcohol was converted to the p-methylbenzyl bromide using the procedure described for the preparation of m-nitrobenzyl bromide. The solid obtained was recrystallized from ethanol to yield 54.8 g.(74%) of p-methylbenzyl bromide, m.p. 35°(reported(66): 35°).

p-Methylbenzyl ethyl sulfide

A 54.8 g.(0.296 mole) quantity of p-methylbenzyl bromide was allowed to react with 19.2 g.(0.31 mole) of ethyl mercaptan and 7.13 g.(0.31 mole) of sodium using the procedure described for the preparation of m-nitrobenzyl ethyl sulfide. The residue was distilled at reduced pressure, b.p.$_{13\ mm.}$ 110-115°, to yield 31.5 g.(64%) of p-methylbenzyl ethyl sulfide. Nmr($CDCl_3$): τ8.8(t, J=7.5 cps, 3H), τ7.7 + τ7.58(s + q(J=7.5 cps), 5H), τ6.33(s, 2H), τ2.85(m, 4H).

p-Methylbenzylethylmethylsulfonium methylsulfate

A 3.7 g.(0.029 mole) quantity of dimethyl sulfate was added to 4.5 g.(0.027 mole) of p-methylbenzyl ethyl sulfide. The procedure was the same as that described for the preparation of m-nitrobenzylethylmethylsulfonium methylsulfate. When the residue was cooled down to dry ice-acetone temperature, 7.2 g.(91%) of glassy material whose nmr corresponds to that of p-methylbenzylethylmethylsulfonium methylsulfate was obtained. Nmr($CDCl_3$): τ8.62(t, J=7.5 cps, 3H), τ7.67(s, 3H), τ7.11(s, 3H), τ6.55(q, J=7.5 cps, 2H), τ6.3(s, 3H), τ5.17(s, 2H), τ2.7(m, 4H).

p-Methylbenzylethylmethylsulfonium bromide

To 3.6 g.(0.19 mole) of p-methylbenzyl bromide was added excess ethyl methyl sulfide(16 g., 0.21 mole) and 50 ml. of acetone. The procedure was the same as that described for the preparation of p-chlorobenzylethylmethylsulfonium bromide. Attempts to crystallize

this salt failed, it was obtained as an oil.

Racemic p-Methylbenzylethylmethylsulfonium perchlorate

A 7.2 g. quantity of p-methylbenzylethylmethylsulfonium methylsulfate dissolved in methanol was passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form, the basic eluent was carefully neutralized with dilute perchloric acid. The solvent was removed using a rotary evaporator. The residue was recrystallized twice from methanol and dried in an Aberhalden drying apparatus which was heated with refluxing ethanol to yield 1.8 g.(25%) of racemic p-methylbenzylethylmethylsulfonium perchlorate, m.p.100-101°. Ir(Nujol): 1530, 1427, 822 $cm.^{-1}$ Nmr($CDCl_3$): τ8.58(t, J=7.5 cps, 3H), τ7.67(s, 3H), τ7.17(s, 3H), τ6.64(q, J=7.5 cps, 2H), τ5.32 (s, 2H), τ2.68(m, 4H).

Anal. Calcd. for $C_{11}H_{17}O_4ClS$: C, 47.06; H, 6.1; Cl, 12.63; S, 11.62.
Found: C, 46.79, 46.53; H, 6.09, 5.74; Cl, 12.75, 12.64; S, 9.82, 10.29.

A better starting material was p-methylbenzylethylmethylsulfonium bromide instead of p-methylbenzylethylmethylsulfonium methylsulfate.

Optically active p-Methylbenzylethylmethylsulfonium perchlorate

The p-methylbenzylethylmethylsulfonium methylsulfate was dissolved in methanol and passed through a column containing Dowex 1-x8 (50-100 mesh) anion exchange resin in its hydroxide form, the basic

eluent was neutralized with d(+)-dibenzoyl tartaric acid. The solvent was removed using a rotary evaporator and the residue was recrystallized from methanol to yield 3 g. (22%) of p-methylbenzylethylmethylsulfonium dibenzoyl tartrate, m.p.135°, $[\alpha]_{589}^{25}$: -77.3; $[\alpha]_{578}^{25}$: -80.4; $[\alpha]_{546}^{25}$: -93; $[\alpha]_{436}^{25}$: -182(c 0.489, methanol).

The 3 g. of dibenzoyl tartrate salt which was obtained was dissolved in methanol and passed through a column of Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form, the basic eluent was carefully neutralized with dilute perchloric acid. The solvent was removed using a rotary evaporator. The residue was recrystallized twice from ether-methanol mixture to yield 0.95 g.(63%) of optically active p-methylbenzylethylmethylsulfonium perchlorate, m.p. 103°. Nmr spectra was superimposable with that of the racemic compound. $[\alpha]_{589}^{25}$: 13.6; $[\alpha]_{436}^{25}$: 53.8(c 0.7459, methanol).

Anal. Calcd. for $C_{11}H_{17}O_4ClS$: C, 47.06; H, 6.10; Cl, 12.63; S, 11.42.

Found: C, 47.04, 46.77; H, 5.98, 5.82; Cl, 12.59, 12.62; S, 11.85, 11.54.

As in the preparation of racemic p-methylbenzylethylmethylsulfonium perchlorate, p-methylbenzylethylmethylsulfonium bromide was found to be a better starting material for the preparation of optically active p-methylbenzylethylmethylsulfonium perchlorate than the p-methylbenzylethylmethylsulfonium methylsulfate.

The p-methylbenzylethylmethylsulfonium benzoyl tartrate which is more soluble in methanol gave the negative perchlorate salt, m.p. 101°. $[\alpha]_{589}^{25}$: -0.7; $[\alpha]_{436}^{25}$: -2; $[\alpha]_{365}^{25}$: -3.6 (c 1.224 , MeOH).

Anal. Calcd. for $C_{11}H_{17}O_4ClS$: C, 47.06; H, 6.10; Cl, 12.63.
Found: C, 47.12, 46.69; H, 6.18, 6.10; Cl, 12.86, 12.99.

o-Methylanisole

To a three-necked flask equipped with a reflux condenser, a mechanical stirrer and a dropping funnel was added 216 g.(2 mole) of o-cresol and then 850 ml. of 10% sodium hydroxide solution (2.1 mole). The mixture was cooled by immersing the reaction vessel in an ice bath. A 252 g.(2 mole) quantity of dimethyl sulfate was added dropwise with stirring. The solution became warm during the addition of dimethyl sulfate, it was allowed to cool and water was then added. The solution was transferred to a separatory funnel, ether was added and the lower layer was discarded. The ether layer was washed once with water, twice with dilute sulfuric acid and again with water until the water washings were neutral to litmus. Some sodium chloride was added to each washing as this will facilitate the separation of the two layers. The solution was dried with magnesium sulfate. The ether was removed using a rotary evaporator and the residue was distilled at reduced pressure, b.p.$_{30\ mm.}$ 70-75°, b.p.$_{704mm.}$ 168-170°(reported(66); b.p.$_{760mm.}$ 171-172°), to yield 194 g.(80%) of o-methylanisole, n_D^{22}: 1.5175(reported(66): n_D^{22}: 1.5174). Nmr($CDCl_3$): τ7.81(s, 3H), τ6.23(s, 3H), τ2.36-3.42 (m, 4H).

