PART I
THE MECHANISM OF THE LIQUID PHASE PYROLYSIS OF DIALKYL OXALATES
PART II
NUCLEAR MAGNETIC RESONANCE STUDIES OF N-METHYLPHENYLHYDRAZONES

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
Karl L. Krumel
1965

ABSTRACT

PART I

THE MECHANISM OF THE LIQUID PHASE PYROLYSIS OF DIALKYL OXALATES

PART II

NUCLEAR MAGNETIC RESONANCE STUDIES OF N-METHYLPHENYLHYDRAZONES

by Karl L. Krumel

The purpose of this investigation was to study in greater detail the mechanism of the liquid phase pyrolysis of dialkyl oxalates that was originally suggested to proceed through an ion pair intermediate (1).

The oxalates of tertiary alcohols decomposed smoothly at 140-170° affording excellent yields of alkenes while those of primary or secondary alcohols decomposed only after prolonged heating at 300-360°.

Systems prone to carbonium ion rearrangements, *i.e.* bis-(2-cyclohexyl-2-propyl) oxalate and bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3) oxalate, underwent approximately 10% of 1,2-hydride or 1,2-alkyl shift.

Bis-(*erythro*-1,2-diphenylethyl-2-d_1) oxalate and bis-(*threo*-1,2-diphenylethyl-2-d_1) oxalate decomposed stereospecifically to give 90% of *trans*-stilbene-α-d_1 and 90% of *trans*-stilbene respectively.

Bis-(*exo*-2-norbornyl) oxalate yielded 95% of norbornene and 5% of nortricyclene, bis-(*endo*-2-norbornyl) oxalate yielded 76%

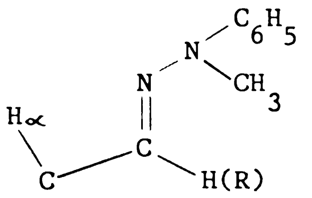
of nortricyclene and 24% of norbornene, and bis-(2-(Δ^3-cyclopentenyl) ethyl) oxalate yielded 70% of nortricyclene, 3% of norbornene, and 27% of Δ^3-cyclopentenylethene.

When the β-hydrogens were replaced with deuterium, the isotope effect k_H/k_D was 1.8 at 170°.

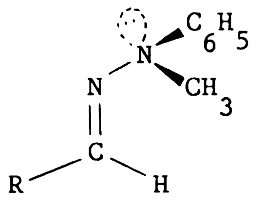
The data suggest that the position of the anion with respect to the cation in the intermediate is important in determining product composition. The mechanism involves first a slow ionization of the ester to an ion pair intermediate and a subsequent fast elimination that competes favorably with carbonium ion rearrangements and ion pair equilibration.

The purpose of the second investigation was to study by n.m.r. the relative stabilities of the various configurations and conformations of N-methylphenylhydrazones.

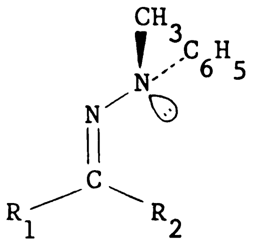
Aldehyde N-methylphenylhydrazones exist only in the syn form (N-methylanilino group cis to the "aldehydic" proton) while ketone N-methylphenylhydrazones exist in both syn and anti forms. Whereas aldehyde N-methylphenylhydrazones show five-bond coupling between the N-methyl and the "aldehydic" proton (J = 0.5-0.7 c.p.s.) and six-bond coupling between the N-methyl and α-hydrogens (J = 0.0-0.4 c.p.s.), ketone N-methylphenylhydrazones do not. These observations, coupled with ultraviolet spectral data (λ_{max} = 275-280mμ and ϵ = 2×10^4 for aldehyde derivatives, and λ_{max} = 248-250mμ and ϵ = 1×10^4 for ketone derivatives), suggest structure II for aldehyde



I



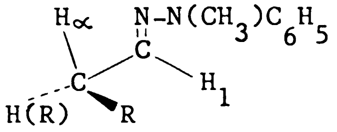
II



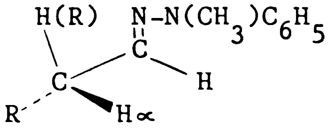
III

N-methylphenylhydrazones and structure III for ketone N-methylphenylhydrazones.

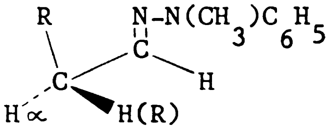
Conformations resulting from rotation about the sp^2-sp^3 bond were studied by measuring the coupling constants between the "aldehydic" proton and the α-proton. Assuming that tert-butylacetaldehyde N-methylphenylhydrazone exists exclusively in conformation IV,



IV



V



VI

J_t ($J_{H_1H_\alpha}$ in IV) and J_g ($J_{H_1H_\alpha}$ in V) were calculated to be 10.30 c.p.s. and 2.44 c.p.s. respectively. Using these values, the relative amounts of rotamers IV, V, and VI were calculated for various substituted acetaldehyde N-methylphenylhydrazones. In all cases the more stable rotamer is one where a proton eclipses the double bond (IV).

LITERATURE CITED

1) G. J. Karabatsos, J. M. Corbett, and K. L. Krumel, J. Org. Chem., 29, 689(1965)

Reason is Unity . . . All arts lie in man, though not all are apparent. The awakening brings them out. To be taught is nothing; everything is in man, waiting to be awakened.

Paracelsus

PART I

THE MECHANISM OF THE LIQUID PHASE PYROLYSIS OF DIALKYL OXALATES

PART II

NUCLEAR MAGNETIC RESONANCE STUDIES OF N-METHYLPHENYLHYDRAZONES

By

Karl L. Krumel

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Chemistry

1965

ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. G. J. Karabatsos for his continued interest, counsel, and encouragement rendered throughout the course of this investigation.

He also thanks the United States Atomic Energy Commission and the National Science Foundation for partial financial support.

Special thanks are extended to his wife Nancy for her patience, understanding, and assistance while attending Michigan State University.

****

TABLE OF CONTENTS

Page

PART I

THE MECHANISM OF THE LIQUID PHASE PYROLYSIS OF DIALKYL OXALATES

TABLE OF CONTENTS - Continued

PART II

NUCLEAR MAGNETIC RESONANCE STUDIES OF N-METHYLPHENYLHYDRAZONES

LIST OF TABLES

TABLE Page

PART I

PART II

LIST OF TABLES - Continued

LIST OF FIGURES

PART I

PART II

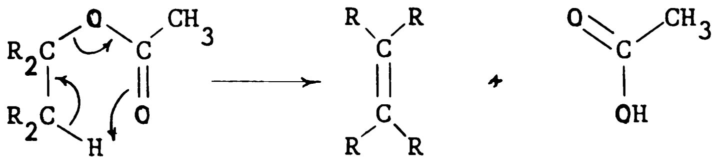
PART I

THE MECHANISM OF THE LIQUID PHASE PYROLYSIS OF DIALKYL OXALATES

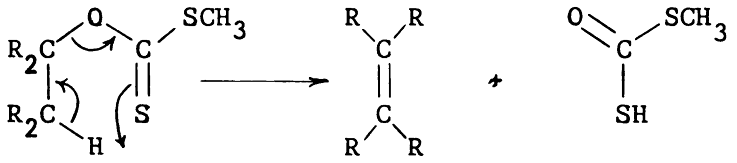
INTRODUCTION

The thermal decomposition of acetate esters, amine oxides, xanthates, and other related organic molecules to yield alkenes has been studied extensively (1,2,3). The reaction has been shown to proceed by a stereospecific <u>cis</u> elimination in which a cyclic concerted mechanism is involved. Three representative reactions are illustrated below.

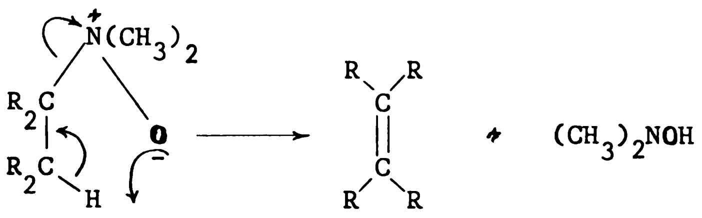
Acetate Ester



Xanthate (Chugaev Reaction)



Amine Oxide



Of the many thermal elimination reactions known, the decomposition of acetate esters has been studied most extensively. The reaction follows definite stoichiometry and first order kinetics, the side reactions are few, it is unimolecular, homogeneous, and generally has a negative entropy of activation (1).

Acetate esters of secondary or tertiary alcohols give mixtures of alkenes in which the less thermodynamically stable alkenes resulting from Hofmann elimination predominate. The composition is thought to be governed by several factors (1): (1) the number of *cis* β-hydrogens, (2) steric crowding in the transition state, (3) thermodynamic stability of the alkenes formed, and (4) the acidity of the β-hydrogens.

G. G. Smith and co-workers have studied the kinetics of the pyrolysis of substituted 1-arylethyl and 2-arylethyl acetates (4), 1,2-diarylethyl acetates (5), and substituted ethyl benzoates (6) in order to obtain a better picture of the transition state. They observed that the pyrolysis of the acetates at 600°K followed σ^{+}. The ρ for 1-aryl-2-phenylethyl acetates and 1-arylethyl acetates were -0.66 and -0.62 respectively. The ρ for 1-phenyl-2-arylethyl acetates and 2-arylethyl acetates were +0.3 and +0.08 respectively. They interpreted these data to suggest that there is a small amount of charge separation of the carbon-oxygen bond and that the strength of the carbon-oxygen bond is more important than the strength of the carbon-β-hydrogen bond in governing ester stability. The stability of the olefin formed is not an important factor since due to the small ρ observed for the 1-aryl-2-phenylethyl acetates and the 1-arylethyl acetates, the rate determining step must have occurred early along the reaction path at which stage, olefin formation is negligible.

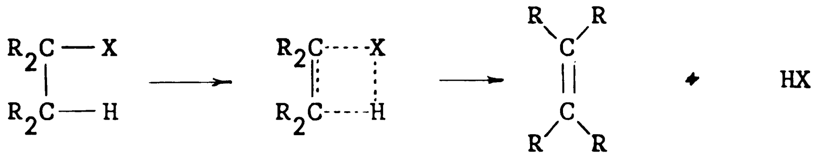
Scheer and co-workers have studied the kinetics of the pyrolysis of aliphatic acetates and have concluded that before a cyclic concerted elimination takes place, an initial small charge separation at the carbon-oxygen bond occurs (7).

The study of substituted ethyl benzoates afforded an examination of the effect of changes in electron availability at the carbonyl carbon on the rate of decomposition. The results were compatible with the postulated small amount of charge separation at the carbon-oxygen bond. The reaction followed σ with electronegative groups accelerating the reaction by stabilizing the partially formed anion.

The mechanism of the pyrolysis of acetate esters is currently viewed as taking place by a concerted mechanism with small charge separation resulting in the partial formation of a positive charge at the carbon bearing the acetoxy group. The rate determining step involves simultaneous cleavage of the carbon-oxygen and carbon-hydrogen bond which accounts for the observed isotope effect of $k_H/k_D = 1.6\text{-}1.9$ at 400° (8,9) when the β-hydrogen is replaced with deuterium. Wiberg has determined the theoretical value for k_H/k_D for the loss of one carbon-hydrogen stretching vibration as a function of temperature (10). At 400° k_H/k_D equals 2.3.

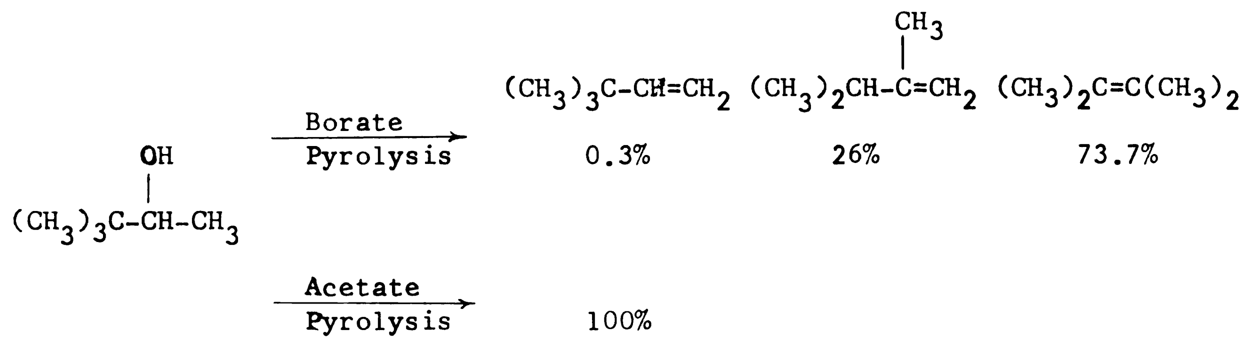
The pyrolysis rates of esters, <u>i.e.</u> tertiary $>$ secondary $>$ primary (1), is in accord with the suggested mechanism.

The thermal decomposition of alkyl halides has also been interpreted as proceeding through a concerted cyclic mechanism in which the products are the thermodynamically more stable alkenes arising from Saytzeff elimination (1,11).



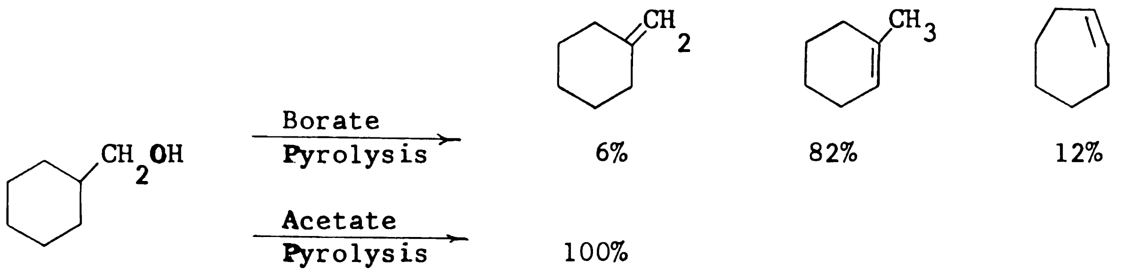
The relative rates of elimination, tertiary > secondary > primary, are much larger than those encountered for the acetate pyrolysis and may be rationalized by suggesting more charge separation at the transition state. An isotope effect of $k_H/k_D = 2.2$ at 500° strongly suggests that cleavage of the carbon-β-hydrogen bond is extensive in the transition state (12). The predominant Saytzeff elimination may be explained by isomerization of the initial alkenes by the hydrogen halide formed in the homogeneous vapor phase reaction.

Several other thermal elimination reactions yield alkenes whose formation is better explained by invoking a carbonium ion mechanism. The pyrolysis of borate esters has been shown to give excellent yields of alkenes at temperatures of 250-290° (13,14). Chapman investigated the structural integrity of the reaction by studying systems which are prone to carbonium ion rearrangements. The pyrolysis of the borates of 3,3-dimethyl-2-butanol and cyclohexylcarbinol are examples of what is observed.



$$(CH_3)_3C\text{-}\overset{\displaystyle OH}{\overset{|}{C}H}\text{-}CH_3 \xrightarrow[\text{Pyrolysis}]{\text{Borate}} \underset{0.3\%}{(CH_3)_3C\text{-}CH{=}CH_2} \quad \underset{26\%}{(CH_3)_2CH\text{-}\overset{\displaystyle CH_3}{\overset{|}{C}}{=}CH_2} \quad \underset{73.7\%}{(CH_3)_2C{=}C(CH_3)_2}$$

$$\xrightarrow[\text{Pyrolysis}]{\text{Acetate}} \quad 100\%$$



Chapman concluded that the reaction proceeds by ionization of the borate ester to either an ion pair or to more completely separated ions. The olefins are then derived from carbonium ions sufficiently free to rearrange.

The dehydration of tertiary aliphatic alcohols in dimethyl sulfoxide at 160-185° provides alkenes in good yield (15). The isomeric distribution arises from predominantly Saytzeff elimination and a carbonium ion mechanism is suggested. The actual mechanism is not clear since alcohols treated under the same conditions in the absence of dimethyl sulfoxide do not react. The elimination may be due to acid impurities in the dimethyl sulfoxide.

$$CH_3CH_2C(CH_3)_2OH \xrightarrow[\Delta]{\text{DMSO}} \underset{59\%}{CH_3CH{=}C(CH_3)_2} + \underset{41\%}{CH_3CH_2C(CH_3){=}CH_2}$$

The first apparent study of the liquid phase pyrolysis of dialkyl oxalates was performed by Karabatsos and co-workers (16). They studied several oxalate esters and made the following observations: (1) esters derived from tertiary aliphatic alcohols decompose smoothly at 140-170° affording good yields of alkenes in which the thermodynamically more stable isomers resulting from Saytzeff elimination predominate; (2) esters derived from primary and secondary acyclic alcohols do not decompose upon heating to 325°; (3) esters derived from secondary alicyclic alcohols decompose at 250-300° yielding the expected alkenes and the corresponding formate esters; (4) the composition of the alkene mixture is not affected by decomposing the ester in the presence of one equivalent of oxalic acid; and (5) no carbon skeletal rearrangements were observed in the decomposition of tertiary dialkyl oxalates. They concluded that due to the similarity of the olefin composition to those observed from acid catalyzed dehydration and from the dehydration in dimethyl sulfoxide of alcohols rather than to those observed from the pyrolysis of acetates, the mechanism of the elimination involves the formation of an ion pair with the oxalate anion acting as the nucleophile rather than proceeding through a cyclic concerted mechanism.

The purpose of this investigation was to elucidate more clearly the mechanism of the liquid phase pyrolysis of dialkyl oxalate esters by analyzing the resulting alkene mixtures and by studying the effects of the structure of the alkyl portion on the ease of decomposition. Of secondary interest was an evaluation of the reaction as a tool for the synthesis of alkenes.

RESULTS AND DISCUSSION

The dialkyl oxalates were prepared by the addition of oxalyl chloride to an ether solution of pyridine and the appropriate alcohol. The purity of the esters was established by infrared (i.r.) and nuclear magnetic resonance (n.m.r.) analysis. The i.r. spectra showed two strong carbonyl stretching frequencies at about 5.7μ and 5.8μ in agreement with the data reported by Corbett (3). The absence of the hydroxyl stretching absorption at about 3.0μ was considered adequate proof that the esters were sufficiently pure.

Table I summarizes the results of the thermal decomposition of dialkyl oxalates. In all subsequent illustrations the formula R-OX refers to the dialkyl oxalate ester.

Pyrolysis of oxalate esters was effected by heating the sample in a small flask equipped with a four-inch Vigreux column and distillation head until a visible reaction accompanied by distillation took place. The distillate was collected in a receiver cooled with an isopropyl alcohol-dry ice bath and immediately analyzed by vapor phase chromatography (v.p.c.) and by n.m.r.