3-Methyl-4-methoxybenzyl bromide(35)

Hydrogen bromide was bubbled through a well-cooled solution

of 75 g.(0.61 mole) of 3-methyl-4-methoxybenzene(o-methylanisole) in 58 g. (0.71 mole) of 37% formaldehyde solution until the solution was saturated with hydrogen bromide. The reaction was carried out at low temperature by immersing the reaction vessel in an ice bath. Ice was added to the solution and the reaction product was extracted with diethyl ether. The extract was washed with water, dried over sodium sulfate and the ether was removed using a rotary evaporator. The residue was distilled at reduced pressure, $b.p._{9mm.}$ 133.5^{o}, to yield 35.2 g.(27%) of 3-methyl-4-methoxybenzyl bromide, $n_D^{25.5}$: 1.4742. Nmr($CDCl_3$): τ7.8(s, 3H), τ6.21(s, 3H), τ5.54(s, 2H), τ3.0(m, 3H).

3-Methyl-4-methoxybenzylethylmethylsulfonium bromide

To 14.8(0.067 mole) of 3-methyl-4-methoxybenzyl bromide in 20 ml. acetone was added excess ethyl methyl sulfide(13.7 g., 0.16 mole). Reaction occurred immediately as evidence by the evolution of heat. The acetone and excess ethyl methyl sulfide was removed using a rotary evaporator. Attempts to solidify the residue by repeated washing with ether and cooling in dry ice-acetone bath failed.

Racemic 3-Methyl-4-methoxybenzylethylmethylsulfonium perchlorate

About 3 g. of 3-methyl-4-methoxybenzylethylmethylsulfonium bromide was dissolved in methanol and passed through a column of Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form, the basic eluent was carefully neutralized with dilute perchloric acid. The solvent was removed using a rotary evaporator. The residue was recrystallized twice from methanol-ether mixture and dried in an Aberhalden

drying apparatus which was heated with refluxing ethanol to yield 1 g. (31%) of racemic 3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate, m.p. 91°. Ir(Nujol): 1605, 1504, 1253, 1220, 900, 870, 810 $cm.^{-1}$ Nmr($CDCl_3$): τ8.57(t, J=7.5 cps, 3H), τ7.84(s, 3H), τ7.19(s, 3H), τ6.67(q, J=7.5 cps, 2H), τ6.2(s, 3H), τ5.28(s, 2H), τ2.5-3.33(m, 3H).

Anal. Calcd. for $C_{12}H_{19}SClO_5$: C, 46.37; H, 6.16; Cl, 11.41.
Found: C, 46.22, 46.39; H, 6.19, 6.18; Cl, 11.72, 11.66.

Optically active 3-Methyl-4-methoxybenzylethylmethylsulfonium perchlorate

About 9 g. of 3-methyl-4-methoxybenzylethylmethylsulfonium bromide was dissolved in methanol and passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with 12 g. of d(+)-dibenzoyl tartaric acid. The volume of the solvent was reduced by evaporating off some of the methanol using a rotary evaporator, the dibenzoyl tartrate salt which precipitated out was washed with ether and dried, m.p. 127°. This compound is insoluble in dimethyl sulfoxide, slightly soluble in methanol. Ir(Nujol): 1713, 1664, 1268, 820, 715 $cm.^{-1}$ $[\alpha]^{25}_{589}$:-69.5; $[\alpha]^{25}_{578}$: -75.9; $[\alpha]^{25}_{546}$: -89.6; $[\alpha]^{25}_{436}$: -172.8; $[M]^{25}_{D}$:-392(c 0.1094, methanol).

The dibenzoyl tartrate salt prepared was changed to the perchlorate salt by dissolving the dibenzoyl tartrate salt in methanol and passing the solution through a column of Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form, the basic eluent was carefully neutralized with dilute perchloric acid. The solvent was

removed using a rotary evaporator. The residue was recrystallized twice from methanol-ether mixture and dried for 2 hours in an Aberhalden drying apparatus which was heated with refluxing ethanol to yield 1.8 g. (19% based on the bromide salt) of (+)-3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate, m.p. 81-82°. Nmr spectrum of this compound was superimposable with that of the racemic compound. $[\alpha]_{436}^{25}$: 26.5; $[\alpha]_{365}^{25}$: 50(c 1.095, methanol).

Anal. Calcd. for $C_{12}H_{19}SClO_5$: C, 46.37; H, 6.16; Cl, 11.41.
Found: C, 46.24, 46.18; H, 5.99, 6.02; Cl, 11.31, 11.43.

The dibenzoyl tartrate salt of 3-methyl-4-methoxybenzylethylmethylsulfonium compound which was very soluble in methanol was converted to the (-)-perchlorate salt using the procedure described for the preparation of the (+)-perchlorate salt. The salt was recrystallized twice from methanol-ether mixture and dried in an Aberhalden drying apparatus to yield 0.6 g.(6%) of (-)-3-methyl-4-methoxybenzylethylmethylsulfonium perchlorate, m.p. 81-82°. Nmr spectrum of this compound was superimposable with that of the racemic compound. $[\alpha]_{589}^{25}$: -2.73; $[\alpha]_{578}^{25}$:-2.73; $[\alpha]_{546}^{25}$: -3.16; $[\alpha]_{436}^{25}$: -6.17; $[\alpha]_{365}^{25}$: -11.5.

Anal. Calcd. for $C_{12}H_{19}SClO_5$: C, 46.37; H, 6.16; Cl, 11.41.
Found: C, 46.47, 46.11; H, 5.97, 6.15; Cl, 11.78, 11.76.

m-Nitrobenzyl methyl ether

A 5 g.(0.023 mole) quantity of m-nitrobenzyl bromide was added to a solution of sodium methoxide prepared by adding 0.5 g.(0.021 mole) of sodium to 20 ml. of methanol. The mixture was refluxed for

16 hours. The solvent was removed using a rotary evaporator. Water was added to the residue and the mixture was extracted with anhydrous diethyl ether. The two extracts were combined and dried with potassium carbonate. The ether was evaporated off using a rotary evaporator and the residue was distilled under pressure, b.p.$_{12mm.}$ 142-143°, to yield 2.5 g.(65%) of impure m-nitrobenzyl methyl ether. VPC showed the product to contain impurities, these were removed by chromatography on alumina, first using pentane as eluent and then benzene-pentane mixture(1:4). n_D^{25}: 1.5359. Ir(CCl_4): 3070, 2990, 2925, 2820, 1526, 1345, 1190, 1110, 923, 884, 805, 722 cm.$^{-1}$ Nmr(CCl_4): τ6.58(s, 3H), τ5.48(s, 2H), τ1.76-2.67(m, 4H).

Anal. Calcd. for $C_8H_9NO_3$: C, 57.48; H, 5.43; N, 8.38.

Found: C, 57.38, 57.36; H, 5.50, 5.49; N, 8.12, 7.88.

p-Chlorobenzyl methyl ether

A solution of sodium methoxide was prepared by adding 1 g. of sodium to 30 ml. of methanol. A 5 g. (0.024 mole) quantity of p-chlorobenzyl bromide was added to the sodium methoxide solution. The rest of the procedure was the same as that described for the preparation of m-nitrobenzyl methyl ether. Impurities were removed by chromatography on alumina using pentane-benzene mixture(2:1) as eluent. The eluent was evaporated off using a rotary evaporator and the residue was distilled at reduced pressure, b.p.$_{13mm.}$ 93-94°, b.p.$_{1mm.}$ 46.5-47°, n_D^{25}: 1.5177. Ir(CCl_4): 2928, 2821, 1596, 1488, 1097, 1085, 1012, 914, 833 cm.$^{-1}$ Nmr(CCl_4): τ6.73(s, 3H), τ5.69(s, 2H), τ2.82(s, 4H).

Anal. Calcd. for C_8H_9OCl; C, 61.35; H, 5.79; Cl, 22.64.

Found: C, 61.26, 61.17; H, 6.04, 5.88; Cl, 23.06, 22.87.

p-Methylbenzyl methyl ether

To 6.3 g.(0.052 mole) of p-methylbenzyl alcohol was added 25 ml. methanol and 7 ml. concentrated hydrochloric acid. The mixture was refluxed for a day. The methanol was removed using a rotary evaporator and the residue was extracted with anhydrous diethyl ether. The extract was washed with 10% sodium bicarbonate solution and then with water, dried with potassium carbonate and the diethyl ether was removed using a rotary evaporator. The residue was distilled at reduced pressure, b.p.$_{7mm.}$ 69.5°, b.p.$_{3mm.}$ 52-57°. VPC showed an extraneous peak with retention time shorter than that corresponding to the p-methylbenzyl methyl ether. Purification was done using a chromatography column packed with aluminum oxide and using a 4:1 mixture of pentane:benzene as eluent. The first three fractions of eluent, 100 ml. each, were collected. The eluent was removed on a rotary evaporator and the residue was distilled at reduced pressure, b.p.$_{11mm.}$ 75°, $n_D^{25.2}$: 1.4981. Ir(CCl_4): 2819, 1090, 832 $cm.^{-1}$ Nmr(CCl_4): τ7.7(s, 3H), τ6.75 (s, 3H), τ5.69(s, 2H), τ2.94(s, 4H).

Anal. Calcd. for $C_9H_{12}O$: C, 79.37; H, 8.88.

Found: C, 78.43, 78.25; H, 8.94, 8.82.

3,5-Dimethyl-4-methoxybenzyl methyl ether

To 1 g. of 3,5-dimethyl-4-methoxybenzyl alcohol was added 10

ml. of methanol and 1 ml. concentrated hydrochloric acid. The solution was refluxed for a day. The rest of the procedure was the same as that described for the preparation of p-methylbenzyl methyl ether. The impurities in the product were removed by chromatography through an alumina column using a 4:1 mixtures of pentane:benzene as eluent. The first three fractions of eluent, 100 ml. each, were discarded, the fourth to eighth fractions were collected and the solvent was removed using a rotary evaporator. The residue was distilled at reduced pressure, b.p.$_{10mm.}$ 110°, to yield 0.1 g.(9%) of 3,5-dimethyl-4-methoxybenzyl methyl ether. Ir(CCl_4): 2820, 1090, 860 cm.$^{-1}$ Nmr(CCl_4): τ7.79(s, 6H), τ6.77(s, 3H), τ5.8(s, 2H), τ3.19(s, 2H), τ6.37(s, 3H).

3-Methyl-4-methoxybenzyl methyl ether

A 10 g.(0.047 mole) quantity of 3-methyl-4-methoxybenzyl bromide was added to a solution of sodium methoxide prepared by adding 2.5 g.(0.051 mole) of sodium to 30 ml. methanol. The mixture was refluxed overnight. The rest of the procedure was the same as that described for the preparation of m-nitrobenzyl methyl ether. The product was distilled at reduced pressure, b.p.$_{3mm.}$ 93-94°, b.p.$_{14mm.}$ 118.5°, to yield 5 g.(64%) of 3-methyl-4-methoxybenzyl methyl ether. The impurities in the product were not removed by chromatography using an alumina column. These impurities were removed by gas chromatography using a 2-meter column of silicon oil DC 200(dimethyl siloxane polymer) on acid washed chromosorb W, with temperature=174°, current=200 milliamperes, flow rate of the helium gas=60 cc/min. Aliquots of 5μl were

injected into the column and samples were collected when the peak corresponding to 3-methyl-4-methoxybenzyl methyl ether appeared in the VPC graph. Ir(CCl_4): 2920, 2833, 1607, 1502, 1460, 1243, 1124, 1087, 1034, 877 $cm.^{-1}$ Nmr(CCl_4): τ7.83(s, 3H), τ6.78(s, 3H), τ6.23(s, 3H), τ5.75(s, 2H), τ2.82-3.47(m, 3H).

Anal. Calcd. for $C_{10}H_{12}O_2$: C, 72.26; H, 8.49.

Found: C, 71.88, 71.70; H, 8.53, 8.64.

Optically active p-chlorobenzylethylmethylsulfonium bromide

A 40 g. quantity of racemic p-chlorobenzylethylmethylsulfonium bromide was passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form and then neutralizing the basic eluent with 29 g. of d(+)-dibenzoyl tartaric acid. Most of the methanol was removed using a rotary evaporator. Acetone was added to the residue until the solution turned cloudy. The solution was allowed to stand in the fridge overnight. A 14 g. quantity of the p-chlorobenzylethylmethylsulfonium dibenzoyl tartrate precipitated out. This was dissolved in methanol and passed through the column containing Dowex 1-x8 anion exchange resin(50-100 mesh) in its hydroxide form. The basic eluent was neutralized with dilute hydrobromic acid. The solvent was removed using a rotary evaporator. The residue was washed several times with ether and then recrystallized twice from methanol-ether mixture. The crystals were dried for 2 hours in an Aberhalden drying apparatus at room temperature to yield 14.8 g.(37%) of optically active p-chlorobenzylethylmethylsulfonium bromide, m.p. 79-82°. Nmr and Ir were superimposable with those of the racemic compound.

$[\alpha]_{436}^{25}$: 24.2; $[\alpha]_{365}^{25}$: 43.8(c 0.9244, methanol).

Anal. Calcd. for $C_{10}H_{14}SBrCl$: C, 42.65; H, 5.01; Br+Cl, 25.18; S, 11.38.

Found: C, 42.94, 42.66; H, 5.08, 5.17; Br+Cl, 24.89, 24.74.

Tetra-n-butylammonium perchlorate

Tetra-n-butylammonium perchlorate prepared by L. Green(67) was recrystallized from aqueous acetone and dried in an Aberhalden drying apparatus at room temperature for 2 days to give crystals which melted at 210-211°(reported(48):213-213.5). The crystals were soluble in DMSO, $CHCl_3$, CH_2Cl_2, ethanol, nitrobenzene but insoluble in water. Nmr(DMSO-D_6): τ7.97(m, 7H), τ6.56-7.15(m, 2H), τ7.39-7.6(m, DMSO-D_6). Nmr($CDCl_3$): τ 8.0-9.33(m, 7H), τ6.5-7.02(m, 2H). Nmr(CD_3NO_2): τ7.96-9.25(m, 7H), τ6.52-7.0(m, 2H). Nmr(CD_3CN): τ7.83-9.29(m, 7H), τ6.69-7.09(m, 2H). Nmr(CD_2Cl_2); See Table XXXIX (Chapter III).

Anal. Calcd. for $C_{16}H_{36}NClO_4$: C, 56.20; H, 10.61; N, 4.1; Cl, 10.37.

Found: C, 55.83, 55.40; H, 10.46, 10.46; N, 4.10, 3.78; Cl, 10.38, 10.03.