Benzylic Systems

Since tertiary aliphatic oxalates decompose smoothly at 140-170°, it was anticipated from normal orders of reactivity that the benzylic system should behave similarly. Bis-(1-phenylethyl)

Table I. Thermal Decomposition of **O**xalate Esters

Oxalate	Decomp. Temp.	Alkenes Formed	Mole % NMR	 VPC	Yield %
Bis-(1-phenylethyl)	150-170	styrene	100		67%[a]
Bis-(1,2-diphenylethyl)	b	*trans*-stilbene	95		
		cis-stilbene	5		51%
Bis-(1-octyl)	350-360	1-octene	98	-	-
		2-octene	2	-	
Bis-(2-octyl)	320-350	1-octene	35	44[c]	-
		2-octene	65	56	
Bis-(cyclohexylcarbinyl)	330-360	methylenecyclohexane	-	88	-
		1-methylcyclohexene	-	12	
Bis-(cyclopentylcarbinyl)	350-360	methylenecyclopentane	77	80	
		1-methylcyclopentene	17	16	
		cyclohexene	6	4	-
Bis-(2-cyclopentylethyl)	350-360	cyclopentylethene		100	-
Bis-(*exo*-2-norbornyl)	245-255	norbornene	95	94	
		nortricyclene	5	6	-
Bis-(*endo*-2-norbornyl)	275-285	norbornene	16	24	
		nortricyclene	84	76	-

Oxalate	Decomp. Temp.	Alkenes Formed	Mole %		Yield %
			NMR	VPC	
Bis-(*endo*-2-norbornyl-2,3,3-d_3)	290-320	norbornene	-	24[d]	
		nortricyclene	-	76	-
Bis-(2-(Δ^3-cyclopentenyl)ethyl)	320-350	norbornene	-	3	
		nortricyclene	-	70	
		Δ^3-cyclopentenylethene	-	27	-
Bis-(2-cyclohexyl-2-propyl)	150-160	isopropenylcyclohexane	72	83[e]	
		1-isopropylcyclohexene	10		
		isopropylidinecyclohexane	18	17	87%
Bis-(2-cyclopentyl-2-propyl)	145-155	isopropenylcyclopentane	10	12	
		1-isopropylcyclopentene	20	24	
		isopropylidinecyclopentane	70	64	86%
Bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3)	160-165	2-(methyl-d_3)-3,3-dimethyl-1-butene	55		
		2,3,3-trimethyl-1-butene-1,1-d_2	31	f	
		2,3,3-trimethyl-1-butene-4,4,4-d_3	14		75%
Bis-(*cis*-1,2-dimethylcyclopentyl)	135-140	1,2-dimethylcyclopentene	-	85	
		2,3-dimethylcyclopentene	-	15	
		1-methylene-2-methylcyclopentane	-	0	92%
Bis-(*trans*-1,2-dimethylcyclopentyl)	140-145	1,2-dimethylcyclopentene	-	22	
		2,3-dimethylcyclopentene	-	75	
		1-methylene-2-methylcyclopentane	-	3	83%
Bis-(*erythro*-1,2-diphenylethyl)	b	*trans*-stilbene-α-d_1	90[g]	-	
		trans-stilbene	10	-	56%
Bis-(*threo*-1,2-diphenylethyl)	b	*trans*-stilbene-α-d_1	10[g]	-	
		trans-stilbene	90	-	48%

	Decomp.		Mole %		Yield
Oxalate	Temp.	Alkenes Formed	NMR	VPC	%
Bis-(2-methyl-2-propyl-1,1,1,2,2,2-d$_6$)	170	2-(methyl-d$_3$)propene-3,3,3-d$_3$	47	-	-
		2-methylpropene-1,1,3,3,3-d$_5$	53	-	
Bis-(*cis*-1-methyl-4-*tert*-butylcyclohexyl)	140-145	1-methyl-4-*tert*-butylcyclohexene	-	91	-
		1-methylene-4-*tert*-butylcyclohexane	-	9	
Bis-(*trans*-1-methyl-4-*tert*-butylcyclohexyl)	175-180	1-methyl-4-*tert*-butylcyclohexene	90	88	60%
		1-methylene-4-*tert*-butylcyclohexane	10	12	
Bis-(1-*tert*-butylcyclohexyl)	150-160	1-*tert*-butylcyclohexene	94	94	85%
		1-isopropenyl-1-methylcyclohexane	6	6	
1,4-Dioxa-5,5,6,6-tetramethyl-2,3-cyclohexanedione	330-360	2,3-dimethyl-1,3-butadiene	100		-

[a] Some polymer remained in the residue.

[b] The compound was decomposed in refluxing quinoline (b.p. 237°).

[c] The 20% apiezon column would not sufficiently separate the alkenes for an accurate integration.

[d] The deuterium content is not noted here and will be discussed later.

[e] The two compounds were not separated on a 20% silicon column.

[f] V.p.c. showed a single peak.

[g] The *cis*-stilbene was removed prior to this analysis.

oxalate decomposed at 150-170° to yield styrene as the sole product which was identified by its i.r. spectrum and from the melting point of the dibromide; m.p. 73-74° (reported (17) m.p. 73°).

Bis-(1,2-diphenylethyl) oxalate was decomposed in refluxing quinoline to yield approximately 95% of *trans*-stilbene and 5% of *cis*-stilbene. The *trans*-stilbene was purified by recrystallization from ethanol and its identity was confirmed by i.r. and no mixed melting point depression with an authentic sample.

Primary and Secondary Acyclic Systems

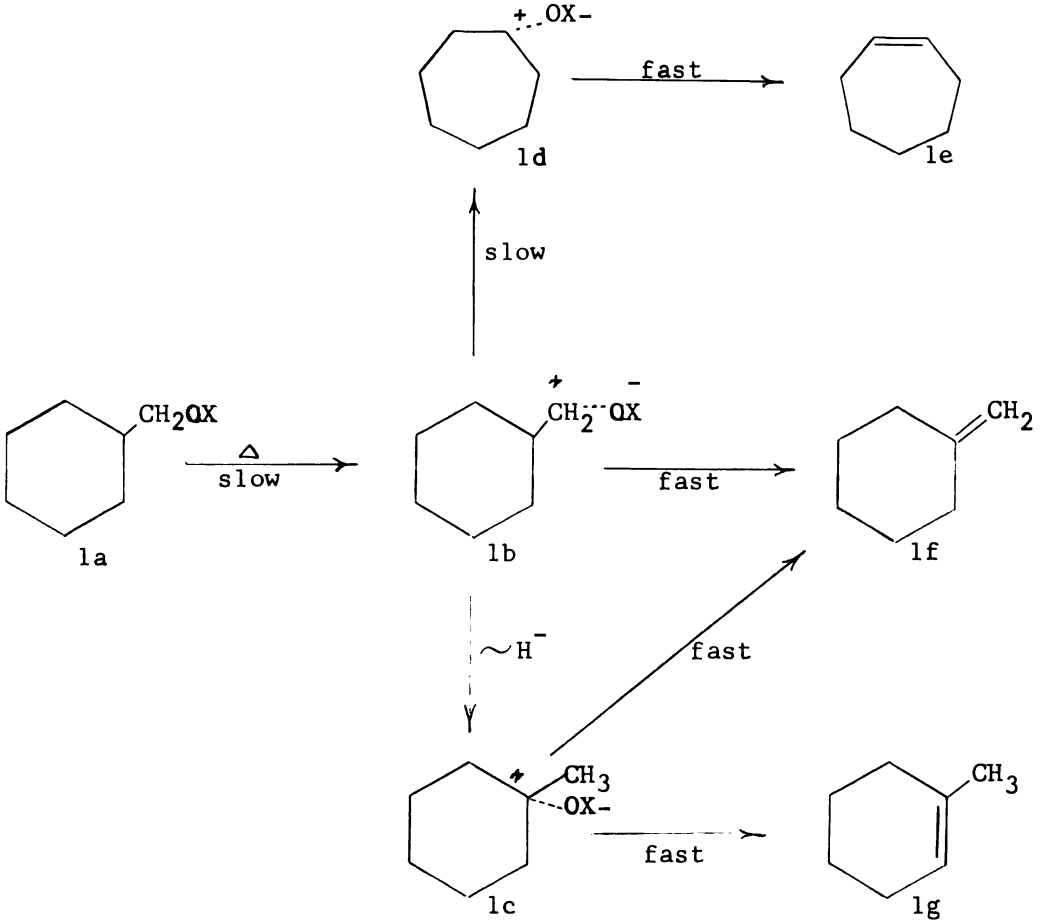
Corbett observed no decomposition when oxalates derived from primary or secondary alcohols were heated to 325° for one hour. Bis-(1-pentyl) oxalate and bis-(3-pentyl) oxalate were reheated and distilled smoothly at 300-330° with no decomposition as evidenced by the fact that the i.r. spectra of the unheated sample, the distillate, and the pot residue were identical.

Bis-(1-octyl) oxalate and bis-(2-octyl) oxalate were prepared and pyrolyzed. Their boiling points were sufficiently high to allow heating to 360° at which temperature they slowly decomposed. After heating for four hours enough distillate was collected for n.m.r. and v.p.c. analysis. The alkenes from bis-(1-octyl) oxalate were 98% of 1-octene and 2% of 2-octene. In addition to the alkenes, the distillate from both esters contained several higher boiling compounds that were not characterized. The alkenes from bis-(2-octyl) oxalate were 40% of 1-octene and 60% of 2-octene. The identity of the alkenes was proven by comparison with authentic samples.

Bis-(Cyclohexylcarbinyl) Oxalate

As stated previously, Chapman interpreted the mechanism of the pyrolysis of borate esters as proceeding either by an ion pair or by a more completely separated carbonium ion that is sufficiently free to rearrange.

Bis-(cyclohexylcarbinyl) oxalate decomposed slowly at 330-360° yielding a mixture of alkenes and higher boiling compounds. Only the alkenes were identified and were shown to be 88% of methylenecyclohexane and 12% of 1-methylcyclohexene. Significantly, no cycloheptene was formed.



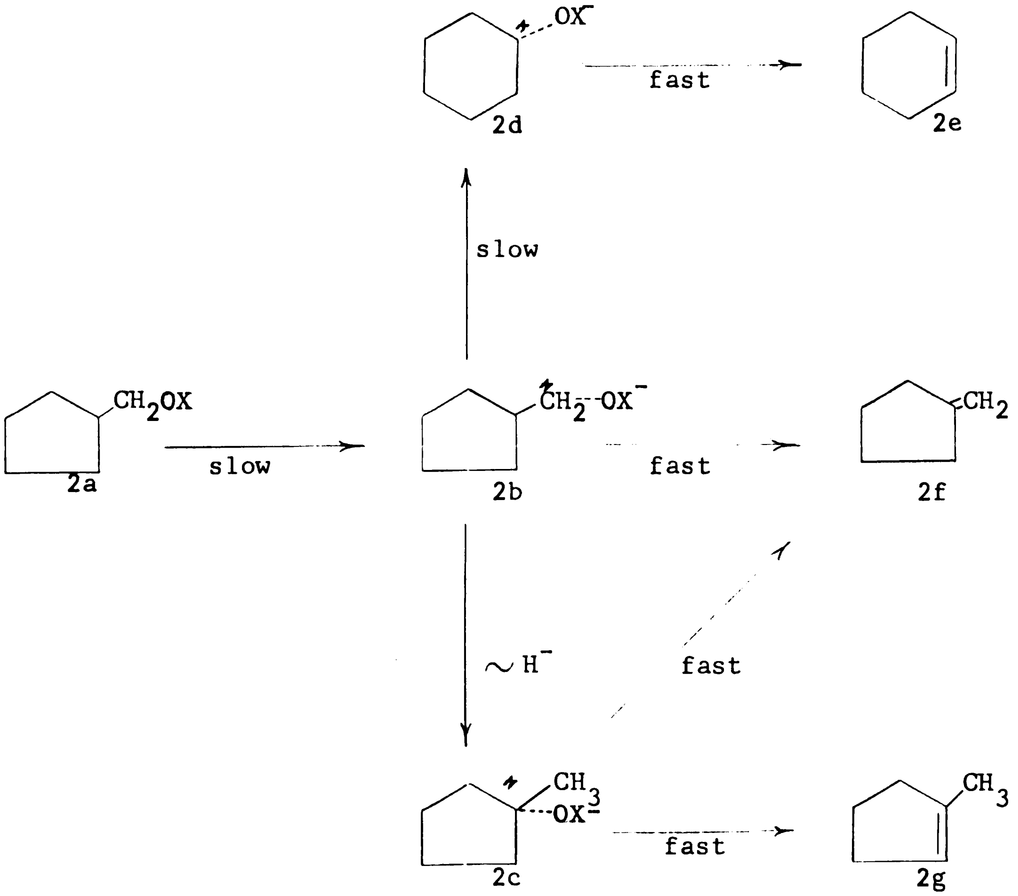
(1)

These data are consistent with an ion pair mechanism as evidenced by the 1,2-hydride shift to the more stable tertiary carbonium ion. Apparently elimination to form methylenecyclohexane is favored over expansion to give the cycloheptyl cation. Energetically there is little to be gained in going from a cyclohexyl to a cycloheptyl system.

Bis-(Cyclopentylcarbinyl) Oxalate

Bis-(cyclopentylcarbinyl) oxalate was heated to 360° for four hours and one ml. of distillate was collected. Analysis showed it to be a mixture of alkenes and higher boiling compounds. Only the alkenes were identified and shown to be 5% of cyclohexene, 79% of methylenecyclopentane, and 16% of 1-methylcyclopentene. These results again indicate that a carbonium ion intermediate is involved and they show an example of ring expansion from a less stable five-membered-ring to a more stable six-membered-ring. Felkin and LeNy reported that ring expansion occurred in the acetolysis of cyclopentylcarbinyl brosylate but not in the acetolysis of cyclohexylcarbinyl brosylate (18). Bartlett and co-workers reported that ring expansion occurs to the extent of 80-92% in the acetolysis of cyclopentylcarbinyl p-nitrobenzenesulfonate (19).

The fact that only 5% of cyclohexene was formed is consistent with the argument that a tight ion pair, not free to undergo normal carbonium ion rearrangements, is involved. However, the energy gained in going from the less stable five-membered-ring to the more stable six-membered-ring is sufficient to permit the rearrangement to occur in competition with elimination.



(2)

Bis-(2-Cyclopentylethyl) Oxalate

Bis-(2-cyclopentylethyl) oxalate decomposed upon heating at 350-360° for four hours yielding cyclopentylethene as the only detectable alkene from v.p.c. and n.m.r. analysis. The distillate also contained several high boiling compounds that were not characterized.

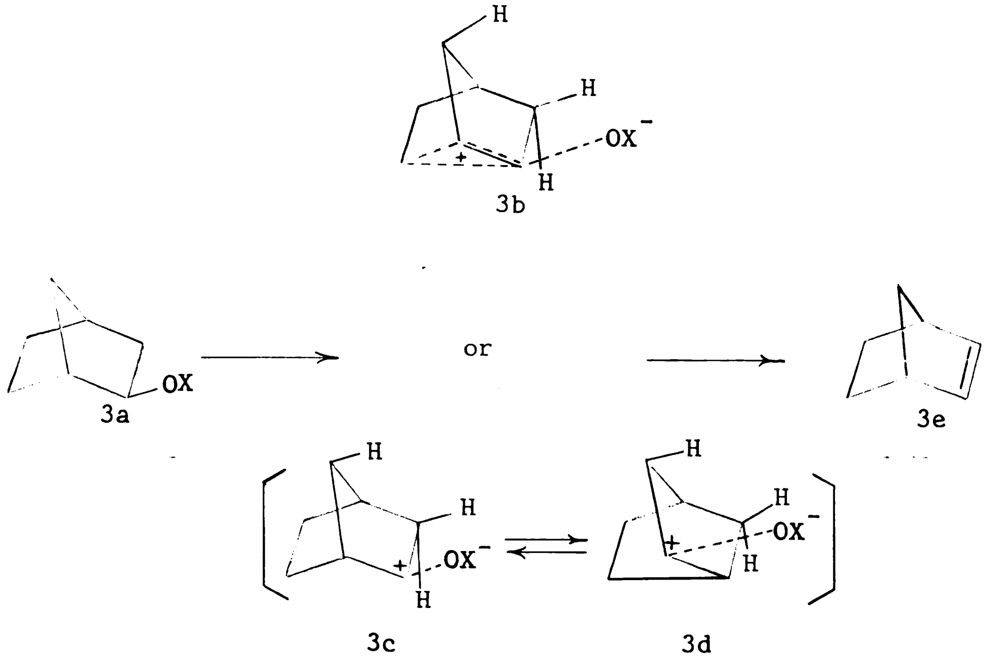
Norbornyl Systems

The variety of carbonium ion reactions involving bicyclic systems in which the norbornyl derivatives have been studied extensively (20), prompted an examination of the pyrolysis of bis-(exo-2-norbornyl) oxalate and bis-(endo-2-norbornyl) oxalate.

Bis-(exo-2-norbornyl) oxalate decomposed at 245-255° yielding a three component mixture (v.p.c.) of which the first two peaks, 60%, were identified as 95% of norbornene and 5% of nortricyclene by comparison with authentic samples. The third peak, which amounted to 40% of the total mixture, was identified as exo-2-norbornyl formate.

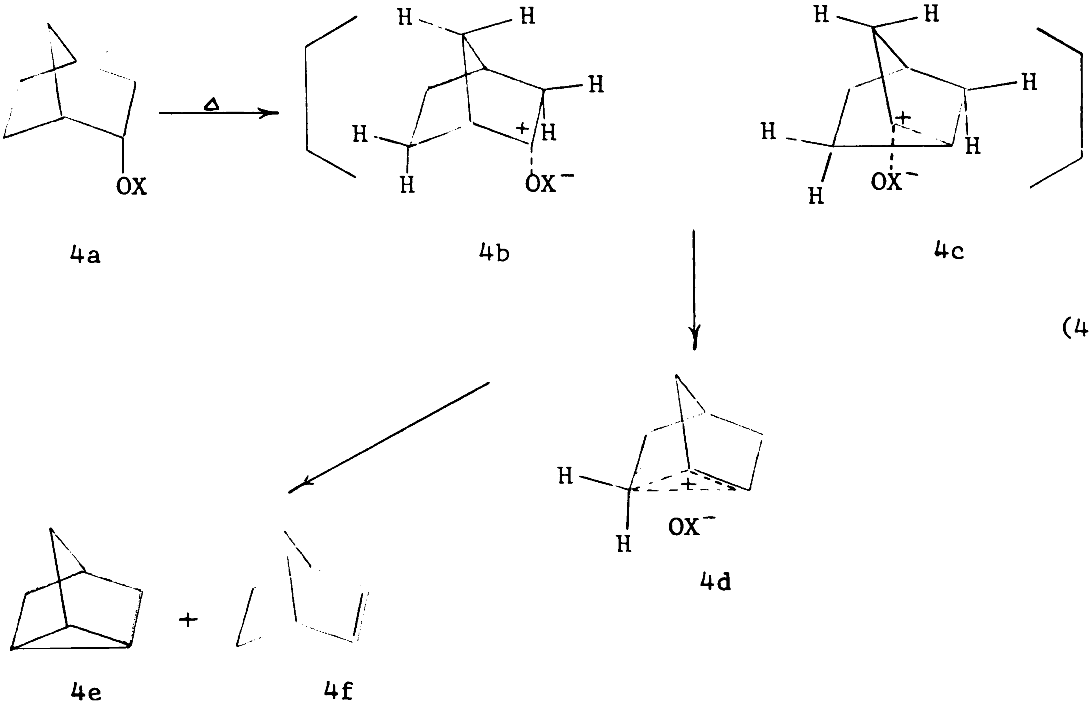
Bis-(endo-2-norbornyl) oxalate decomposed at 275-285° to also yield a three component mixture of which the formate ester comprised 28%. The remaining 72% was 76% of nortricyclene and 24% of norbornene.