Tetra-n-butylammonium bromide

Tetra-n-butylammonium bromide prepared by L. Green(67) was recrystallized from ethyl acetate to give crystals which melted

at 102°(reported(48):118-119°). The crystals were soluble in ethanol, nitrobenzene, CH_3CN and CH_3NO_2. Uv(CD_3CN): $\lambda_{max.}$=218 mμ(ε=21800); $\lambda_{max.}$=203 mμ(ε=21800). Nmr($CDCl_3$): τ 8-9.28(m, 7H), τ 6.39-6.89 (m, 2H). Nmr(CD_3NO_2): τ7.89-9.25(m, 7H), τ6.42-6.92(m, 2H), τ5.63(s, CD_3NO_2). Nmr(CD_3CN): τ7.92-9.26(m, 7H), τ6.5-7.0(m, 2H). Anal. Calcd. for $C_{16}H_{36}NBr$: C, 59.61; H, 11.26; N, 4.34; Br, 24.79.

Found: C, 59.84, 59.44; H, 11.30, 10.78; N, 4.22, 4.42; Br, 25.07, 25.30.

Tetra-n-butylammonium 2,4,6-trinitrobenzenesulfonate

A 2 g. quantity(0.006 mole) of tetra-n-butylammonium bromide was dissolved in methanol and passed through a column packed with Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The base formed was neutralized with 1.05 g.(0.0036 mole) of 2,4,6-trinitrobenzenesulfonic acid. The methanol was evaporated off using a rotary evaporator. The residue was washed repeatedly with ethyl acetate and then recrystallized from methanol-ether mixture. The crystals were dried for two days in an Aberhalden drying apparatus which was heated with refluxing ethanol to yield 0.5 g.(16%) of tetra-n-butylammonium 2,4,6-trinitrobenzenesulfonate, m.p.153°. Satisfactory C, N, H analysis could not be obtained. Nmr(CD_3CN): τ7.83-9.3(m, 28H), τ6.68-7.17(m, 8H), τ2.83(s, 2H). Nmr(CD_3NO_2): τ7.94-9.33(m, 28H), τ6.5-7.0(m, 8H), τ2.76(s, 2H). Nmr(CD_2Cl_2): See Table XXXIX (Chapter III).

N-benzyltrimethylammonium perchlorate

A 3.63 g. quantity of N-benzyltrimethylammonium hydroxide (40% in methanol, Aldrich Chemical Co. Inc. n_D^{20}: 1.4310) was neutralized with dilute perchloric acid. The solid which precipitated out was recrystallized from methanol and dried for 2 hours in an Aberhalden drying apparatus which was heated with refluxing ethanol to yield 1.22 g.(78%) of N-benzyltrimethylammonium perchlorate, m.p.127°. The compound was soluble in acetonitrile, acetone, DMSO-D_6, slightly soluble in 95% ethanol but insoluble in CH_2Cl_2, $CHCl_3$, H_2O and $HCONH_2$. Nmr(CD_3CN): τ6.98(s, 9H), τ5.57(s, 2H), τ2.46(s, 5H), τ7.83-8.18(m, CD_3CN). Uv(CH_3CN): $\lambda_{max.}$=207 mμ(ε=8535).

Anal. Calcd. for $C_{10}H_{16}NClO_4$: C, 48.10; H, 6.46; N, 5.61; Cl, 14.2.

Found; C, 47.96, 47.79; H, 6.18, 6.06; N, 5.05, 5.15; Cl, 14.60, 14.89.

N-benzyltrimethylammonium bromide

A 3.64 g. quantity of N-benzyltrimethylammonium hydroxide (40% in methanol, Aldrich Chemical Co. Inc. n_D^{20}: 1.4310) was neutralized with dilute hydrobromic acid solution. No precipitate was formed after addition of ether. The ether, methanol and water were evaporated off using a rotary evaporator. The residue was recrystallized twice from methanol-ether mixture to yield 0.86 g.(43%) of N-benzyltrimethylammonium bromide, m.p. 235-236°(reported(68): 235°). The compound was insoluble in methylene chloride, acetonitrile and acetone, slightly soluble in dimethylsulfoxide and 95% ethanol

but soluble in chloroform, water and formamide. Uv(CH_3CN): $\lambda_{max.}$: 203 mμ(ε=17104). Nmr(D_2O): τ6.97(s, 9H), τ5.57(s, 2H), τ2.48 (s, 5H), τ5.37(s, D_2O).

Anal. Calcd. for $C_{10}H_{16}NBr$:C, 52.19; H, 7.01; N, 6.09; Br, 34.72.
Found: C, 52.01, 51.81; H, 7.08, 6.95; N, 5.41, 5.42; Br, 34.72.

N-benzyltrimethylammonium chloride

A 4 g. quantity of N-benzyltrimethylammonium hydroxide (40% in methanol, Aldrich Chemical Co. Inc. n_D^{20}: 1.4310) was neutralized with concentrated hydroxhloric acid. Methanol was added and the methanol-water mixture was removed using a rotary evaporator. The residue was recrystallized from acetone-ether mixture and dried in an Aberhalden drying apparatus to yield 1.8 g.(40%) of N-benzyltrimethylammonium chloride, m.p.235-236°. The compound was soluble in water and methanol, slightly soluble in nitrobenzene, chloroform and nitromethane. No satisfactory C, N, H analysis could be obtained. Nmr($CDCl_3$): τ6.54(s, 6H), τ4.87(s, 2H), τ2.08-2.69(m, 5H), τ6.95(s, 6H), τ5.5(s, 2H), τ2.44(s, 5H), τ5.34(s, D_2O).

Triethyloxonium fluoroborate(69)

A 200 ml. three-necked flask, a stirrer, a dropping funnel, a condenser provided with a drying tube were dried in an oven at 110°, assembled while hot and cooled in a stream of dry nitrogen. A 50 ml. quantity of sodium dried ether and 28.4 g.(25.2 ml., 0.2 mole) of freshly distilled boron fluoride etherate were placed in the flask.

Epichlorohydrin(14 g., 11.9 ml., 0.151 mole) was added dropwise to the stirred solution at a rate sufficient to maintain vigorous boiling, about one hour is needed. The mixture was refluxed an additional hour and allowed to stand at room temperature overnight. The solution was filtered and the crystalline mass of triethyloxonium fluoroborate was washed several times with ether and kept under ether at 0°. The triethyloxonium fluoroborate is colorless.(reported(69): m.p.91-92°, yield:4.5 g.).

Benzyl methyl sulfide(63)

To an ice cooled solution of sodium methoxide prepared by dissolving 12 g. of sodium in 300 cc. of methanol was added 25 g.(0.5 mole) of methyl mercaptan and then 63 g. of benzyl chloride. The mixture was refluxed for 2 hours on steam bath, the methanol was removed using a rotary evaporator. The residue was mixed with water and extracted three times with ether. The ether solution was dried with calcium chloride and the ether was evaporated off using a rotary evaporator. The residue was distilled at reduced pressure to yield 51 g. (74%) of benzyl methyl sulfide, b.p.$_{3mm.}$ 60°. Nmr(CS_2): τ8.23 (s, 3H), τ6.53(s, 2H), τ2.93(s, 5H).