The fact that the exo isomer decomposed 30° below the endo isomer is consistent with current views of anchimeric assistance by the 1,6-bond in exo but not in endo compounds (21). The striking feature of these eliminations is the difference in the product ratio of norbornene to nortricyclene obtained from the exo isomer as compared to the endo isomer. Whereas bis-(endo-2-norbornyl) oxalate forms mainly nortricyclene, bis-(exo-2-norbornyl) oxalate almost exclusively forms norbornene. This difference may be rationalized using two reasonable assumptions with regard to the mechanism: (a) the ionization to the tight ion pair occurs in a slow step and (b) the elimination of the hydrogen to form the products occurs in a very fast step that competes favorably with carbonium ion rearrangements and ion pair equilibration. For example, in bis-(exo-2-norbornyl) oxalate, the oxalate anion is situated in a position favorable for removal of a proton from carbon-3 or carbon-7 to form norbornene, and unfavorable for the removal of a proton from carbon-6 to form nortricyclene (equation 3).



(3)

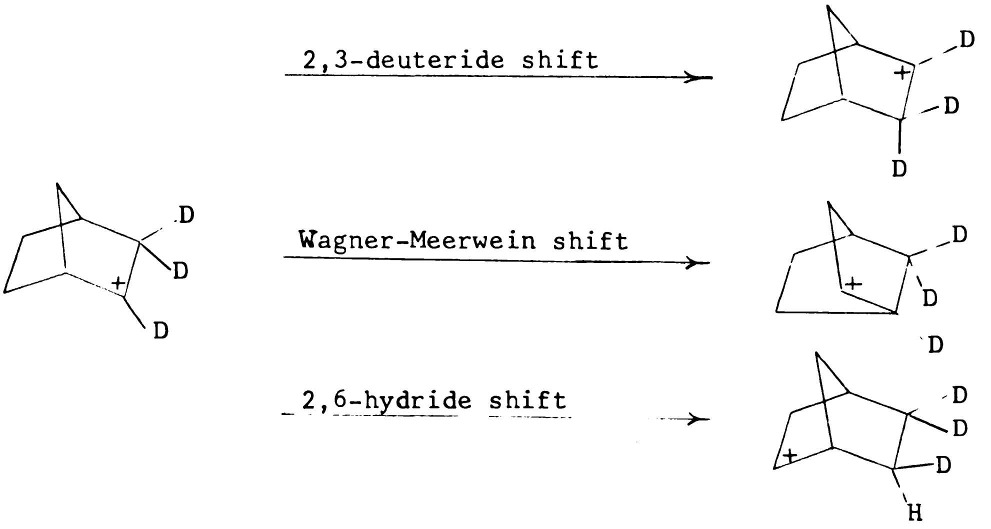
On the other hand, the intermediate from bis-(endo-2-norbornyl) oxalate has the oxalate anion in a position most favorable for abstraction of a proton from carbon-6 to yield nortricyclene (equation 4). Abstraction of the endo proton of carbon-3 would yield norbornene.



(4)

In order to ascertain the extent of rearrangement of the norbornyl cation prior to elimination, bis-(<u>endo</u>-2-norbornyl-2,3,3-d_3) oxalate was pyrolyzed. The ester decomposed at 290-320^o yielding products whose isomer distribution was identical with that reported for the unlabeled bis-(<u>endo</u>-2-norbornyl) oxalate. The product mixture was analyzed by n.m.r. in order to determine the deuterium content on the vinyl positions of norbornene. This was accomplished by integrating the vinyl proton region versus the bridgehead proton region of the norbornene which numerically was 0.43 to 1.00.

The 2-norbornyl-2,3,3-d_3 cation (for simplicity it is presented as the classical ion) may rearrange by three paths as in equation 5. Assuming that any isomerization of the carbonium ion derived from the ion pair of bis-(*endo*-2-norbornyl-2,3,3-d_3) oxalate proceeds by the Wagner-Meerwein path, the extent of rearrangement may be estimated from the above integration.



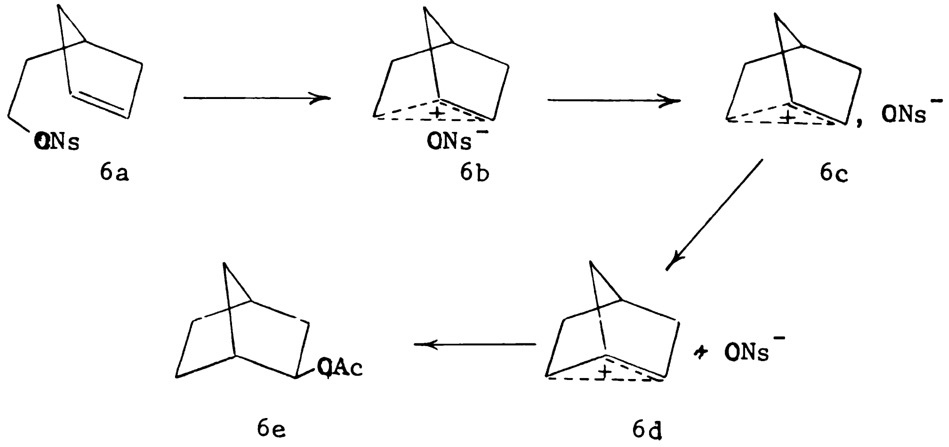
(5)

Accounting for the fact that the deuterium content at carbon-3 of the oxalate was about 85%, and assuming an isotope effect of $k_H/k_D=1.8$ (the determination of the isotope effect will be discussed later), the calculations show that less than 32% of the norbornene arose from rearrangement. This lends support to the suggestion that the hydrogen abstraction from the slowly formed ion pair is a fast process that competes with rearrangement. In reactions involving more complete carbonium ion formation in norbornyl derivatives, the products resulting from rearrangements within the norbornyl cation have exceeded 60% (22).

Bis-(2-(Δ^3-Cyclopentenyl)ethyl) Oxalate

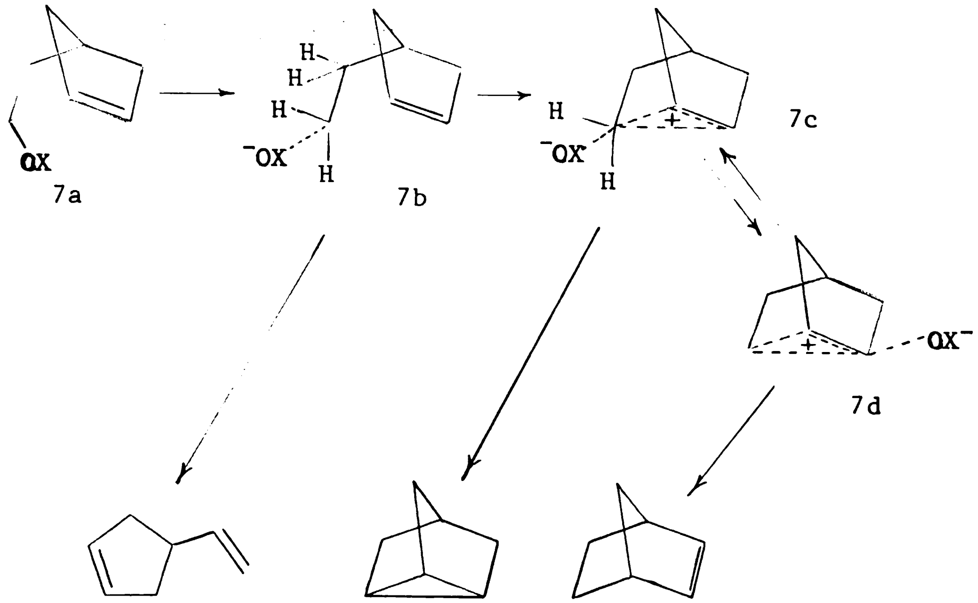
In view of the interesting solvolytic behavior of 2-(Δ^3-cyclopentenyl)ethyl tosylate (23) and p-nitrobenzenesulfonate (24) to yield only exo-2-norbornyl derivatives, and in order to test further the previous conclusions regarding the importance of the position of the anion, bis-(2-(Δ^3-cyclopentenyl)ethyl) oxalate was synthesized and pyrolyzed. It decomposed upon heating at 320-350° for four hours to yield a mixture of alkenes and higher boiling compounds. The alkenes were analyzed by v.p.c. and n.m.r. and shown to be 3% of norbornene, 70% of nortricyclene, and 27% of Δ^3-cyclopentenylethene. The higher boiling compounds were not characterized. These data suggest that the double bond plays an important role in product formation. Since bis-(2-(Δ^3-cyclopentenyl)ethyl) oxalate and bis-(2-cyclopentylethyl) oxalate required nearly identical conditions and times for pyrolysis, the double bond apparently does not influence the rate of ionization to the ion pair.

The solvolysis of 2-(Δ^3-cyclopentenyl)ethyl p-nitrobenzenesulfonate in acetic acid and sodium acetate yields only exo-2-norbornyl acetate that may arise from a tight ion pair (6b), a solvent separated ion pair (6c), or from the free ions (6d) (equation 6).



(6)

In the case of bis-(2-(Δ^3-cyclopentenyl)ethyl) oxalate the product ratios can be rationalized if the rate of hydrogen abstraction is assumed to be faster than the rate of ion pair equilibration.

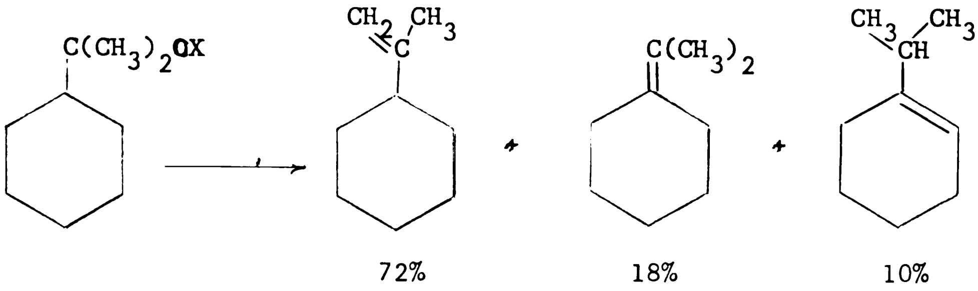


(7)

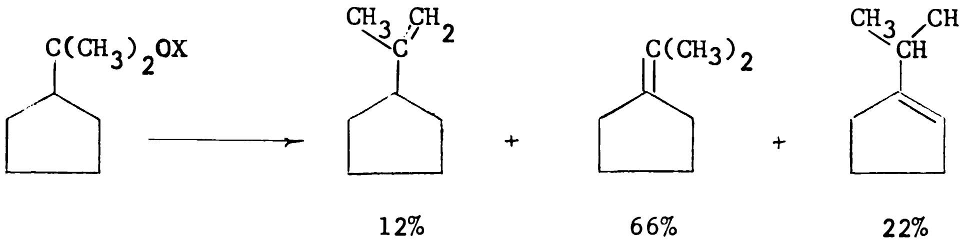
The fact that only 3% of norbornene is formed suggests that the equilibrium between 7c and 7d is slow compared to the rate of hydrogen abstraction (equation 7).

1,2-Hydride Shifts and 1,2-Alkyl Shifts

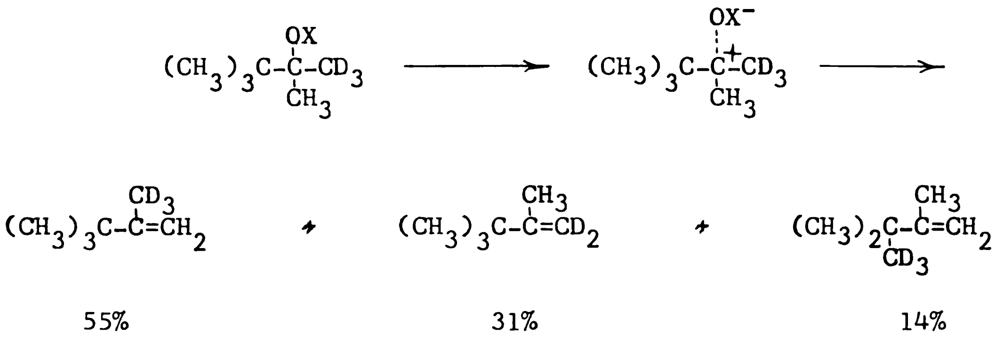
To test further the ion pair mechanism, several esters were studied whose decomposition should lead to carbonium ions that can undergo facile 1,2-hydride or 1,2-alkyl shifts.



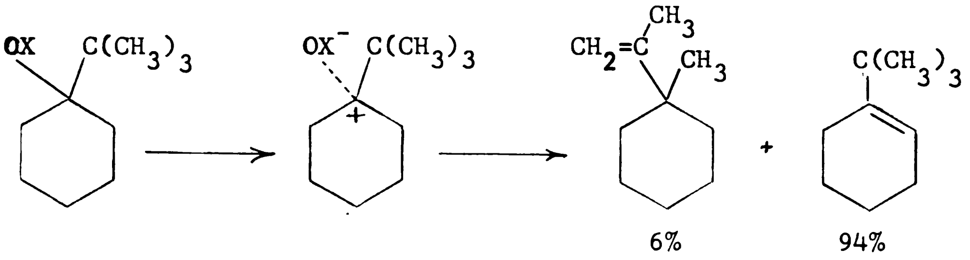
(8)



(9)



(10)



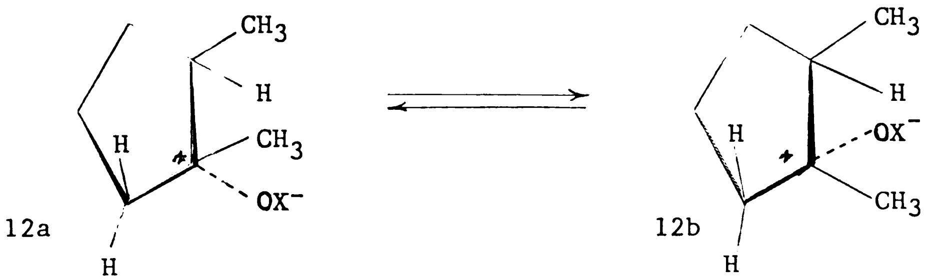
(11)

Bis-(2-cyclohexyl-2-propyl) oxalate (equation 8) and bis-(2-cyclopentyl-2-propyl) oxalate (equation 9) decomposed at 150-160° with appreciable 1,2-hydride shifts as evidenced by the formation of 1-isopropylcyclohexene and 1-isopropylcyclopentene respectively. Bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3) oxalate (equation 10) and bis-(1-*tert*-butylcyclohexyl) oxalate (equation 11) decomposed at 150-170° with 14% and 6% methyl rearrangement respectively. In the two examples involving methyl shifts (equations 10 and 11), it should be noted that the carbonium ion is the very labile *neo*-pentyl ion that has been shown to rearrange extensively even under very mild conditions (25).

Stereospecificity

The stereospecific integrity of the pyrolysis of dialkyl oxalates was evaluated from a study of the decomposition products from bis-(cis-1,2-dimethylcyclopentyl) oxalate, bis-(trans-1,2-dimethylcyclopentyl) oxalate, bis-(erythro-1,2-diphenylethyl-2-d_1) oxalate, and bis-(threo-1,2-diphenylethyl-2-d_1) oxalate. The results are compared with those obtained from the corresponding acetates in Table II.

If the mechanism of the oxalate pyrolysis were a concerted stereospecific cis elimination, very little 1,2-dimethylcyclopentene should be formed from bis-(trans-1,2-dimethylcyclopentyl) oxalate. Since 22% of 1,2-dimethylcyclopentene was formed from the trans ester, an ion pair is suggested which, upon elimination, can form the thermodynamically more stable alkene. In view of the significantly different amounts of 1,2-dimethylcyclopentene and 2,3-dimethylcyclopentene obtained from the cis and trans esters, the elimination of the β-hydrogen must be governed by three factors: (1) the thermodynamic stability of the olefin being formed; (2) the availability of a β-hydrogen for abstraction; and (3) the position of the anion with respect to the cation. It is apparent that olefin formation is faster than equilibration between 12a and 12b.



(12)

Table II. A Comparison of the Pyrolysis Products From the Oxalates and Acetates of *cis*- and *trans*-1,2-Dimethylcyclopentanol and *erythro*- and *threo*-1,2-diphenylethanol-2-d_1.

		Mole %	
Alkyl Portion	Alkenes Formed	Oxalate Pyrolysis	Acetate Pyrolysis
Cis-1,2-dimethylcyclopentyl	1,2-dimethylcyclopentene	85%	40-50%[a]
	2,3-dimethylcyclopentene	15%	25-30%
	1-methylene-2-methylcyclopentane	0%	20-30%
Trans-1,2-dimethylcyclopentyl	1,2-dimethylcyclopentene	22%	5-10%[a]
	2,3-dimethylcyclopentene	75%	85-95%
	1-methylene-2-methylcyclopentane	3%	1-4 %
Erythro-1,2-diphenylethyl-2-d_1	*trans*-stilbene-α-d_1	90%	95%[b,c]
	trans-stilbene	10%	
Threo-1,2-diphenylethyl-2-d_1	*trans*-stilbene-α-d_1	10%	
	trans-stilbene	90%	74%[b,c]

[a] Reference 26. The alkenes isomerize slightly at 400°.

[b] Reference 27. Stilbenes decompose above 300° and thermally isomerize in the presence of organic acids.

[c] Reference 27. These numbers were calculated from the per cent deuterium retention in the *trans*-stilbenes formed.

The importance of the position of the anion with respect to the cation is demonstrated further by the results from the pyrolysis of bis-(*erythro*-1,2-diphenylethyl-2-d_1) oxalate and bis-(*threo*-1,2-diphenylethyl-2-d_1) oxalate. The oxalate esters were decomposed in refluxing quinoline so as to preclude any adverse reactions of oxalic acid with the stilbenes at the elevated temperatures. The *trans*-stilbene was isolated, purified by recrystallization from ethanol, and analyzed by n.m.r. Figures I and II illustrate the observed n.m.r. spectra of the *trans*-stilbenes obtained from the *erythro* and *threo* esters. The spectrum of the stilbene from the *erythro* ester shows in the vinyl region (τ=2.91) a triplet of almost equal peak intensity as expected for the vinyl proton split by the deuterium. The spectrum of the stilbene obtained from the *threo* ester shows a singlet (τ=2.88) for the vinyl protons. This spectrum was almost identical with that recorded for authentic *trans*-stilbene. The per cent of labeled and unlabeled *trans*-stilbene in each sample was determined by integration of the phenyl region versus the vinyl region. The ratios were found to be 9.2 to 1.0 for the *erythro* ester pyrolysis product (Figure I), and 5.3 to 1.0 for the *threo* ester pyrolysis product (Figure II) for the phenyl region and the vinyl region respectively in each case.

Figure I. N.M.R. Spectrum of the Product from Bis-(<u>erythro</u>-1,2-diphenylethyl-2-d_1) oxalate.

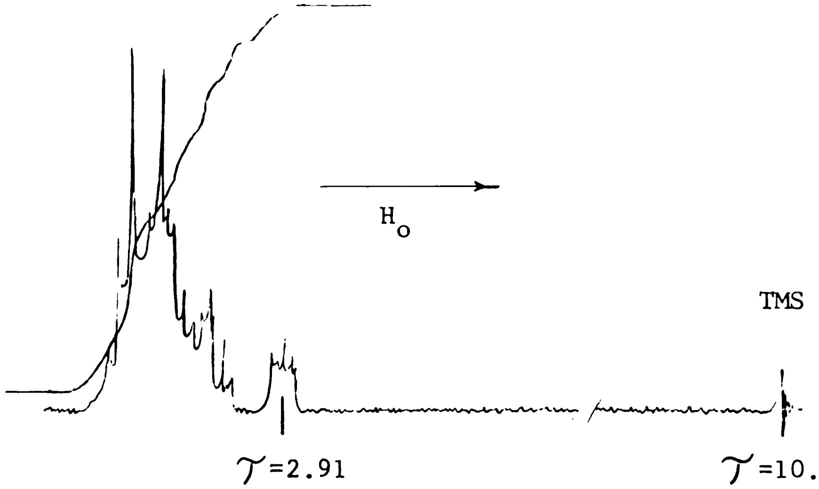
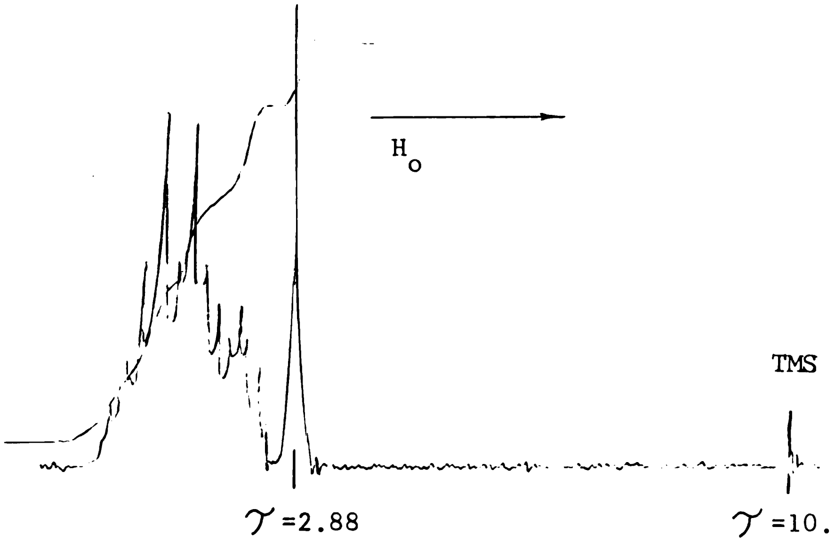
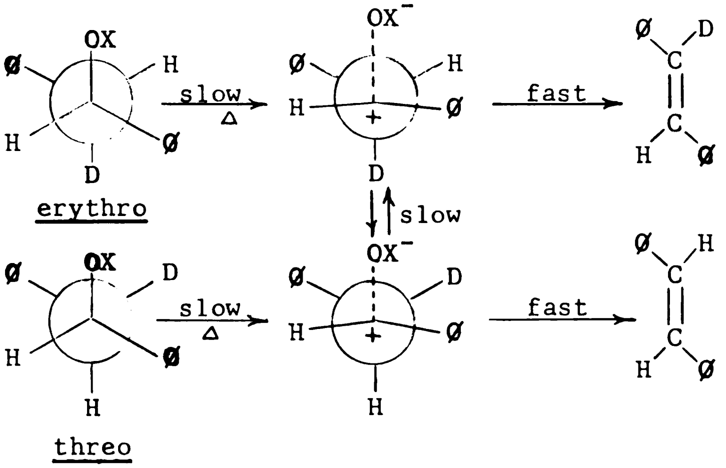


Figure II. N.M.R. Spectrum of the Product from Bis-(<u>threo</u>-1,2-diphenylethyl-2-d_1) oxalate.



The results are mechanistically interpreted in equations 13 and 14.



(13)

(14)

Isotope Effect

The extent of carbon-β-hydrogen bond breaking in the ion pair may be estimated by studying the isotope effect when the β-hydrogen is replaced with deuterium. The results are summarized in Table III. Bis-(2-methyl-2-propyl-1,1,1,2,2,2-d_6) oxalate and bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3) oxalate decomposed at 160-170° yielding the olefins shown in Table III. The alkene mixture was analyzed by n.m.r. (Table III and Figures III-VI) and the isotope effect was calculated by the internal competition method as described by DePuy and co-workers (8). The corresponding unlabeled compounds pyrolyzed at 140-150°. The experimental k_H/k_D was 1.8. Wiberg has shown that at 170° the theoretical k_H/k_D is 3.8.

Table III. The Pyrolysis of Bis-(2-methyl-2-propyl-1,1,1,2,2,2-d_6) oxalate, Bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3) oxalate, and the Corresponding Unlabeled Compounds.

Oxalate	Decomp. Temp.	Alkenes Formed	% NMR	k_H/k_D	Figure	NMR Integration Ratios t-butyl	methyl	vinyl
Bis-(*tert*-butyl)	140-150	isobutylene	100		III	-	3.0	1.0
Bis-(2-methyl-2-propyl-1,1,1,2,2,2-d_6)	170	2-(methyl-d_3)propene-3,3,3-d_3	47					
		2-methylpropene-1,1,3,3,3-d_5	53	1.8	IV	-	1.7	1.0
Bis-(2,3,3-trimethyl-2-butyl)	140-150	2,3,3-trimethyl-1-butene	100		V	9.0	3.0	2.0
Bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3)		2-(methyl-d_3)-3,3-dimethyl-1-butene	55					
		2,3,3-trimethyl-1-butene-1,1-d_2	31					
	160-170	2,3,3-trimethyl-1-butene-4,4,4-d_3	14	1.8	VI	6.3	1.0	1.0

Figure III. N.M.R. Spectrum of the Pyrolysis Product from Bis-(*tert*-butyl) oxalate.

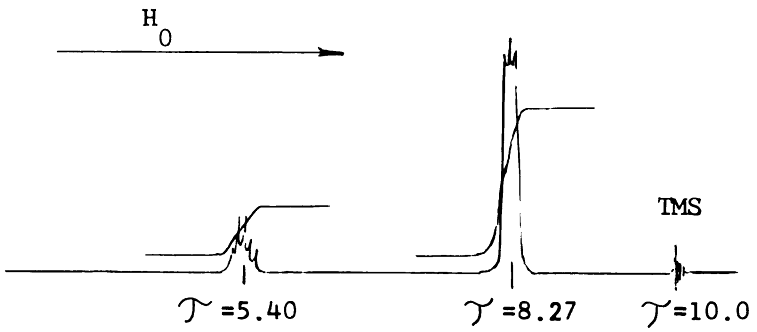


Figure IV. N.M.R. Spectrum of the Pyrolysis Products from Bis-(2-methyl-2-propyl-1,1,1,2,2,2-d_6) oxalate.

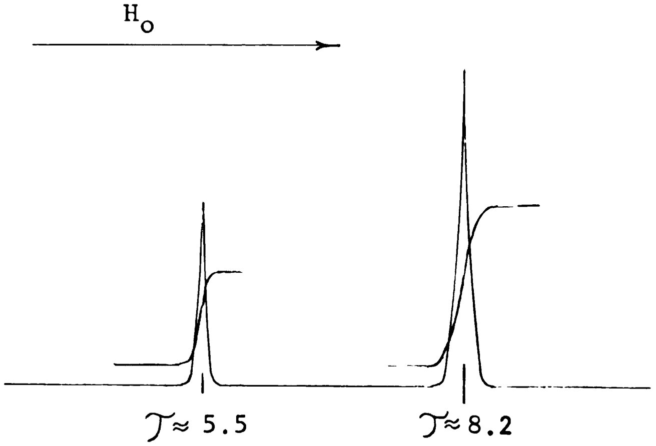


Figure V. N.M.R. Spectrum of the Pyrolysis Product from Bis-(2,3,3-trimethyl-2-butyl) oxalate.

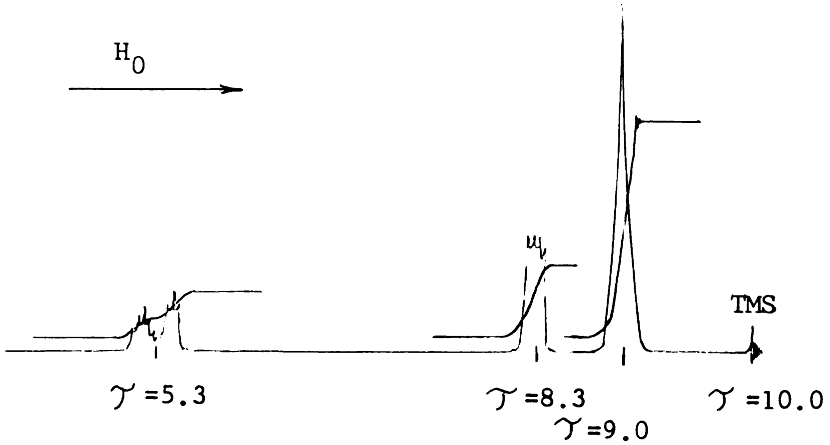
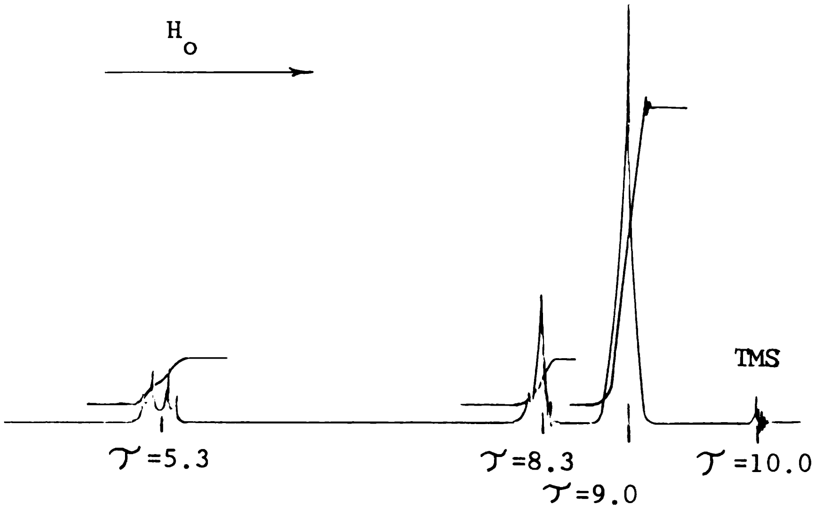


Figure VI. N.M.R. Spectrum of the Pyrolysis Products from Bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3) oxalate.



At 400°, k_H/k_D observed for the pyrolysis of acetate esters is 1.6-1.9 (8,9) (theoretical $k_H/k_D = 2.3$ (10)). This large isotope effect has been interpreted in terms of extensive carbon-β-hydrogen bond breaking in the transition state in accord with the cis concerted elimination mechanism previously discussed.

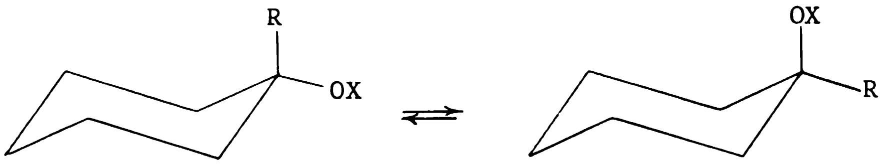
The smaller isotope effect observed in the pyrolysis of oxalate esters is consistent with the ion pair mechanism, although by itself is insufficient evidence to distinguish between an ion pair mechanism and a concerted mechanism involving small carbon-β-hydrogen bond breaking.

Mechanism

In summary, the mechanism of the liquid phase pyrolysis of dialkyl oxalates proceeds first by ionization of the carbon-oxygen bond in a slow step to form the tight ion pair. The oxalate anion then abstracts a β-hydrogen in a fast step before the ion pair may completely equilibrate and at a rate that competes favorably with carbonium ion rearrangements. That oxalate and acetate esters decompose by different mechanisms is not surprising in view of the fact that the decompositions of the oxalates are performed in the liquid phase and oxalic acid is a stronger acid than acetic acid.

Conformational Effects of Cyclohexyl Ring Systems

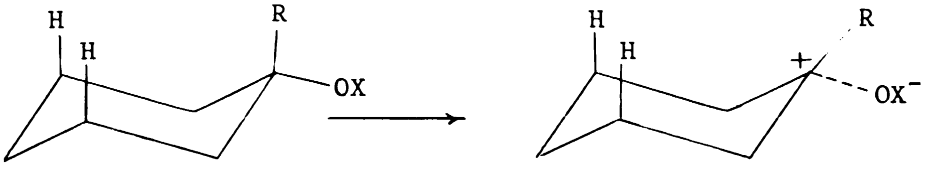
Karabatsos and co-workers observed (16) that whereas bis-(1-methylcyclohexyl) oxalate and bis-(1-ethylcyclohexyl) oxalate decomposed at 160°, bis-(1-isopropylcyclohexyl) oxalate decomposed at 250°. This difference in the rates of decomposition could be attributed to differences in the relative populations of 15a and 15b (equation 15). For example, when R is methyl or ethyl the population of 15a should be significant. When R is isopropyl, 15b should be the main conformer. Consideration of ground state and transition state energy differences between 15a and 15b and between their ion pairs leads to the conclusion that 15a should decompose faster. First of all, because of more severe 1,3-alkyl-hydrogen interactions in 15a than in 15b, 15a should be the less stable conformer. Secondly, these interactions should be relieved in the transition state leading to the ion pair from 15a but not from 15b (equations 15a and 15b)



15a 15b

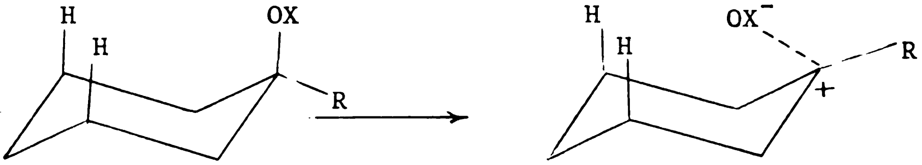
(15)

This explanation was tested by synthesizing and pyrolyzing bis-(*cis*-1-methyl-4-*tert*-butylcyclohexyl) oxalate (equatorial oxalate) and bis-(*trans*-1-methyl-4-*tert*-butylcyclohexyl) oxalate (axial oxalate). The use of the *tert*-butyl group as a conformational anchor for the cyclohexane ring is an established procedure (29). The finding that the cis isomer decomposes 30° below the trans isomer (Table IV) supports the proposed explanation.



15a

(15a)



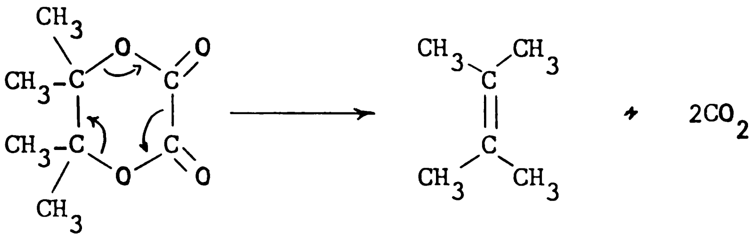
15b

(15b)

The fact that bis-(1-tert-butylcyclohexyl) oxalate, which should exist exclusively in 15a, decomposes at lower temperatures, 150-160°, is not surprising in view of the severe crowding of the groups in the ground state of this molecule.

1,4-Dioxa-5,5,6,6-tetramethylcyclohexane-2,3-dione

1,4-Dioxa-5,5,6,6-tetramethylcyclohexane-2,3-dione, prepared from pinacol and oxalyl chloride, was pyrolyzed to see if it would decompose by a cyclic mechanism as shown in equation 16. Pyrolysis



(16)

Table IV. Pyrolysis of Bis-(1-methylcyclohexyl) oxalate, Bis-(*cis*-1-methyl-4-*tert*-butylcyclohexyl) oxalate, and Bis-(*trans*-1-methyl-4-*tert*-butylcyclohexyl) oxalate.

Oxalate	Decomp. Temp.	Exo-Olefin	Endo-Olefin
Bis-(*cis*-1-methyl-4-*tert*-butylcyclohexyl)	140-150	9%	91%
Bis-(*trans*-1-methyl-4-*tert*-butylcyclohexyl)	175-180	10%	90%
Bis-(1-methylcyclohexyl)[a]	160	6%	94%

[a] Data from G. J. Karabatsos and co-workers (16).

was effected by heating to 350-360° for four hours. The distillate contained 2,3-dimethyl-1,3-butadiene as the only alkene and several higher boiling materials that were not characterized. The 2,3-dimethyl-1,3-butadiene was identified by its n.m.r. spectrum and by comparison with an authentic sample. The decomposition mechanism is apparently the same as the one discussed above for non-cyclic dialkyl oxalates.

Evaluation of the Reaction as a Synthetic Tool

The liquid phase pyrolysis of oxalates derived from tertiary alcohols provides a convenient method for the synthesis of alkenes in view of the simplicity of the apparatus required, the mild conditions under which decomposition is effected, and the good yields that are obtained. The fact that more than one alkene is obtained is an obvious disadvantage.

EXPERIMENTAL

Preparation of Cyclohexylcarbinol

Thirty-five g. (0.225 moles) of ethyl cyclohexanecarboxylate was reduced with 6.0 g. (0.158 moles) of lithium aluminum hydride in anhydrous ether. After stirring at room temperature for 24 hours, the reaction was hydrolyzed with 50 ml. of water and the reaction contents were poured onto 250 ml. of 10% sulfuric acid and ice. The ether layer was separated, the aqueous layer was extracted with 100 ml. of ether, the ether layers were combined, dried over magnesium sulfate, and fractionated, yielding 20.3 g. (79%) of cyclohexylcarbinol, b.p. 84-85°/15 mm. (reported (30) 82°/11 mm.).

Preparation of Cyclopentylcarbinol

Ten g. (0.07 moles) of ethyl cyclopentanecarboxylate was reduced with 1.9 g. (0.05 moles) of lithium aluminum hydride by the above procedure yielding 5.4 g. (77%) of cyclopentylcarbinol, b.p. 82°/22 mm., n_D^{25} 1.4562 (reported (31) b.p. 68-70°/15 mm., n_D^{25} 1.4570).