Benzyl methyl sulfoxide(70)

A 35.1 g.(0.25 mole) quantity of benzyl methyl sulfide in 102 ml. of acetone was cooled in ice and 25.8 ml. of 30% H_2O_2 was added. the solution was stirred with a magnetic stirrer overnight. The acetone was removed using a rotary evaporator. When pentane was

added and the solution was cooled in dry ice-acetone bath, a solid was formed. This solid was washed with pentane which yield 18 g.(45%) of benzyl methyl sulfoxide, m.p.51-52°(reported(70): 54°). Nmr(CCl_4): τ7.71(s, 3H), τ6.13(s, 2H), τ2.74(s, 5H). Ir(CCl_4): 1050, 1066 $cm.^{-1}$

Benzylmethylethoxysulfonium fluoroborate

A 6.65 g.(0.035 mole) quantity of triethyloxonium fluoroborate was added to an equimolar amount of benzyl methyl sulfoxide(5.4 g) in methylene chloride. The solution was allowed to stand at room temperature for 5 hours. Ether was then added to induce precipitation. The solid which precipitated out was recrystallized from methylene chloride-ether mixture and dried overnight in an Aberhalden drying apparatus at room temperature to yield 8.8 g.(93%) of benzylmethylethoxysulfonium fluoroborate, m.p.76-77°. Nmr($CDCl_3$): τ8.8(t, J=7 cps, 3H), τ6.78 (s, 3H), τ5.75(q, J=7 cps, 2H), τ5.21(d, J=7 cps, 2H), τ2.57(m, 5H).

Anal. Calcd. for $C_{10}H_{15}SOBF_4$: C, 44.47; H, 5.60.
Found: C, 44.47, 44.57; H, 5.88, 5.77.

p-Chlorobenzylethylmethylsulfonium fluoroborate

A 2.5 g. quantity (0.009 mole) of p-chlorobenzylethylmethylsulfonium bromide was dissolved in methanol and passed through a column containing Dowex 1-x8(50-100 mesh) anion exchange resin in its hydroxide form. The basic eluent was neutralized with fluoroboric acid prepared (71) by adding 5 g. of boric acid in small proportions to 1.63 g. of

hydrofluoric acid(40% HF) cooled in ice. Most of the methanol was removed using a rotary evaporator. Ether was added until the solution turned cloudy. The solution was then allowed to stand in the fridge overnight. The p-chlorobenzylethylmethylsulfonium fluoroborate which crystallized out was dried for an hour in the Aberhalden drying apparatus which was heated with refluxing ethanol. The yield was 2.6 g. (100%), m.p. 84-84.5°. Nmr(CD_2Cl_2): See Run IV-87-A in Table XXXVIII(Chapter III).

Anal. Calcd. for $C_{10}H_{14}ClSBF_4$: C, 41.63; H, 4.89; Cl, 12.29; S, 11.11.

Found: C, 41.45, 41.98; H, 4.67, 4.93; Cl, 12.28, 12.30; S, 11.28, 11.00.

Trimethylsulfonium iodide

A 14.2 g.(0.095 mole) of methyl iodide was added to 4.5 g. (0.073 mole) of dimethyl sulfide in 10 ml. of acetone. The solution was allowed to stand at room temperature for 20 hours in an Erlenmayer flask wrapped with aluminum foil. On mixing the two reagents, brownish precipitate was formed immediately. The precipitate formed was washed thoroughly with ether until the color was pale yellow. After drying, the yield was 6.6 g.(44%), m.p. 204°(reported(66): 203-207°). The crystals turned yellowish on exposure to light.

Trimethylsulfonium perchlorate

Fresh silver oxide was prepared by adding 6.3 g.(0.033 mole) of silver nitrate to 1.9 g. (0.034 mole) of potassium hydroxide

and then washed free from base. A 6.6 g. quantity of trimethylsulfonium iodide prepared as described in the preceeding section was dissolved in 60% ethanol-40% water and then added to this freshly prepared silver oxide. The trimethylsulfonium hydroxide solution was divided into two portions. One portion was neutralized with dilute perchloric acid. The trimethylsulfonium perchlorate crystallized out when most of the ethanol was evaporated off using a rotary evaporator. The solid was recrystallized from acetone-ether mixture and dried in an Aberhalden drying apparatus heated with refluxing ethanol for two hours. Melting point of this compound was not taken because it was reported(66) that it may be highly explosive on decomposition. The compound was soluble in acetonitrile, dimethylsulfoxide, nitromethane, acetone, water, insoluble in chloroform, methylene chloride and slightly soluble in methanol. Nmr(90% CD_3COCD_3-10% D_2O): τ6.93(s), τ7.9(m, CD_3COCD_3), τ6.3(s, D_2O).

Anal. Calcd. for $C_3H_9ClO_4$: C, 20.40; H, 5.14; S, 18.15; Cl, 20.07.
Found: C, 20.03, 20.10; H, 4.73, 4.52; S, 17.87, 18.31; Cl, 20.00.

Trimethylsulfonium bromide

The second portion of trimethylsulfonium hydroxide solution prepared in the preceeding section was neutralized with dilute hydrobromic acid. The solvent was evaporated off on a rotary evaporator. Methanol was added several times to facilitate the evaporation of water. The residue was recrystallized from acetone-ether mixture and dried for 2 hours in an Aberhalden drying apparatus which was heated

with refluxing ethanol to yield 1 g. of trimethylsulfonium bromide, m.p. 201-202°(reported(66): m.p. 201-202°, decompose at 172°). Nmr(90% CD_3COCD_3-10% D_2O): τ6.84(s), τ7.93(m, CD_3COCD_3), τ6.51(s, D_2O). The compound was insoluble in acetonitrile, nitromethane, chloroform, acetone, methylene chloride but soluble in water, dimethylsulfoxide and methanol.

Anal. Calcd. for C_3H_9SBr: C, 22.94; H, 5.78; S, 20.41; Br, 50.87.
Found: C, 23.17, 22.64; H, 5.47, 5.31; S, 20.63, 20.36; Br, 50.98, 50.40.

KINETICS:

Titrimetric rates:

The sulfonium salt was accurately weighed into a tared flask. Solvent was added to the mark. The flask was shaken until all the salt was dissolved and a homogeneous solution was obtained. Aliquots of the solution(ca. 5.5 ml.) were transferred to thoroughly cleaned, partially drawn test tubes. These ampoules were then sealed and immersed in the appropriate constant temperature baths. These baths were thermostated at 70.00±0.02°, 50.00±0.02°or 25.00±0.02°. At appropriate time intervals, the ampoules were removed from the bath, placed in a dry ice-acetone bath and shaken for 30 seconds in order to quench the reaction. The first point was taken at least 4 minutes after the ampoules were placed in the bath so as to insure temperature equilibration. Infinity measurements were taken at approximately ten and twenty half-lives. Before the ampoules were opened, they were allowed to equilibrate to 25° in a constant temperature bath for 5 minutes. A 5 ml. aliquot was removed by means of a calibrated automatic pipette and delivered into a 50 ml. Erlenmayer flask containing 25 ml. of distilled water which had been boiled and cooled to room temperature prior to being used. Before the 5 ml. aliquot was added to the 25 ml. of water in the Erlenmayer flask, the water was first titrated with the sodium methoxide solution until the end point was reached. Each sample was titrated for acid with a standard solution of sodium methoxide in methanol using phenolphthalein as indicator. For reactions at 25°, sealed ampoules were not used, the volumetric flask containing the

solution was immersed in the 25°bath. At appropriate intervals, a 5 ml. aliquot was withdrawn from the volumetric flask and delivered into a 50 ml. Erlenmayer flask containing 25 ml. distilled water and titrated as described above.