Preparation of 2-Cyclopentylethanol

Cyclopentylacetic acid was prepared by a typical malonic ester synthesis from bromocyclopentane and diethyl malonate. The procedure was adapted from one described by Adams and Johnson (32). The cyclopentylacetic acid was reduced with lithium aluminum hydride to yield 2-cyclopentylethanol, b.p. 85-90°/40 mm. (reported (33) 70-73°/22 mm.).

Preparation of endo-2-norborneol

To a suspension of 1.14 g. (0.08 moles) of lithium aluminum hydride and 100 ml. of anhydrous ether was added in the period of one hour 10 g. (0.106 moles) of 2-norbornanone dissolved in 50 ml. of ether. The solution was then stirred and refluxed for five hours.

After cooling, the reaction was hydrolyzed with 25 ml. of water. The ether layer was decanted, the inorganic complex was washed with four 100 ml. portions of ether, the ether layers were combined, dried over magnesium sulfate, and the ether was removed by distillation. The crude *endo*-2-norborneol was recrystallized from low boiling petroleum ether yielding 6.98 g. (68%) of pure *endo*-2-norborneol, m.p. 147-149° (reported (34) m.p. 149°), its 3,5-dinitrobenzoate melted at 123-124° (reported (34) m.p. 123°).

Preparation of 2-norbornanone-3,3-d_2

Twenty-five g. (0.23 moles) of 2-norbornanone was refluxed with 50 ml. of about 80% deuterium oxide and a trace of sodium methoxide for 24 hours. The solution was cooled and the 2-norbornanone was extracted with 50 ml. of anhydrous ether. The ether layer was dried over calcium chloride and the ether was removed by distillation. The recovered 2-norbornanone was treated with a fresh portion of 80% deuterium oxide by the same procedure as above.

An n.m.r. analysis of the resulting 2-norbornanone showed 60% deuterium exchange at carbon-3. This procedure was then repeated three more times using 25 ml. portions of pure (99.77%) deuterium oxide. The resulting 2-norbornanone showed approximately 90% deuterium exchange at carbon-3. A more complete exchange could not be attained utilizing this procedure.

Preparation of endo-2-norborneol-2,3,3-d_3

2-Norbornanone-3,3-d_2, 12.3 g. (0.11 moles), was reduced with 2.0 g. (0.047 moles) of lithium aluminum deuteride by the same procedure as described for the unlabeled 2-norbornanone. Six g. (47%) of *endo*-2-norborneol-2,3,3-d_3, m.p. 142-145°, was obtained.

An i.r., n.m.r., and v.p.c. analysis showed that the product was contaminated with a trace of unreacted 2-norbornanone and less than 2% of the *exo* isomer. The n.m.r. analysis showed 98% deuterium content at carbon-2, and 85% deuterium content at carbon-3.

Preparation of 4-bromocyclopentene

Cyclopentadiene was treated with bromine at -30° by the method described by Bartlett and Rice (35) to give 3,5-dibromocyclopentene which was immediately reduced with lithium aluminum hydride yielding 5% of 4-bromocyclopentene, b.p. 47-49°/40 mm., n_D^{25} 1.4987 (reported (35) b.p. 43°/35 mm., n_D^{25} 1.4992).

Preparation of diethyl Δ^3-cyclopentenyl malonate

Diethyl malonate, 27.7 g. (0.175 moles), was added to a solution of sodium ethoxide and ethanol prepared by the addition of 3.65 g. (0.16 moles) of freshly cut sodium to 100 ml. of absolute ethanol. 4-Bromocyclopentene, 23.42 g. (0.159 moles), was added during five minutes and the stirred solution was refluxed for seven hours. The ethanol was removed by distillation, 250 ml. of benzene was added to dissolve the organic materials, and the inorganic materials were removed by washing with 100 ml. of 2% hydrochloric acid solution. The benzene layer was separated, dried over magnesium sulfate, and fractionated, yielding 18.43 g. (51%) of diethyl Δ^3-cyclopentenyl malonate, b.p. 105°/3 mm.

Preparation of Δ^3-cyclopentenyl malonic acid

To a solution of 18 g. of potassium hydroxide and 20 ml. of water was added 18.43 g. (0.08 moles) of diethyl Δ^3-cyclopentenyl malonate. A vigorous reaction took place almost immediately during which time most of the ethanol boiled off. The reaction was then refluxed for two hours. Fifty ml. of water was added and the solution was distilled until 50 ml. of distillate was collected. The residual liquid was cooled and acidified with 6N hydrochloric acid. The acid solution was extracted with four 125 ml. portions of ether, the ether layer was dried over magnesium sulfate, and the ether was removed by distillation. The resulting crude Δ^3-cyclopentenyl malonic acid, m.p. 156-160° (reported (36) m.p. 149-150°), was not purified further.

Preparation of Δ^3-cyclopentenyl acetic acid

The crude Δ^3-cyclopentenyl malonic acid was refluxed for 20 hours with 50 ml. of pyridine. After cooling, the reaction mixture was dissolved in 200 ml. of ether and washed with three 100 ml. portions of 5% hydrochloric acid. The ether layer was dried over magnesium sulfate, and the Δ^3-cyclopentenyl acetic acid was reduced immediately without isolation.

Preparation of 2-(Δ^3-cyclopentenyl) ethanol

To a mixture of 3.1 g. (0.081 moles) of lithium aluminum hydride and 100 ml. of ether was added the ether solution of Δ^3-cyclopentenyl acetic acid. After refluxing for 18 hours, the mixture was hydrolyzed with 30 ml. of water and the ether layer was decanted. The complex was washed with three 50 ml. portions of ether, the ether layers were combined, dried over magnesium sulfate, and fractionated, yielding 2.87 g. (29%--based on diethyl Δ^3-cyclopentenyl malonate) of 2-(Δ^3-cyclopentenyl) ethanol, b.p. 84-85°/20 mm. n_D^{25} 1.4678 (reported (36) b.p. 180-182°, n_D^{25} 1.4691).

Preparation of 2-cyclohexyl-2-propanol

Seventy-eight g. (0.5 moles) of ethyl cyclohexane carboxylate was dissolved in an equal volume of ether and slowly added over a period of two hours to an ether solution of methyl magnesium bromide prepared from 24.3 g. (1.0 mole) of magnesium and excess methyl bromide. The reaction was stirred at room temperature overnight. The solution was hydrolyzed with 250 ml. of saturated ammonium chloride solution, the ether layer was separated, dried over anhydrous magnesium sulfate, and fractionated, yielding 50.1 g. (72%) of 2-cyclohexyl-2-propanol, b.p. 82-83°/12 mm., n_D^{20} 1.4683 (reported (37) b.p. 100-102°/25 mm., n_D^{20} 1.4688).

Preparation of 2-cyclopentyl-2-propanol

Ethyl cyclopentane carboxylate was reacted with methyl magnesium bromide using the same molar quantities and experimental technique as described above. The resulting alcohol was contaminated with unreacted ester which could not be separated by distillation so the product mixture was refluxed with 250 ml. of 8% sodium hydroxide for 12 hours. The organic layer was separated, dried over anhydrous calcium chloride, and fractionated, yielding 23.6 g. (37%) of pure 2-cyclopentyl-2-propanol, b.p. 67-69°/13 mm.

Preparation of 3,3-dimethyl-2-butanone-1,1,1-d_3

A mixture of 20 g. (0.20 moles) of 3,3-dimethyl-2-butanone, 50 ml. of about 80% deuterium oxide, and a trace of anhydrous potassium carbonate was refluxed for 24 hours. The organic layer was separated and dried over calcium chloride. This procedure was repeated three more times using 25 ml. portions of pure (99.77%) deuterium oxide. An n.m.r. analysis of the recovered 3,3-dimethyl-2-butanone showed greater than 99% deuterium exchange at carbon-1.

Preparation of 2,3,3-trimethyl-2-butanol-1,1,1-d_3

3,3-Dimethyl-2-butanone-1,1,1-d_3 was added to an ether solution of methyl magnesium iodide affording a 56% yield of 2,3,3-trimethyl-2-butanol, b.p. 126-131°. An n.m.r. analysis show greater than 99% deuterium content at carbon-1.

Preparation of 2,3,3-trimethyl-2-butanol

3,3-Dimethyl-2-butanone was added to an ether solution of methyl magnesium iodide affording 51% of 2,3,3-trimethyl-2-butanol, b.p. 127-129° (reported (38) 131-132°).

Preparation of cis and trans 1,2-dimethylcyclopentanol

The cis and trans 1,2-dimethylcyclopentanols were prepared and separated by the method described by Hammond and Collins (39). Treatment of 2-methylcyclopentanone with methyl magnesium iodide yielded a mixture of the cis and trans alcohols. The two isomers were separated by fractional distillation using an 18-inch spinning band column with a reflux to take-off ratio of 20:1. Trans-1,2-dimethylcyclopentanol boiled at 51-54°/18 mm. (reported (39) b.p. 50-51.2°/17 mm.) and cis-1,2-dimethylcyclopentanol boiled at 63-63.5°/18 mm. (reported (39) b.p. 59.5-61°/16 mm.) Vapor phase chromatography, using a six-foot Carbowax 20M column, showed that the alcohols were pure.

Preparation of trans-stilbene oxide

Thirty g. (0.167 moles) of trans-stilbene was oxidized with 47.3 g. (0.25 moles) of 40% peracetic acid by the method described in Organic Syntheses (40). Twenty-three g. (72%) of trans-stilbene oxide, m.p. 68-70° (reported (40) m.p. 68-69°), was obtained.

Preparation of cis-stilbene oxide

Thirty-three g. (0.184 moles) of cis-stilbene was oxidized with 52.3 g. (0.275 moles) of 40% peracetic acid by the same method as described in Organic Syntheses (40) for the synthesis of trans-stilbene oxide. The crude cis-stilbene oxide was obtained as an oil after the removal of the solvent. The oil was dissolved in 100 ml. of hot 70% ethanol. The oil that was obtained on cooling solidified when placed overnight in a refrigerator. The solid was filtered, dried, and recrystallized from hexane yielding 18.1 g. (51%) of cis-stilbene oxide, m.p. 38.5-39.5° (reported (27) 40-42°).

Preparation of erythro-1,2-diphenylethanol-2-d_1

Eleven g. (0.056 moles) of trans-stilbene oxide was reduced with 3.41 g. (0.081 moles) of lithium aluminum deuteride by the procedure described by Curtin and Kellom (27) except that the reaction mixture was refluxed for 11 hours. Recrystallization from ethanol yielded 8.78 g. (79%) of pure erythro-1,2-diphenylethanol-2-d_1, m.p. 65-66° (reported (27) 64.4-65.4°).

Preparation of threo-1,2-diphenylethanol-2-d_1

cis-Stilbene oxide, 9.8 g. (0.05 moles), was reduced with 1.60 g. (0.038 moles) of lithium aluminum deuteride by the same procedure as described above, affording 8.43 g. (85%) of threo-1,2-diphenylethanol-2-d_1, m.p. 66-66.5° (reported (27) m.p. 64.5-65.5°).

Preparation of 2-methyl-2-propanol-1,1,1,2,2,2-d_6

Ten g. (0.156 moles) of acetone-d_6 was added to an ether solution of methyl magnesium iodide prepared from 25.4 g. (0.18 moles) of methyl iodide and 4.37 g. (0.18 moles) of magnesium. The reaction was refluxed and stirred for eight hours. Sixty ml. of saturated ammonium chloride solution was added, the ether layer was separated, the aqueous layer was extracted with 50 ml. of ether, and the ether layers were combined. The aqueous layer was distilled until the temperature of the distillate remained constant at 100° for five minutes. The distillate was saturated with sodium chloride and extracted with 50 ml. of ether. The ether layers were combined, dried over magnesium sulfate, and fractionated, yielding 6.50 g. (52%) of 2-methyl-2-propanol-1,1,1,2,2,2-d_6, b.p. 80-81°. An n.m.r. analysis showed the deuterium content at carbon-1 and carbon-2 to be greater than 99%.

Preparation of cis and trans-1-methyl-4-tert-butylcyclohexanol

The *cis* and *trans*-1-methyl-4-*tert*-butylcyclohexanols were prepared and separated by the method described by DePuy and King (29). 4-*Tert*-butylcyclohexanone was treated with methyl magnesium iodide and the resulting alcohol mixture was chromatographed on alumina. The progress of the separation was followed by v.p.c.

utilizing a six-foot Carbowax 20M column. The crude _trans_ isomer was sublimed at 60°/6 mm. The pure _trans_-1-methyl-4-_tert_-butylcyclohexanol melted at 66-68° (reported (29) m.p. 70.5-71°). The crude _cis_ isomer was recrystallized from hexane. The pure _cis_-1-methyl-4-_tert_-butylcyclohexanol melted at 93.5-95° (reported (29) m.p. 97.5-98°). A v.p.c. analysis showed each alcohol to be isomerically pure.

Preparation of 1-tert-butylcyclohexanol

An ether solution of _tert_-butyl lithium was prepared from 6.9 g. (1.0 mole) of lithium sand and 92 g. (1.0 mole) of _tert_-butyl chloride by the method described by Bartlett and Lefferts (41). To this solution, maintained at -40° throughout the addition, was added 73.5 g. (0.75 moles) of cyclohexanone dissolved in an equal volume of ether. The addition required two hours. After the addition was complete, the solution was stirred at -45° for one hour.

The reaction was hydrolyzed by the careful addition of 250 ml. of water while the reaction temperature was maintained below -10° until all of the excess lithium metal was destroyed. The mixture was then allowed to warm to room temperature, the ether layer was separated, the aqueous layer was extracted with 100 ml. of ether, and the ether layers were combined. After drying over magnesium sulfate, the ether solution was fractionated yielding 14.4 g. (12%) of 1-_tert_-butylcyclohexanol, b.p. 73-76°/10 mm., m.p. 48-50° (reported (42) b.p. 80°/13 mm., m.p. 49-50°).

Preparation of 1,4-dioxa-5,5,6,6-tetramethylcyclohexane-2,3-dione

To a solution of 5.9 g. (0.05 moles) of 2,3-dimethyl-2,3-butanediol, 4.19 g. (0.053 moles) of pyridine, and 100 ml. of ether was added over a 40-minute period, 6.34 g. (0.05 moles) of oxalyl chloride dissolved in 25 ml. of ether. After stirring, at room temperature for 18 hours, the reaction was hydrolyzed with 25 ml. of water. The ether layer was washed with three 20 ml. portions of 10% sulfuric acid, three 20 ml. portions of saturated sodium bicarbonate solution, and once with 20 ml. of water. After drying over magnesium sulfate, the ether was removed by distillation. The crude product was recrystallized from hot ethanol yielding 4.2 g. (50%) of 1,4-dioxa-5,5,6,6-tetramethylcyclohexane-2,3-dione, m.p. 110-111°.

Other Alcohols Used

1-Phenylethanol, 1,2-diphenylethanol, 1-octanol, 2-octanol, and *exo*-2-norborneol were available as commercial samples of high purity and were used without further purification.

General Procedure for the Preparation of Dialkyl Oxalates

In a 300-ml., three-necked flask equipped with a stirrer, condenser, dropping funnel, and drying tube were placed 0.10 moles of the alcohol, 0.11 moles of pyridine, and 100 ml. of anhydrous ether. Five-hundredths moles of oxalyl chloride dissolved in 25 ml. of anhydrous ether was added over a period of 30-40 minutes. The reaction was then stirred at room temperature for at least 12 hours. The ether layer that was separated after hydrolysis with 30 ml. of water was washed with three 30 ml. portions of 10% sulfuric acid, three 30 ml. portions of saturated sodium bicarbonate solution, and once with 30 ml. of water. The ether layer was dried over magnesium sulfate and the ether was removed by distillation.

If the oxalate ester was obtained as an oil, it was not purified further. If the oxalate ester was obtained as a solid, it was recrystallized from hot ethanol. N.m.r. and i.r. spectra were taken for each ester to establish its purity and authenticity.

Table V lists the reaction time, yield, and melting point of each ester.

General Procedure for the Thermal Decomposition of Dialkyl Oxalates

Three g. of the ester were placed in a 10-ml., pear-shaped flask equipped with a four-inch Vigreux column and a distillation head. The receiver was cooled with a dry ice-isopropyl alcohol bath. If the temperature of decomposition was anticipated to be below 200°, the flask was heated with an oil bath. For temperatures

Table V. Reaction Time, Yield, and Melting Point of the Oxalates.

Oxalate	Reaction Time (hrs.)	% Yield	Melting Point
Bis-(1-phenylethyl)	14	81	oil
Bis-(1,2-diphenylethyl)	14	82	67-71°
Bis-(1-octyl)	20	86	oil
Bis-(2-octyl)	20	77	oil
Bis-(cyclohexylcarbinyl)	12	80	48-50°
Bis-(cyclopentylcarbinyl)	18	65	oil
Bis-(2-cyclopentylethyl)	18	57	oil
Bis-(*exo*-2-norbornyl)	12	68	oil
Bis-(*endo*-2-norbornyl)	14	72	oil
Bis-(*endo*-2-norbornyl-2,3,3-d_3)	18	85	oil
Bis-(2-(Δ^3-cyclopentenyl)ethyl)	16	70	oil
Bis-(2-cyclopentyl-2-propyl)	16	86	oil
Bis-(2-cyclohexyl-2-propyl)	14	84	54-56°
Bis-(2,3,3-trimethyl-2-butyl-1,1,1-d_3)	18	46	143-144°
Bis-(*cis*-1,2-dimethylcyclopentyl)	20	77	oil
Bis-(*trans*-1,2-dimethylcyclopentyl)	15	78	oil
Bis-(*erythro*-1,2-diphenylethyl-2-d_1)	14	73	67-72°
Bis-(*threo*-1,2-diphenylethyl-2-d_1)	14	-	69-75°
Bis-(2-methyl-2-propyl-1,1,1,2,2,2-d_6)	12	62	71-73°

Table V. (continued)

Oxalate	Reaction Time (hrs.)	% Yield	Melting Point
Bis-(*cis*-1-methyl-4-*tert*-butylcyclohexyl)	12	42	oil
Bis-(*trans*-1-methyl-4-*tert*-butylcyclohexyl)	19	82	oil
Bis-(1-*tert*-butylcyclohexyl)	105	41	oil

above 200° a sand bath was used. The flask was heated slowly until a vigorous reaction accompanied by distillation of the alkene mixture occurred. The temperature of decomposition was noted by placing a thermometer close to the heated pear-shaped flask.

Esters derived from tertiary or benzylic alcohols decomposed easily at 150-170° requiring five or ten minutes for a complete reaction. Complete reaction of esters derived from secondary alicyclic alcohols required heating at 250-300° for 60-90 minutes. Esters derived from primary aliphatic alcohols required prolonged heating at temperatures of 330-360° in order to obtain enough distillate for analysis. The technique employed was to heat the flask with a sand bath until the ester was refluxing smoothly approximately halfway up the Vigreux column, and to maintain this temperature until approximately one ml. of distillate was collected. This usually required around four hours. The alkenes were immediately analyzed without further purification by i.r., n.m.r., and v.p.c.