Polarimetric rates

Method I. Aliquots of a standard solution of the optically active sulfonium salt were transferred to ampoules. The ampoules were sealed and placed in a constant temperature bath as described for the titrimetric rate analyses. Reactions measured at 70° and 50° were quenched as described above. After equilibration to 25°, the ampoules were opened and an aliquot of the solution was transferred to a 1 dm. polarimeter tube. The optical rotation was obtained from the digital readout of a Model 141 Perkin-Elmer Polarimeter. Measurements were made using an incident light beam with wavelengths of 589 mμ, 436 mμ and 365 mμ. A 'zero' reading was obtained before each measurement.

Method II. For some of the polarimetric analyses, the Model 141 Perkin-Elmer Polarimeter was equipped with a Honeywell recorder having a chart speed of 4 inches per hour. Water from a constant temperature bath, 49.99±0.02 or 25.01±0.02, was circulated through jacketed polarimeter tubes. An aliquot of the solution of the optically active salt was placed in the polarimeter tube and for some of the experiments, the optical rotation was continuously recorded. A 'zero' reading was taken before and after each run. For most of the runs, the optical rotation was taken from the digital readout at appropriate time

intervals and recorded in the laboratory book. The rate constants were calculated on the basis of the experimental infinity obtained after 10 half-lives(zero).

Analyses:

The product analyses for the solvolyses of the sulfonium perchlorates were performed by injecting the reaction solution directly into the gas chromatography apparatus.

The different columns and conditions of operation employed for gas chromatographic analysis are listed in Table XLVIII. For each determination, the analytical method was calibrated by control analyses on solutions of known composition.

Details of the analysis of the product distribution from the methanolysis of p-methylbenzylethylmethylsulfonium perchlorate are presented as typical example to illustrate the method of product analysis.

Two standard solutions were prepared. The first, III-152-1, contained p-methylbenzyl methyl ether(0.0725 M) and ethyl methyl sulfide (0.2032 M) in anhydrous methanol. The second, III-152-2, contained naphthalene(0.1064 M). benzene(0.1426 M) and 2,6-lutidine(0.08038 M) in chloroform.

A series of standard solutions containing various concentrations of p-methylbenzyl methyl ether were prepared by making a series of dilutions of the stock solution(III-152-1) with methanol as shown in Table XLIX.

TABLE XLVIII

COLUMNS AND CONDITIONS OF OPERATION FOR GAS CHROMATOGRAPHIC ANALYSES OF SUBSTITUTED BENZYLETHYLMETHYLSULFONIUM PERCHLORATES($R\emptyset CH_2\overset{+}{S}(CH_3)CH_2CH_3\ ClO_4^-$).

Solvent: Methanol; Column: Silicon oil DC 200(Dimethylsiloxane polymer) on acid washed chromosorb W; Detector Current: 200 ma.

R	Temperature Column (°C)	Injector (°C)	He Flow Rate (cc./min.)	Products(retention time in minutes are in brackets).
p-CH_3	105	317	300	p-$CH_3\emptyset CH_2OCH_3$(7.3); naphthalene (internal standard, 12.8).
p-Cl	174	320	60	p-$Cl\emptyset CH_2OCH_3$(3.3); phenyl ether(internal standard, 7.5).
m-NO_2	174	320	60	m-$NO_2\emptyset CH_2OCH_3$(6); naphthalene (internal standard, 2.6).
3-CH_3-4-OCH_3	174	307	60	3-CH_3-4-$OCH_3\emptyset CH_2OCH_3$(6.6); phenyl ether(internal standard, 8.1).
3,5-diCH_3-4-OCH_3	169	323	120	3,5-diCH_3-4-$OCH_3\emptyset CH_2OCH_3$(6.1); naphthalene(internal standard, 3.3).

Product analysis:

The solvolysis rates were determined by following the rates of acid production. Each mole of the sulfonium salts solvolyzed would account for one mole of acid. The amount of acid produced was determined by titration with standard solution of sodium methoxide using phenolphthalein as indicator as described in detail in the kinetics section.

The amounts of the other products were determined by gas chromatography. The products were not isolated from the solvent but the reaction solution was injected directly into the Perkin-Elmer Model 154-D Vapor Fractometer.

An accurately known amount of internal standard was added to each solution in order to ascertain the per cent recovery. The area of each component peak relative to the peak area of the internal standard was calculated using a Honeywell Disc Chart Integrator.

A series of control solutions containing various ratios of each product relative to the internal standard were prepared and analyzed in exactly the same manner as the product analysis in order to calibrate the analytical method. Standardization curves were constructed by plotting the weight ratios of each component and the standard vs. the ratios of their peak areas. From the curve, the yield of product was computed for each product analysis.

TABLE XLIX

STANDARD SOLUTIONS FOR THE PRODUCT ANALYSIS OF p-METHYLBENZYL METHYL ETHER

Solution	Aliquots of stock solution III-152-1(ml)	Aliquots of solvent (ml)
III-152-100	1 x 1.97	0
III-152-80	4 x 1.97	1 x 1.97
III-152-75	3 x 1.97	1 x 1.97
III-152-66 2/3	2 x 1.97	1 x 1.97
III-152-50	1 x 1.97	1 x 1.97
III-152-37 1/2	1 x 1.97 of III-152-75	1 x 1.97
III-152-20	1 x 1.97	4 x 1.97

Control solutions were prepared by transferring 1.97 ml. aliquots of each of these solutions by means of calibrated automatic pipette to 1.97 ml. aliquots of III-152-2. The weight of each component in the control solutions are listed in Table L. The plot of $A_{\phi CH_2OCH_3}/A_{naphthalene}$ vs. $g_{\phi CH_2OCH_3}/g_{naphthalene}$ is shown in Figure XIX.

TABLE L

CONTROL ANALYSES OF THE p-METHYLBENZYL METHYL ETHER FROM METHANOLYSIS OF p-METHYLBENZYLETHYLMETHYLSULFONIUM PERCHLORATE. RUN III-152.

Control	$g_{p\text{-}CH_3\phi CH_2OCH_3}$	$g_{naphthalene}$	weight ratio $g_{p\text{-}CH_3\phi CH_2OCH_3}/g_{naphthalene}$	area ratio $A_{p\text{-}CH_3\phi CH_2OCH_3}/A_{naphthalene}$
III-152-100	0.01946	0.02683	0.725	0.733
III-152-80	0.01557	0.02683	0.580	0.582
III-152-75	0.0146	0.02683	0.544	0.556
III-152-66 2/3	0.01297	0.02683	0.483	0.478
III-152-50	0.00973	0.02683	0.363	0.366
III-152-37 1/2	0.007298	0.02683	0.272	0.271
III-152-20	0.00389	0.02683	0.145	0.163

Product analysis: Run III-152

A 0.2255 g. quantity of p-methylbenzylethylmethylsulfonium perchlorate was added to a tared 25 ml. volumetric flask, 0.1749 g. of 2,6-lutidine was also added. After dilution to the mark with anhydrous methanol and mixing by shaking the flask 100 times, 6 ml. aliquots were transferred to ampoules which were sealed and put in the 90° bath. After 30 half-lives, the ampoules were opened, 4.93 ml. aliquots were withdrawn from the ampoules and transferred to Erlenmayer flasks. A 1.97 ml. quantity of control solution III-152-2

was added to the Erlenmayer flask and 20 µl. aliquots were injected into the VPC. The relative area of p-methylbenzyl methyl ether to naphthalene were determined. From the plot in Figure XIX , the weight of p-methylbenzyl methyl ether relative to the weight of naphthalene was determined. The weight of the p-methylbenzyl methyl ether in the 4.93 ml. aliquot was then determined by multiplying the relative weight ratio by the weight of naphthalene in 1.97 ml. of control solution, III-152-2.

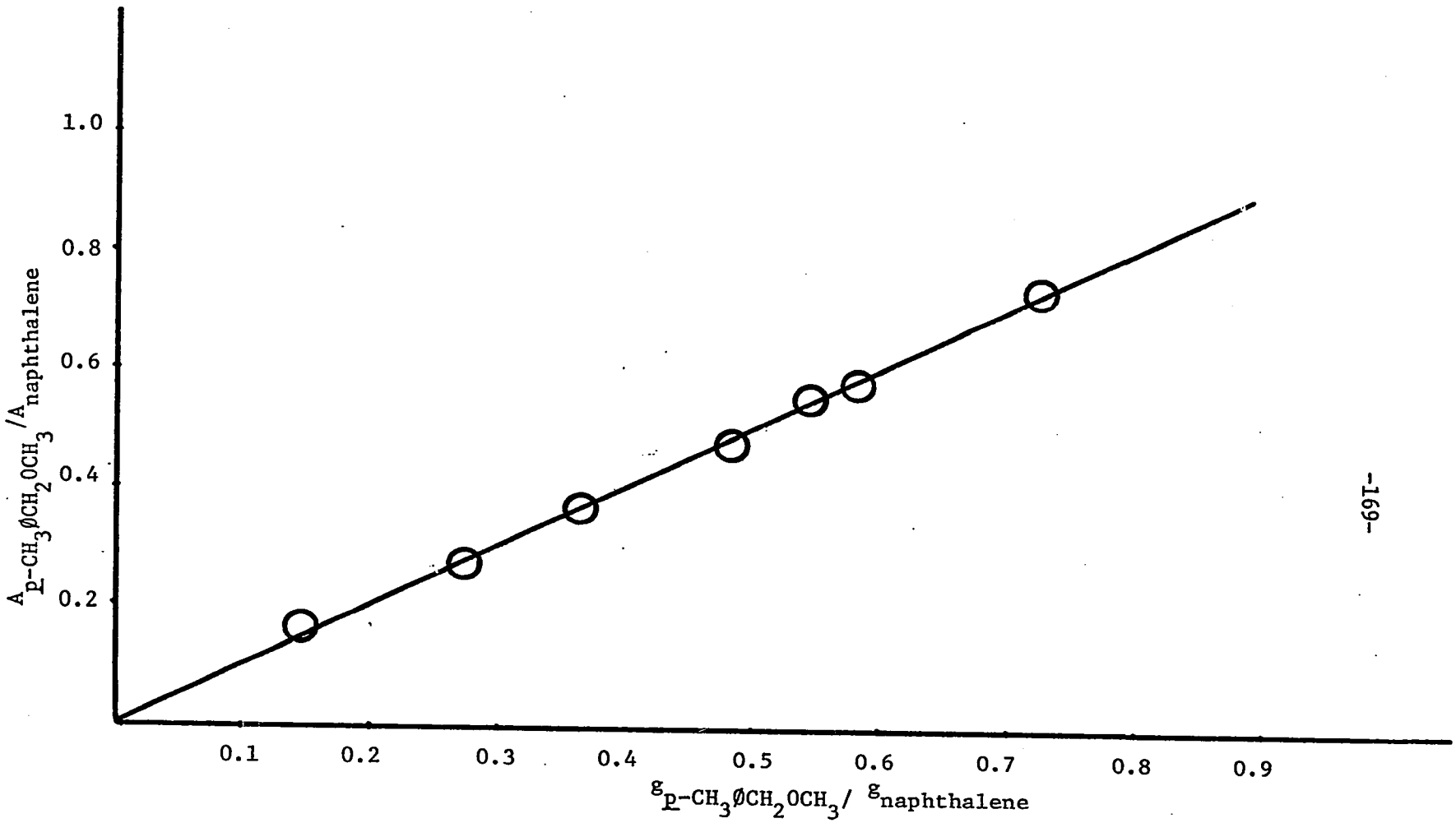


Figure XIX. Calibration curve for the product analysis of p-methylbenzylethylmethylsulfonium perchlorate with added 2,6-lutidine in anhydrous methanol using naphthalene as internal standard. Run III-152.

Volhard determination of bromide ion(72)

A 4.93 ml. aliquot of solution containing the reaction product was pipetted into 25 ml. of pentane in a 50 ml. separatory funnel. The mixture was extracted with two successive 10 ml. portions of boiled distilled water. The procedure was standardized at 40 'shakes' for the first extraction and 30 for the second. The aqueous extracts were combined, acidified with 5 drops of 6N nitric acid, using 20 drops of ferric alum as indicator, an excess of silver nitrate solution was added and the excess back titrated with a standard solution of potassium thiocynate until a brownish color was produced.

Preparation of mixtures for low temperature nmr runs

Benzylmethylethoxysulfonium fluoroborate was allowed to react with p-chlorobenzylethylmethylsulfonium bromide. When the crystals were mixed, the mixtures turned yellowish. Therefore, the two compounds were weighed accurately into two separate vials. One compound was first put into the nmr tube, the nmr tube was then immersed in the dry ice-acetone bath, about half of the required amount of solvent was put into the tube using a hypodermic syringe. The other compound was then added to the tube. Both vials were washed with a small amount of the solvent and the solutions were put into the nmr tube. More solvent was put into the nmr tube until the required amount had been added. The nmr tube was capped and shaken at room temperature until the solids all dissolved. The tube was repeatedly immersed in the dry ice-acetone bath in order to insure that the temperature was kept low. The same procedure was used for

Run IV-88-A in Table XLV which contained a mixture of p-chlorobenzylethylmethylsulfonium bromide and tetra-n-butylammonium perchlorate. In Run IV-86-B(Table XLV), a slightly different procedure was used. The two compounds were weighed in the same vial and the mixture of crystals were put in CD_2Cl_2 ccooled in dry ice-acetone bath. Both Runs IV-86-B and IV-88-A gave the same nmr spectra.

Run IV-88-A in Table XLV which contained a mixture of p-chlorobenzylethylmethylsulfonium bromide and tetra-n-butylammonium perchlorate. In Run IV-86-B(Table XLV), a slightly different procedure was used. The two compounds were weighed in the same vial and the mixture of crystals were put in CD_2Cl_2 cooled in dry ice-acetone bath. Both Runs IV-86-B and IV-88-A gave the same nmr spectra.

BIBLIOGRAPHY

(1) C.K. Ingold: Structure and Mechanism in Organic Chemistry, Chapter VII. Cornell University Press, Ithaca, New York (1953).

(2) C. W. Bwan, E. D. Hughes and C. K. Ingold: Nature, 171, 301(1953).

(3) J. W. Baker and W. S. Nathan: J. Chem. Soc. 1844(1935).

(4) L. C. Bateman, M. G. Church, E. D. Hughes, C.K. Ingold and N. A. Taher: J. Chem. Soc. 979(1940).

(5) W. G. Young, S. Winstein and H. L. Goering: J. Amer. Chem. Soc. 73, 1958(1951).

(6) E. D. Hughes: Trans. Faraday Soc. 37, 603(1941).

(7) L. P. Hammett, Physical Organic Chemistry, p. 40, McGraw-Hill Book Company Inc., New York(1940).

(8) R. M. Fuoss: Chem. Rev. 17, 27(1935).

(9) R. M. Fuoss: J. Amer. Chem. Soc. 79, 3304(1957).