Thermal Decomposition of bis-(1,2-diphenylethyl) oxalate, bis-(erythro-1,2-diphenylethyl-2-d_1) oxalate, and bis-(threo-1,2-diphenylethyl-2-d_1) oxalate

One g. of the ester was refluxed in 1.0 ml. of quinoline, b.p. 237°, for one hour. The reaction mixture was cooled and dissolved in 25 ml. of ether. The ether solution was washed with three 20 ml. portions of 10% sulfuric acid, once with 20 ml. of water, once with 20 ml. of saturated sodium bicarbonate solution, and once with 20 ml. of water. The ether layer was decolorized with decolorizing carbon, dried over magnesium sulfate, and the ether was removed by distillation.

The crude material was analyzed by n.m.r. to obtain the ratio of *cis*-stilbene to *trans*-stilbene. The solid material was then recrystallized from hot ethanol for further n.m.r. analysis of the purified *trans*-stilbene.

Infrared Spectra (I.R.)

All i.r. spectra were recorded using a Beckman I.R.-5 double beam spectrophotometer. The liquids were analyzed as thin films between salt plates. The solids were analyzed as 20% solutions in carbon tetrachloride using 0.1 mm. spaced solution cells.

Vapor Phase Chromatography (V.P.C.)

All v.p.c. data were obtained using an Aerograph A-90-P equipped with a thermal conductivity detector and employing helium as the carrier gas. The alcohols were analyzed using a six-foot by 0.25-inch column packed with 20% Carbowax 20M on Chromosorb W. The alkene mixtures were analyzed using a six-foot by 0.25-inch column packed with 20% Apiezon L on Chromosorb W. Peak areas were determined using a planimeter.

Nuclear Magnetic Resonance Spectra (N.M.R.)

All n.m.r. spectra were recorded using a Varian Associates Model A-60 Analytical N.M.R. Spectrometer. The samples were placed in thin-walled tubes using tetramethylsilane as an internal reference. All liquid samples were analyzed neat. The solid materials were analyzed as approximately 20% solutions in an appropriate solvent. Peak areas were determined by electronic integration.

PART II

NUCLEAR MAGNETIC RESONANCE STUDIES OF N-METHYLPHENYLHYDRAZONES

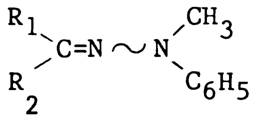
INTRODUCTION

Nuclear magnetic resonance spectroscopy (n.m.r.) has been successfully applied to the study of configurational isomerism resulting from hindered rotation about a carbon-nitrogen double bond in phenylhydrazones (1), 2,4-dinitrophenylhydrazones (2), semicarbazones and thiosemicarbazones (3), methyl ether imines, methyl imines, and hydrazones (4), N-methylhydrazones and N,N-dimethylhydrazones (5), nitrosamines (6), alkyl nitrites (7), and oximes (8,9). The purpose of this investigation was to study various N-methylphenylhydrazones with the following objectives in mind: (a) to measure the effect of solvent on chemical shifts; (b) to obtain several proton-proton and proton-^{13}C spin-spin coupling constants; and (c) to establish the relative stabilities of the various configurations and conformations of these compounds.

RESULTS AND DISCUSSION

Chemical Shifts

To facilitate the discussion of the results, the following notations will be used: (a) The *syn* isomer of I will have the

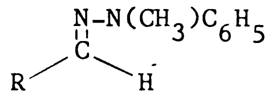


I

N-methylanilino group *cis* to the smaller R group. This notation will also be used to distinguish between various protons of the R groups: *i.e.*, protons will be referred to as being *syn* or *anti* with respect to the N-methylanilino group. In those cases where both *syn* and *anti* isomers exist, if a particular proton *syn* to the anisotropic group resonates at a higher magnetic field than the corresponding *anti* proton, it will be termed "shielded." Conversely, if it resonates at a lower magnetic field, it will be termed "deshielded."

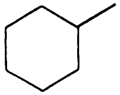
Table I summarizes the chemical shifts of aldehyde N-methylphenylhydrazones in neat, 10% in carbon tetrachloride, and 10% in benzene. Table II summarizes those of the ketone N-methylphenylhydrazones and the *syn*-*anti* isomer ratios. Figures I-VI show the spectra of the N-methylphenylhydrazones of acetaldehyde, propionaldehyde, acetone, 2-butanone, 3-methyl-2-butanone, and pinacolone.

Table I. Chemical Shifts (τ-Values) of N-Methylphenylhydrazones.



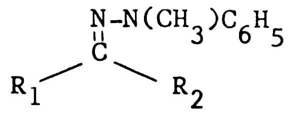
$R-CH=N-N(CH_3)C_6H_5$

R	Solvent	α-CH_3	α-CH_2	α-CH	β-CH_3	β-CH_2	β-CH	γ-CH_3	N-CH_3	"Aldehyde" H	N-C_6H_5[a]	syn H	anti H
CH_3-	Neat	8.21							7.17	3.41	2.58		
	CCl_4	7.95							6.75	3.11	2.65		
	C_6H_6	8.14							7.25	3.48	-		
CH_3CH_2-	Neat		7.72		8.92				7.13	3.32	2.59		
	CCl_4		7.55		8.82				6.75	3.06	2.65		
	C_6H_6		7.68		8.92				7.22	3.38	-		
$CH_3(CH_2)_2$-	Neat		7.80			8.51		9.08	7.16	3.48	2.77		
	CCl_4		7.66			8.41		9.02	6.83	3.28	-		
	C_6H_6		7.75			8.50		9.08	7.28	3.55	-		
$(CH_3)_2CH$-CH_2-	Neat		7.84				7.44	9.10	7.14	3.49	2.79		
	CCl_4		7.76				-	9.02	6.92	-	2.82		
	C_6H_6		7.80				-	9.07	7.27	3.52	-		
$(CH_3)_3C$-CH_2-	Neat		7.86					9.08	7.20	3.48	2.71		
	CCl_4		7.78					9.02	6.84	3.34	2.75		
	C_6H_6		7.78					9.07	7.30	3.48	-		
C_6H_5-CH_2-	Neat		-						-	-	-		
	CCl_4		6.34						6.82	3.20	2.76		
	C_6H_6		6.37						7.37	3.55	-		

R	Solvent	α-CH3	α-CH2	α-CH	β-CH3	β-CH2	β-CH	γ-CH3	N-CH3	"Aldehyde" H	N-C6H5	syn H	anti H
$(CH_3)_2CH-$	Neat			7.48	8.92				7.18	3.54	2.85		
	CCl_4			-	8.85				6.86	3.37	2.87		
	C_6H_6			-	8.92				7.32	3.58	-		
$CH_3CH_2\diagdown$ $\diagup CH-$ CH_3	Neat			7.72	8.92	8.62		9.08	7.15	3.52	2.80		
	CCl_4			-	8.88	8.55		9.05	6.84	3.36	2.65		
	C_6H_6			-	8.86	8.58		9.07	7.24	3.52	-		
$(CH_3CH_2)_2CH-$	Neat			7.90		8.60		9.08	7.12	3.57	2.74		
	CCl_4			7.80		8.53		9.07	6.82	3.44	2.82		
	C_6H_6			7.78		8.60		9.08	7.25	3.61	-		
$CH_3(CH_2)_3\diagdown$ $\diagup CH-$ CH_3CH_2 [b]	Neat			7.75					7.05	3.53	2.80		
	CCl_4			-					6.80	3.44	2.84		
	C_6H_6			-					7.24	3.58	-		
$((CH_3)_2CH)_2CH-$ [b]	Neat							9.08	7.08	3.55	2.77		
	CCl_4							9.07	6.80	3.44	2.83		
	C_6H_6							9.08	7.24	3.58	-		
 [b]	Neat								7.16	3.50	2.77		
	CCl_4								6.82	3.33	2.80		
	C_6H_6								7.28	3.51	-		
H	Neat								7.20		-	-	-
	CCl_4								6.82		2.73	3.68	3.83
	C_6H_6								7.37		-	3.90	4.04

[a] Center of a complex multiplet.
[b] Alkyl region is quite complex.

Table II. Chemical Shifts (τ-Values) of N-Methylphenylhydrazones.


$R_1R_2C=N-N(CH_3)C_6H_5$

			α-CH_3		α-CH_2		α-CH		β-CH_3		γ-CH_3				Isomer Ratio
R_1	R_2	Solvent	syn	anti	syn	anti	syn	anti	syn	anti	syn	anti	N-CH_3	N-C_6H_5[a]	syn-anti
CH_3-	CH_3-	Neat	8.33	8.13									7.22	3.11	-
		CCl_4	8.15	7.97									7.05	3.10	
		C_6H_6	8.42	8.20									7.17	-	
CH_3CH_2-	CH_3-	Neat	8.30	8.07	-	7.50			9.16	8.93			7.18	2.97	86-14
		CCl_4	8.13	7.93	-	7.35			8.99	8.80			7.02	2.99	
		C_6H_6	8.30	8.13	-	7.52			9.27	8.95			7.16	-	
$(CH_3)_2CH$-	CH_3-	Neat	8.28	8.13			-	7.50	9.17	8.92			7.16	2.99	94-6
		CCl_4	8.17	8.00			-	7.35	9.00	8.82			7.02	3.00	
		C_6H_6	8.37	8.17			-	7.52	9.25	8.93			7.15	-	
$(CH_3)_3C$-	CH_3-	Neat	8.37	-							-	8.87	7.24	3.00	100-0
		CCl_4	8.15	-							-	8.80	7.08	3.32	
		C_6H_6	8.32	-							-	8.87	7.20	-	
$(CH_3)_3C$-CH_2-	CH_3-	Neat	8.20	8.00	7.53	7.82					9.13	9.00	7.17	2.76	93-7
		CCl_4	8.07	7.87	7.18	7.71					9.03	8.95	7.00	2.95	
		C_6H_6	8.27	8.00	7.31	7.82					9.15	9.02	7.15	-	
C_6H_5-	CH_3-	Neat	7.94	-									7.05	2.58[b]	100-0
		CCl_4	7.64	-									6.82	2.57	
		C_6H_6	8.00	-									7.05	-	

[a] Center of a complex multiplet.
[b] Includes the resonance for both phenyls.

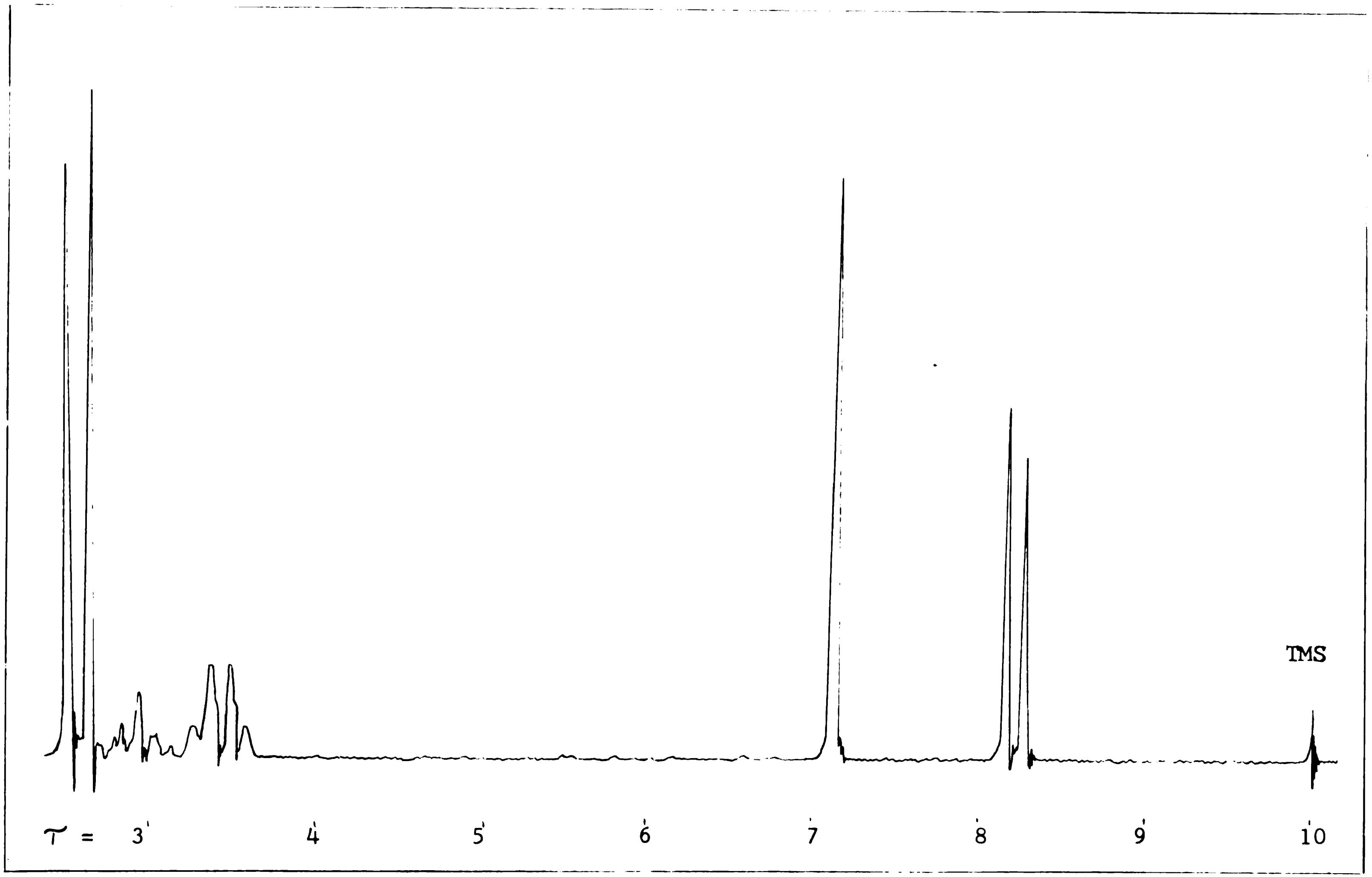


Figure I. N.M.R. Spectrum of Acetaldehyde N-methylphenylhydrazone (neat).

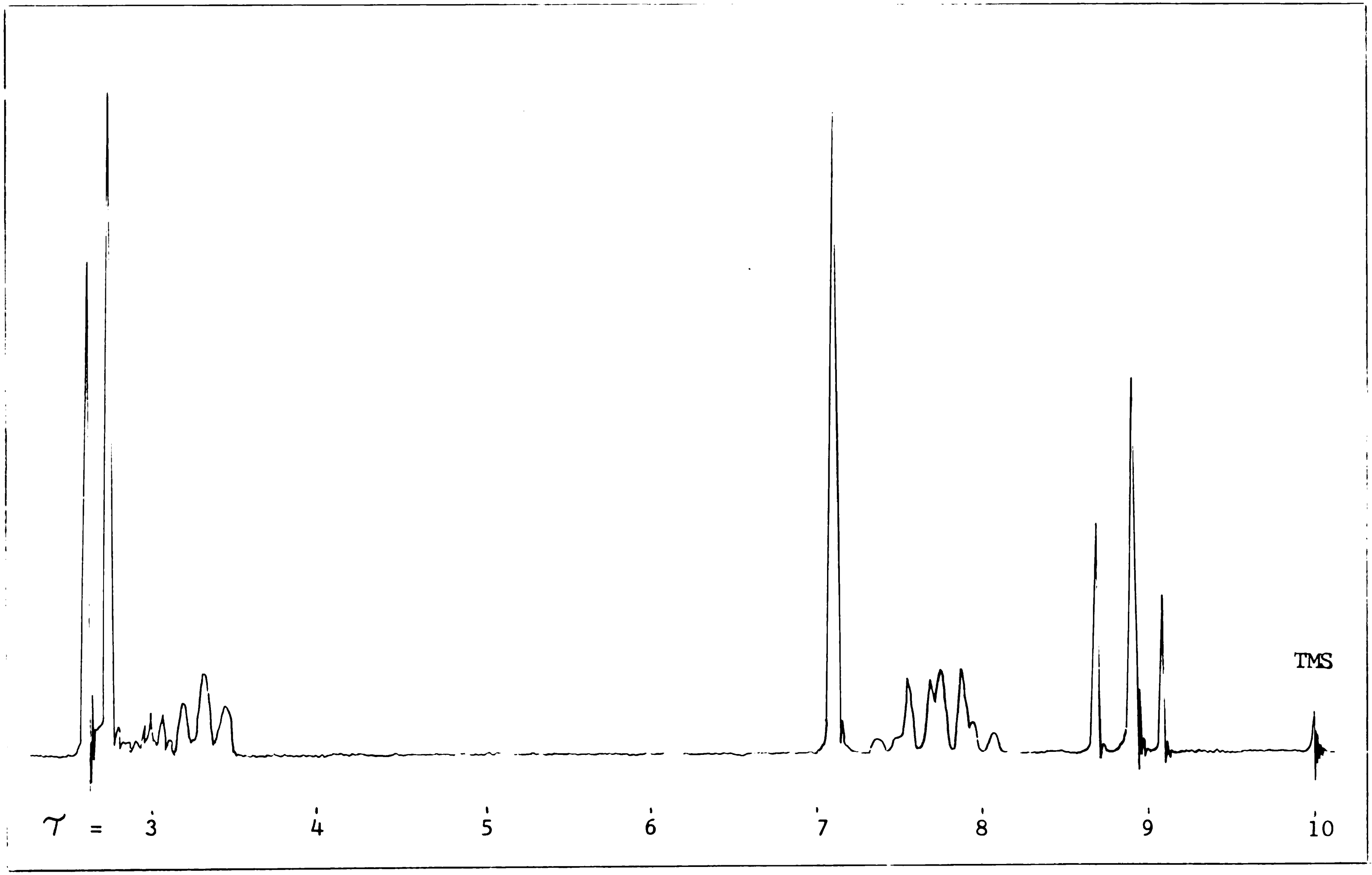


Figure II. N.M.R. Spectrum of Propionaldehyde N-methylphenylhydrazone (neat).

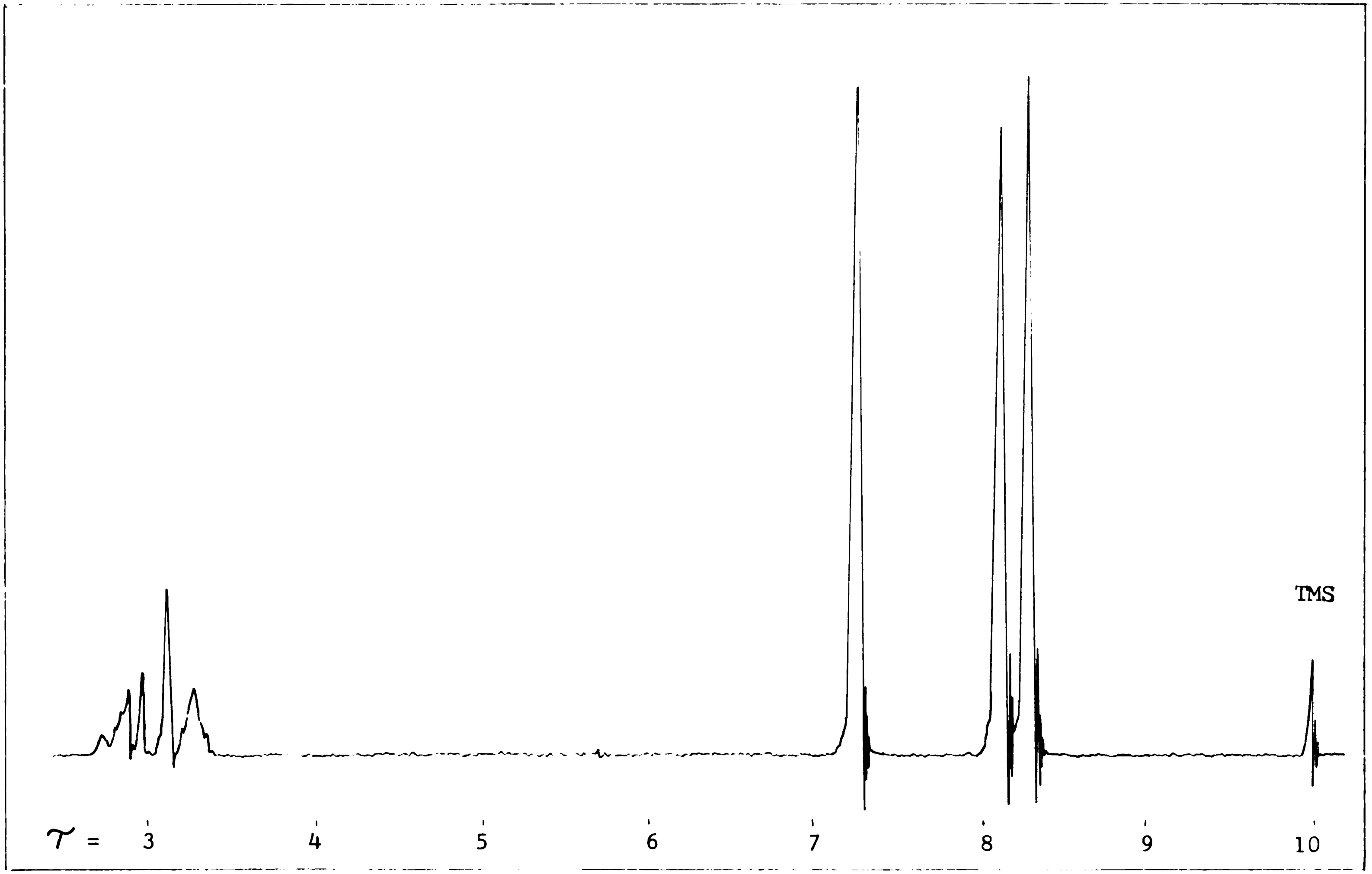


Figure III. N.M.R. Spectrum of Acetone N-methylphenylhydrazone (neat).

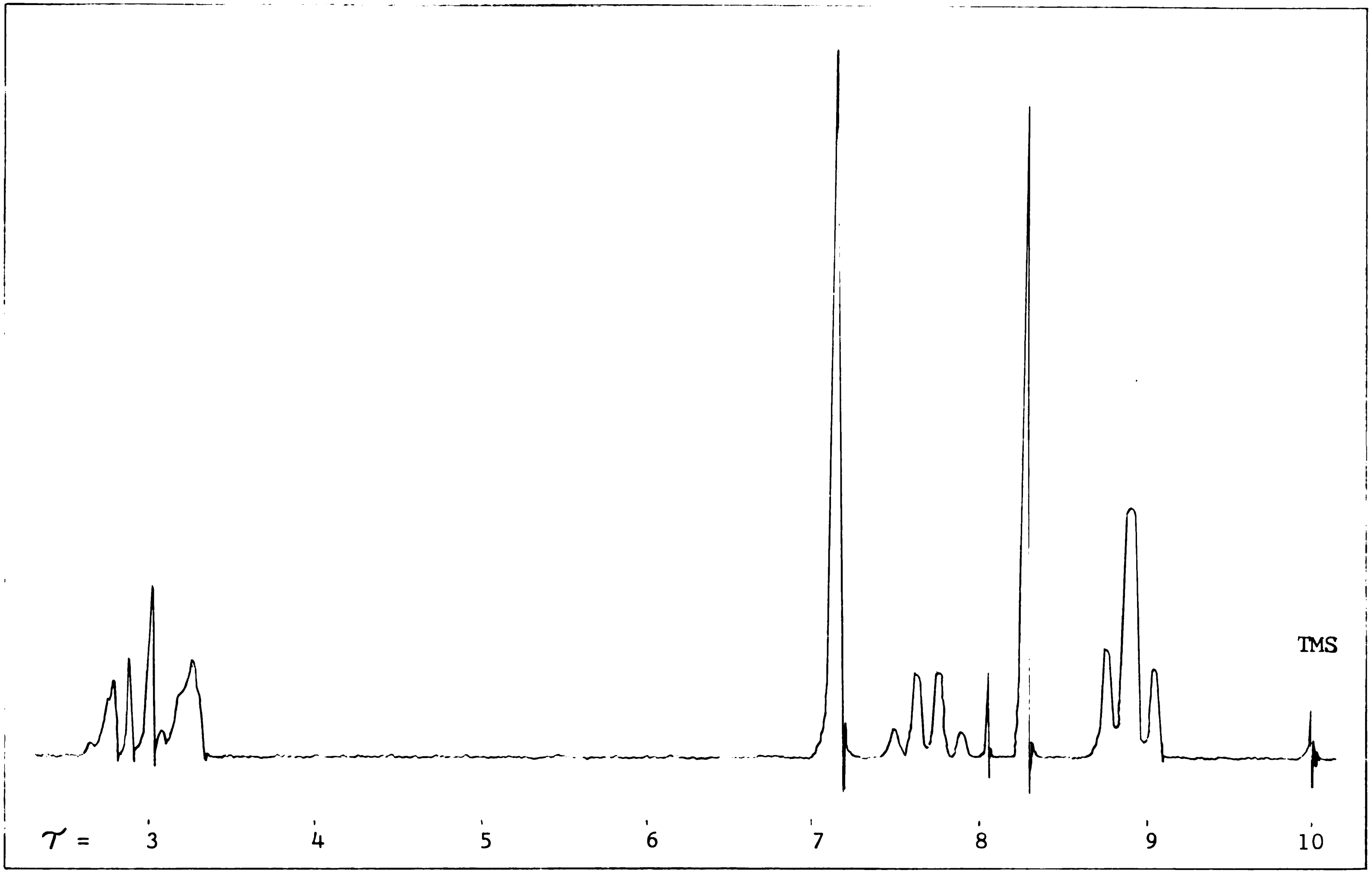


Figure IV. N.M.R. Spectrum of 2-Butanone N-methylphenylhydrazone (neat).

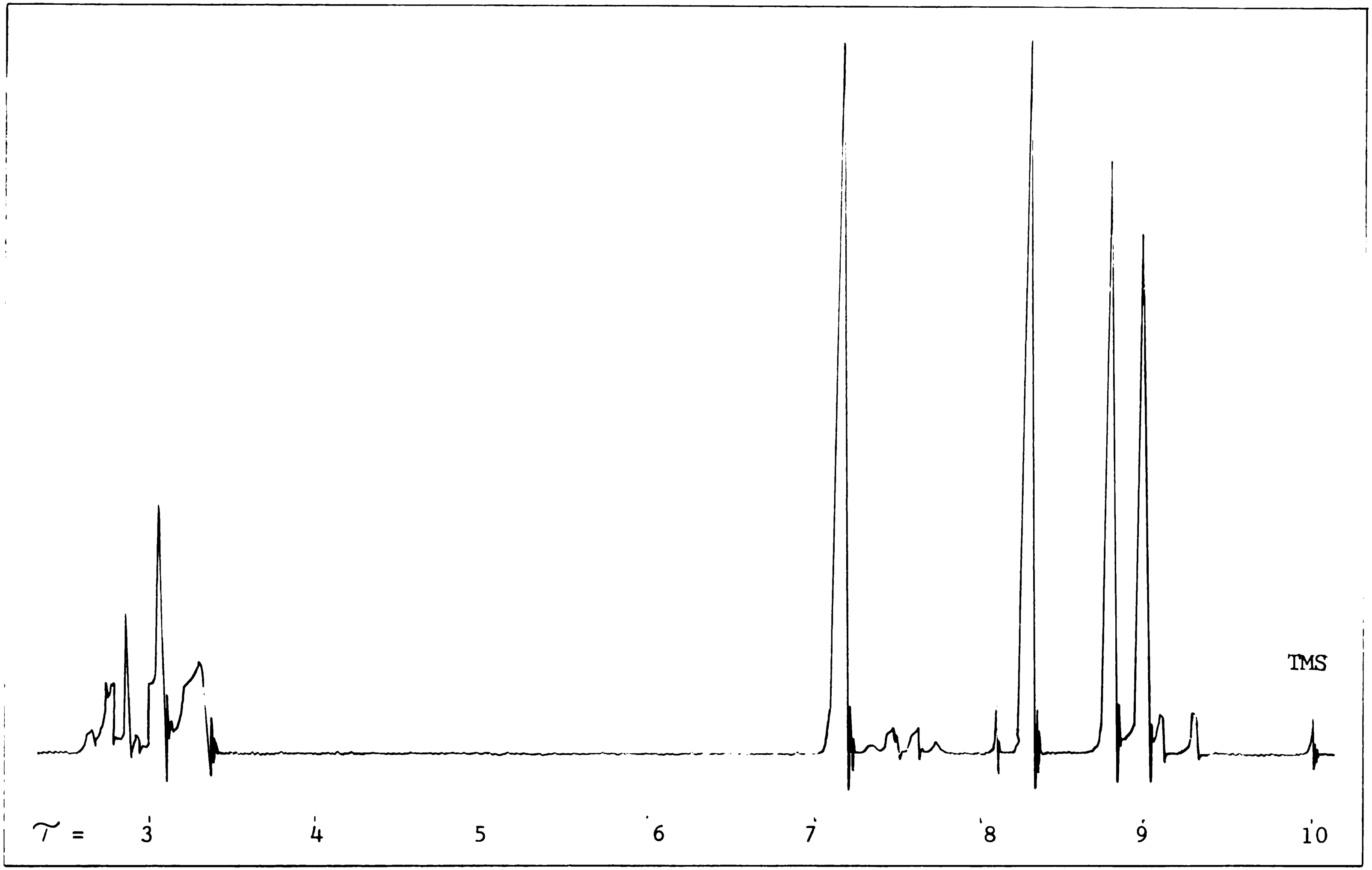


Figure V. N.M.R. Spectrum of 3-Methyl-2-butanone N-methylphenylhydrazone (neat).

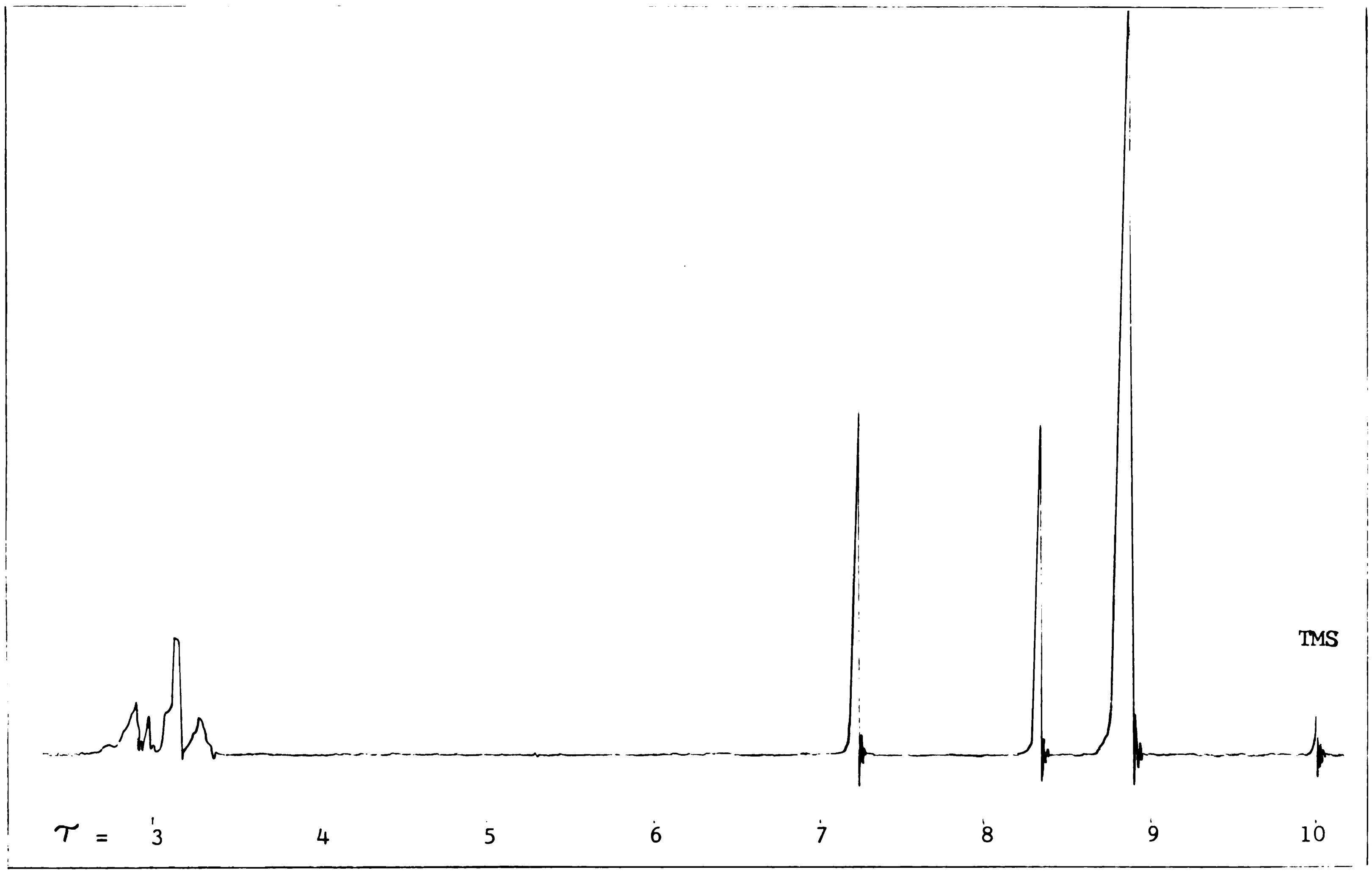


Figure VI. N.M.R. Spectrum of Pinacolone N-methylphenylhydrazone (neat).

The chemical shifts are accurate to ± 0.01 p.p.m. and the differences in chemical shifts of the syn and anti protons are accurate to ± 0.10 c.p.s. The syn-anti ratios, accurate to about 5%, were calculated from integration of the appropriate peak areas. Table III summarizes the differences in chemical shift of syn and anti protons. Structural assignments, syn and anti, were based on the assumption (9) that, when R_1 is methyl (I), the equilibrium ratio syn-anti increases as R_2 changes from ethyl to isopropyl to tert-butyl. The chemical shifts for any given series of hydrogens, α-methyl, β-methylene, etc., are internally consistent as their variation in a particular solvent is usually less than ± 0.10 p.p.m. As shown in Table III, whereas α-methyl, β-methyl, and γ-methyl protons are shielded, α-methylene protons are deshielded.

Dilution Studies

The effect of dilution with benzene and carbon tetrachloride on the chemical shifts of the α-methyl protons, the "aldehydic" proton and the N-methyl protons of acetaldehyde and acetone N-methylphenylhydrazones are illustrated in Figures VII and VIII. The most striking feature of these results is the difference in the behavior of the chemical shift of the N-methyl protons on dilution with benzene. Whereas the N-methyl protons of acetaldehyde N-methylphenylhydrazone move to higher magnetic fields, those of acetone N-methylphenylhydrazone move to lower magnetic fields.

Table III. Chemical Shift Differences ($\Delta\nu$ c.p.s.) Between syn and anti Protons.[a] $R_1R_2C{=}N{-}N(CH_3)C_6H_5$

R_1	R_2	Solvent	α-CH_3	α-CH_2	β-CH_3	γ-CH_3
CH_3-	CH_3-	Neat	+12.0			
		CCl_4	+10.8			
		C_6H_6	+13.2			
CH_3CH_2-	CH_3-	Neat	+13.8		+13.8	
		CCl_4	+12.0		+11.4	
		C_6H_6	+10.2		+19.2	
$(CH_3)_2CH$-	CH_3-	Neat	+ 9.0		+15.0	
		CCl_4	+10.2		+10.8	
		C_6H_6	+12.0		+19.2	
$(CH_3)_3C$-CH_2-	CH_3-	Neat	+12.0	-17.4		+ 7.8
		CCl_4	+12.0	-31.8		+ 4.8
		C_6H_6	+16.2	-30.6		+ 7.8

[a] A plus sign denotes "shielding" and a minus sign denotes "deshielding."