(10) R. M. Fuoss and C. A. Kraus: J. Amer. Chem. Soc. 79, 3304(1957).

(11) S. Winstein and G. Robinson: J. Amer. Chem. Soc. 80, 169(1958).

(12) K. A. Cooper, E. D. Hughes, C. K. Ingold and B. J. MacNulty J. Chem. Soc. 2038(1948).

(13) K. A. Cooper, M. L. Dhar, E. D. Hughes, C. K. Ingold, B. J. MacNulty and L. I. Woolf: J. Chem. Soc. 2043(1948).

(14) K. A. Cooper, E. D. Hughes, C. K. Ingold, G. A. Maw and B. J. MacNulty: J. Chem. Soc. 2049(1948).

(15) E. D. Hughes, C. K. Ingold and G. A. Maw: J. Chem. Soc. 2072(1948).

(16). E. D. Hughes, C. K. Ingold, G. A. Maw and C. I. Woolf: J. Chem. Soc. 2079(1948).

(17) E. D. Hughes, C. K. Ingold and L. I. Woolf: J. Chem. Soc. 2084 (1948).

(18) E. D. Hughes, C. K. Ingold and A. M. M. Mandour: J. Chem. Soc. 2090(1948).

(19) M. L. Dhar, E. D. Hughes, C. K. Ingold, A. M. M. Mandour, G. A. Maw and L. I. Woolf: J. Chem. Soc. 2093(1948).

(20) C. G. Swain, L. K. Kaiser and T. E. C. Knee: J. Amer. Chem. Soc. 80, 4089(1958).

(21) A. L. Jacobsen and J. B. Hyne: J. Amer. Chem. Soc. 80, 2418(1960).

(22) J. B. Hyne: Can. J. Chem. 39, 1207(1961).

(23) J. B. Hyne and J. W. Abrell: Can. J. Chem. 39, 1657(1961).

(24) J. B. Hyne and J. H. Jensen: Can. J. Chem. 40, 1394(1962).

(25) J. B. Hyne and J. H. Jensen: Can. J. Chem. 41, 1679(1963).

(26) J. B. Hyne and H. S. Golinkin: Can. J. Chem. 41, 3139(1963).

(27) J. B. Hyne and J. H. Jensen: Can. J. Chem. 43, 57(1965).

(28) M. P. Balfe, J. Kenyon and H. Phillips: J. Chem. Soc. 2554(1930).

(29) D. Darwish and G. Tourigny: J. Amer. Chem. Soc. 88, 4303(1966).

(30) D. Darwish and R. Tomilson: J. Amer. Chem. Soc. 90, 5938(1968).

(31) R. Scartizzini and K. Mislow: Tetrahedron Letters No. 28, 2717 (1967).

(32) D. Darwish, S. H. Hui and R. Tomilson: J. Amer. Chem. Soc. 90, 5631(1968).

(33) Dennis G. Owsley, G. K. Helmkamp and M. F. Rettig: J. Amer. Chem. Soc. 91, 5239(1969).

(34) C. R. Johnson and Juan J. Rigau: J. Amer. Chem. Soc. 91, 5239 (1969).

(35) Raymond Quelet, Juan Allard, Joseph Ducasse and Yuette Germain: Bull. Soc. Chim.(5), 4, 1092(1937).

(36) Goering and Levy: J. Amer. Chem. Soc. 84, 3835(1962).

(37) A. A. Frost and R. G. Pearson: Kinetics and Mechanisms, p.98-100. John Wiley and Sons, Inc. N. Y. (1953).

(38) S. Winstein, E. Grunwald and H. W. Jones: J. Amer. Chem. Soc. 73, 2700(1951).

(39) F. H. Westheimer: Accounts of Chemical Research Vol. 1, 70 (1968).

(40) K. R. Brower and I. B. Douglass: J. Amer. Chem. Soc. 73, 5787 (1951).

(41) I. B. Douglass, K. R. Brower and F. T. Martin: J. Amer. Chem. Soc. 74, 5770(1952).

(42) W. A. Sheppard: J. Amer. Chem. Soc. 84, 3058(1962).

(43) R. M. Rosenberg and E. L. Muetterties: Inorg. Chem. 1, 756(1962).

(44) H. Kwart, R. W. Body and D. M. Hoffmann: Chem. Commun.765(1967).

(45) H. Kwart and P. S. Strilko: Chem. Commun. 767(1967).

(46) W. E. McEwen, G. H. Briles and B. E. Giddings: J. Amer. Chem. Soc. 91, 7079(1969).

(47) C. G. Swain and L. K. Kaiser: J. Amer. Chem. Soc. 79, 1612(1957).

(48) R. L. Buckson and Stanley G. Smith: J. Phys. Chem. 68,1875(1964).

(49) Weast: Hand ook of Chemistry and Physics, 47th Edition, 1966-1967, P. E-54. The Chemical Rubber Co. (Ohio).

(50) Kosower, An Introduction to Physical Organic Chemistry, p. 269-271, John Wiley and Sons, Inc.

(51) C. G. Swain, L. K. Kaiser and T. E. C. Knee: J. Amer. Chem. Soc. 80, 4093(1958).

(52) L. F. Fieser: Experiments in Organic Chemistry, 3rd Edition, p. 289, D. Heath and Co., Boston(1957).

(53) S. G. Smith, A. H. Fainberg and S. Winstein: J. Amer. Chem. Soc. 83, 624(1961).

(54) Ralph Tomilson: M. Sc. Thesis, Alberta(1968).

(55) S. G. Smith, A. H. Fainberg and S. Winstein: J. Amer. Chem. Soc. 83, 618(1961).

(56) L. F. Fieser: Experiments in Organic Chemistry, 3rd Edition, p. 291, D. Heath and Co., Boston(1957).

(57) H. C. Brown, S. Johnson and H. Podell: J. Amer. Chem. Soc. 76, 5556(1954).

(58) C. L. Butler and L. H. Cretcher: J. Amer. Chem. Soc. 55, 2605 (1933).

(59) F. Zetzche and M. Hubachu: Helv. Chim. Acta. 9, 293(1926).

(60) W. E. McEwen, D. M. Coyne and C. A. Vanderwerf: J. Amer. Chem. Soc. 78, 3061(1956).

(61) Bamberger: Ber. 36, 2028(1903).

(62) Norris, Watt and Thomas: J. Amer. Chem. Soc. 38, 1077(1916).

(63) Horst Bohme and Walter Krause: Chem. Ber. 426-432(1949).

(64) Vogel, Practical Organic Chemistry, 3rd Edition, p. 669, Longmans, Green and Co. Ltd., London(1956).

(65) Carothers, Adams: J. Amer. Chem. Soc. 46, 1681(1924).

(66) Heilbron and Bunbury: Dictionary of Organic Compounds, Vol 3, London(1953).

(67) Lois Green: Ph. D. Thesis, Alberta(1969).

(68) M. S. Kharasch, G. N. Williams and W. Nudenberg: J. Org. Chem. 20, 937-52(1955).

(69) H. Meerwein; Org. Syn. 46, 113(1966).

(70) Siegfried Hunig and Otto Boes, Ann. 579, 23-7(1958).

(71) Vogel, Practical Organic Chemistry, 3rd Edition, p. 612, Longmans, Green and Co. Ltd., London(1956).

(72) L. F. Hamilton and S. G. Simpson: Quantitative Chemical Analysis, Eleventh Edition, p. 296. The Macmillan Company(1958).