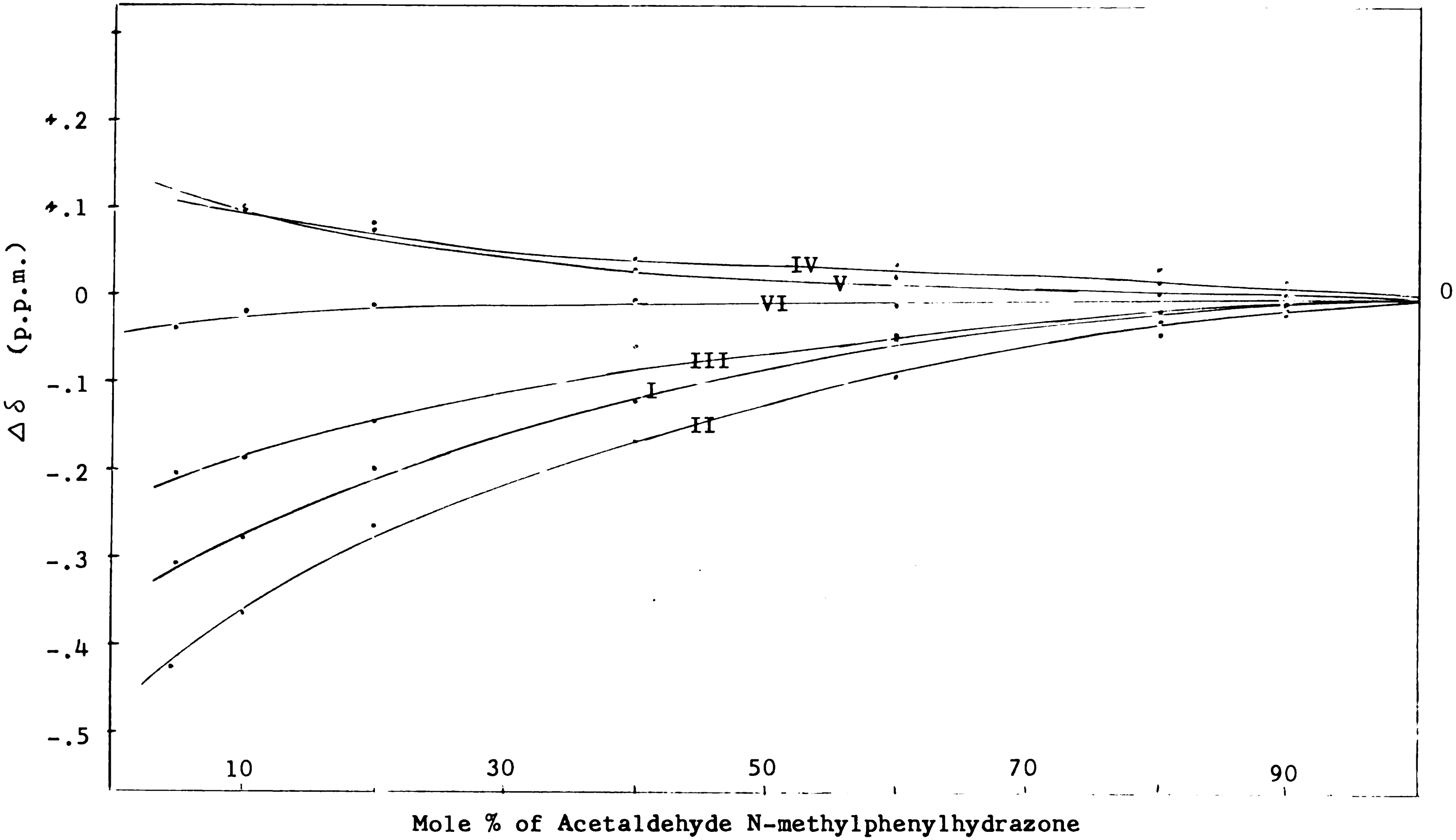


Figure VII. Effect of dilution on Chemical Shift: I "aldehyde" H in CCl_4, II $N-CH_3$ in CCl_4, III $\alpha-CH_3$ in CCl_4, IV "aldehyde" H in C_6H_6, V $N-CH_3$ in C_6H_6, and VI $\alpha-CH_3$ in C_6H_6

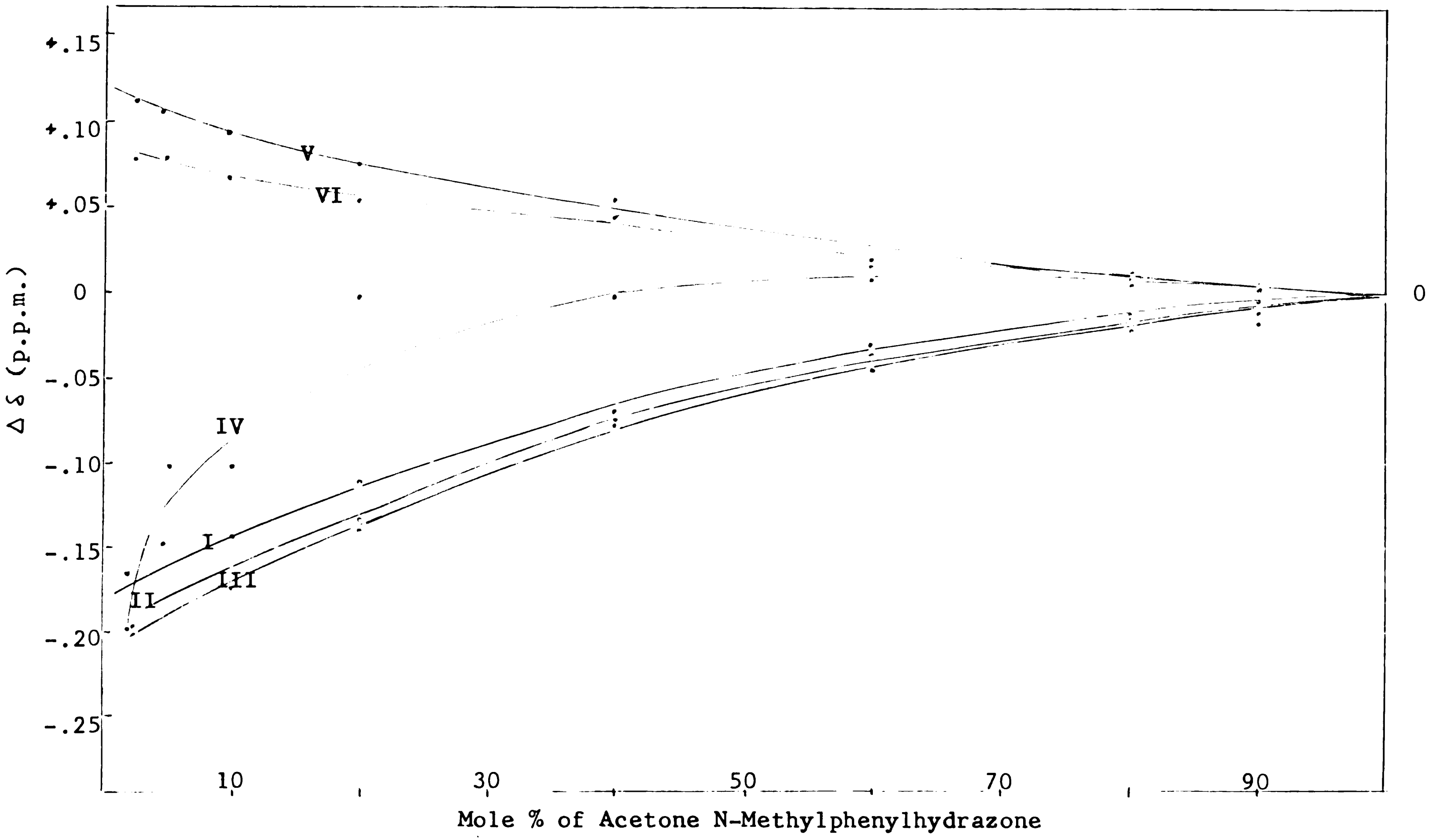
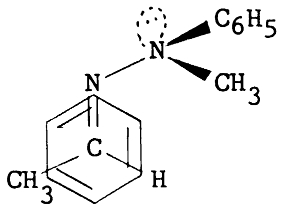
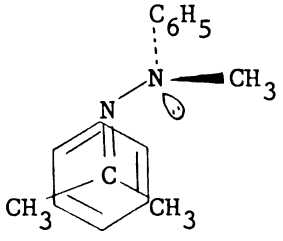


Figure VIII. Effect of Dilution on Chemical Shift: I N-CH_3 in CCl_4, II anti-CH_3 in CCl_4, III syn-CH_3 in CCl_4, IV N-CH_3 in C_6H_6, V anti-CH_3 in C_6H_6, and VI syn-CH_3 in C_6H_6

These results can be adequately explained by assuming stereospecific association between benzene and substrate as illustrated in II and III. Such association has been proposed for amides (10)



II



III

and alkyl nitrites, nitrosamines, and oximes (8,9). The peculiar behavior of the N-methyl protons can be rationalized by assuming that the conformation of the N-methylanilino group of acetaldehyde N-methylphenylhydrazone is different from that of acetone N-methylphenylhydrazone. Thus, whereas the N-methyl protons of the acetaldehyde derivative are in the shielding region of benzene (II), those of the acetone derivative are in the deshielding region (III). Further support of this conformational argument will be given later.

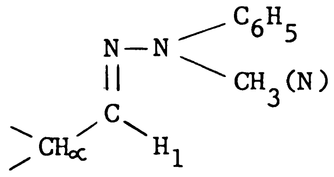
Proton-^{13}C Spin-Spin Coupling Constants

In general, $J_{^{13}C\text{-}H}$ is a function of the s character of the carbon bonding orbital (11). The limitations of the correlation have been recently discussed (12).

The $J_{^{13}C\text{-}H}$ coupling constants for a number of the aldehyde N-methylphenylhydrazones were calculated from ^{13}C natural abundance measurements. The values are well within the limits anticipated for an *sp^2* hybridized carbon and are summarized in Table IV.

Long Range Proton-Proton Coupling Constants

An interesting feature of the n.m.r. spectra of aldehyde N-methylphenylhydrazones is the appearance of five and six bond coupling constants between H_N and H_1 and between H_α and H_N respectively (IV). Figure IX shows some pertinent spectra.



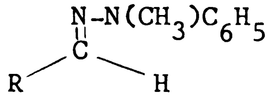
IV

These long-range couplings are probably less than 0.1 c.p.s. in the ketone N-methylphenylhydrazones as demonstrated by the fact that the N-methyl and the α-hydrogen resonance peaks have half widths of 0.5-0.6 c.p.s. (half width of tetramethylsilane was 0.5-0.6 c.p.s.). Table V and Table VI summarize the long-range coupling constants for the aldehyde derivatives and the line half widths for the ketone derivatives respectively.

This anomaly in long-range coupling can be again ascribed to conformational effects (II versus III). This point will now be considered in detail.

When Z is NHY, both *syn* (V) and *anti* (VI) isomers of aldehyde derivatives are present in solution, the isomer ratios being functions

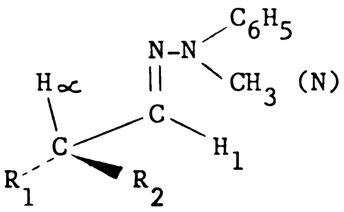
Table IV. Proton-^{13}C Spin-Spin Coupling Constants.



$R-CH=N-N(CH_3)C_6H_5$

R	$J_{^{13}C-H}$ (c.p.s.)
Methyl	162
Ethyl	154
n-Propyl	157
i-Propyl	156
i-Butyl	156
2-Butyl	153
3-Pentyl	155
Cyclohexyl	158

Table V. Long Range Spin-Spin Coupling Constants (c.p.s.).

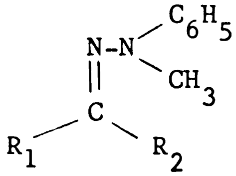


R_1	R_2	$J_{H_N H_1}$ [a]	$J_{H_N H_\alpha}$ [b]
H	H	0.77	0.40
Methyl	H	0.76	0.40
Ethyl	H	0.66	-
i-Propyl	H	0.70	-
t-Butyl	H	0.76	-
Phenyl	H	0.79	-
Methyl	Methyl	0.80	0.20
Ethyl	Methyl	0.71	0.20
Ethyl	Ethyl	0.67	-
n-Butyl	Ethyl	0.70	0.2
i-Propyl	*i*-Propyl	0.75	0.2
$-(CH_2)_5-$		0.72	0.2

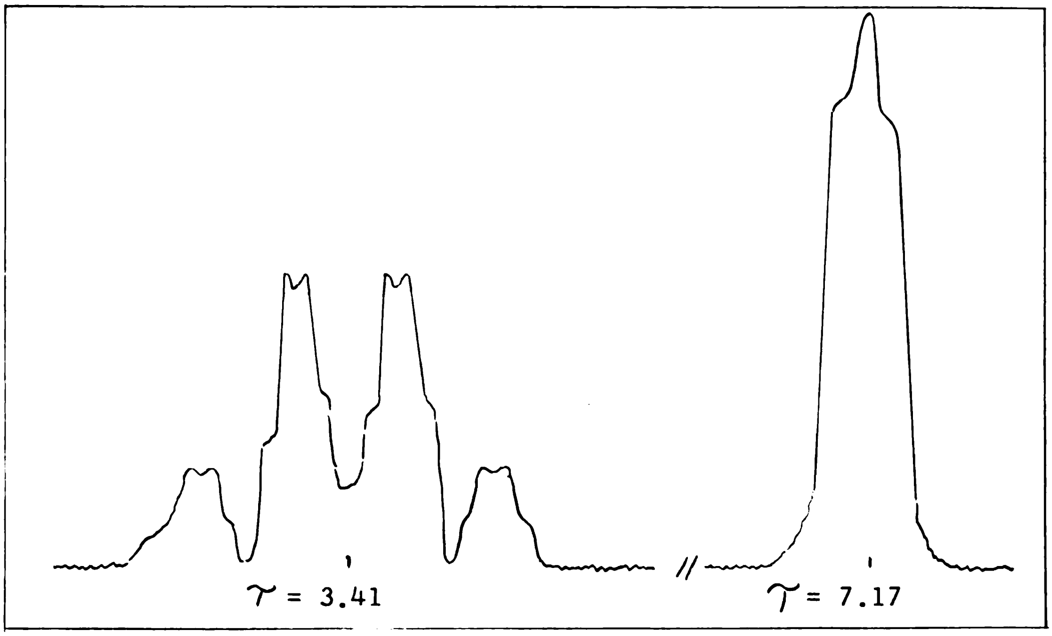
[a] These values were obtained from the "aldehyde" proton region at a sweep width of 50 c.p.s. (see Figure IX).

[b] These values were obtained from the N-methyl proton region at a sweep width of 50 c.p.s. and could not be measured accurately.

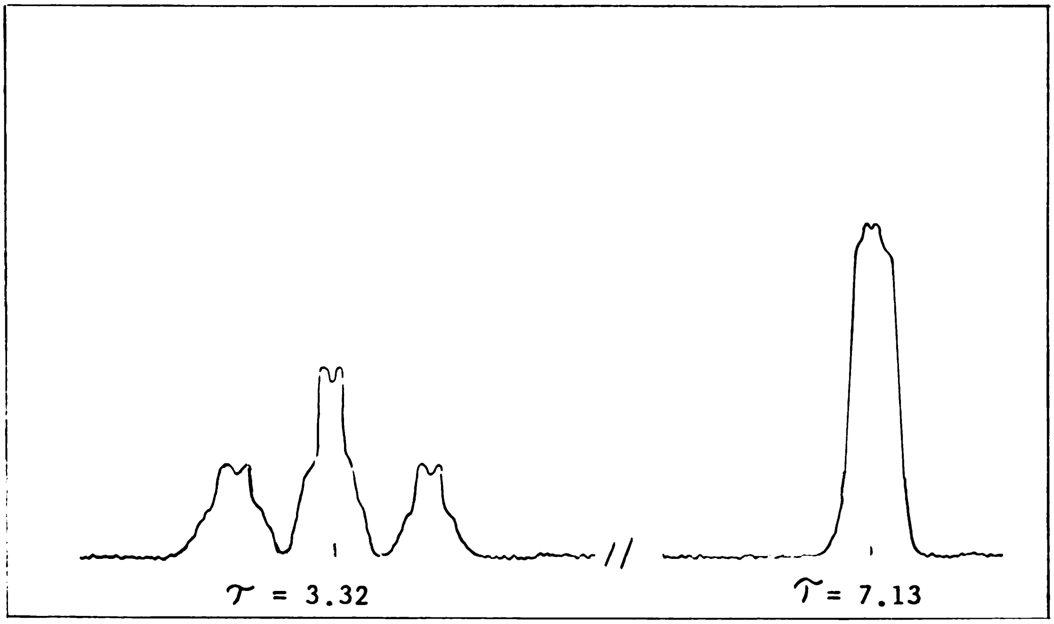
Table VI. Line Half-Widths of *syn*-Methyl, *anti*-Methyl, and N-Methyl Protons of Ketone N-methylphenylhydrazones (c.p.s.).



R_1	R_2	*syn*-α-CH_3	*anti*-α-CH_3	N-CH_3
Methyl	Methyl	0.60	0.51	0.59
Ethyl	Methyl	0.61	-	0.57
i-Propyl	Methyl	0.54	-	0.55
t-Butyl	Methyl	0.58	-	0.60
Ethyl	Ethyl	-	-	0.60
neo-Pentyl	Methyl	0.54	-	0.61



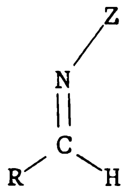
A. "Aldehyde" proton (τ=3.41) and N-methyl proton (τ=7.17) absorption region at sweep width = 50 c.p.s.



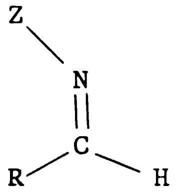
B. "Aldehyde"proton (τ=3.32) and N-methyl proton (τ=7.13) absorption region at sweep width = 50 c.p.s.

Figure IX. Expanded N.M.R. Spectra of Neat Samples of: A. Acetaldehyde N-methylphenylhydrazone and B. Propionaldehyde N-methylphenylhydrazone.

of the size and nature of R. When Z is $N(CH_3)C_6H_5$, however, a single isomer is present that does not isomerize on heat or acid



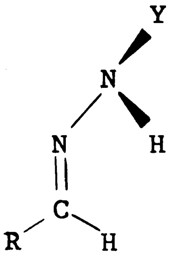
V



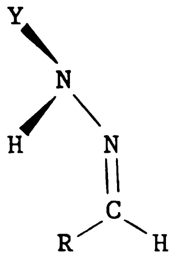
VI

treatment. Regardless of the nature of Z, both *syn* and *anti* isomers of ketone derivatives are present.

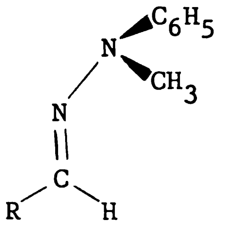
Steric considerations offer a rational explanation of these differences. When Z is NHY, *syn* (VII) and *anti* (VIII) isomers should have similar conformations, the unshared pairs of electrons in both isomers being parallel to and overlapping with the π-orbitals. When Z is $N(CH_3)C_6H_5$, only the *syn* (IX) isomers could assume such conformations; in the *anti*, because of strong nonbonded interactions between R and methyl or phenyl, the unshared electrons would become nonparallel with the π-orbital (X). Formation of the less instead of the more substituted (double bond) enamines has also



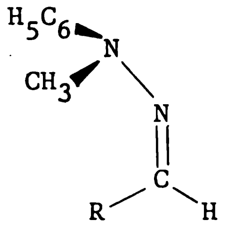
VII



VIII



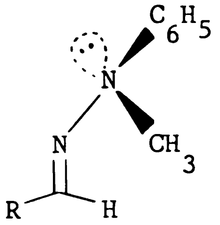
IX



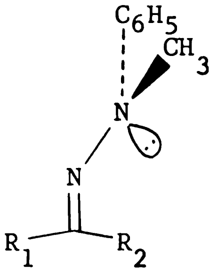
X

been rationalized in terms of steric interactions (13).

Aldehyde N-methylphenylhydrazones (XI), whose lone pair of electrons are overlapping with the π electrons of the double bond, should have a higher λ_{max} and ϵ in the ultraviolet than ketone



XI



XII

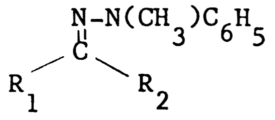
N-methylphenylhydrazones (XII). The data summarized in Table VII support this prediction.

The ketone derivative bands at 250 mμ agree with the λ_{max}= 247 mμ (ϵ = 1.0 x 10^4) of 1-methyl-1-phenylhydrazine and the λ_{max}=251 mμ (ϵ = 1.0 x 10^4) of N,N-dimethylaniline. On the other hand, the aldehyde derivative bands at 278 mμ agree with those of phenylhydrazones, λ_{max}=275 mμ (ϵ = 1.8 x 10^4) (14).

<u>Stereospecificity of the Six Bond Coupling</u>

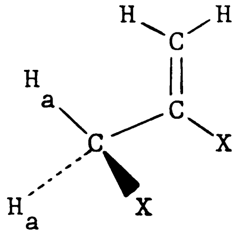
Whipple and co-workers (15,16) concluded that in 2,3-dihalopropenes (XIII) and (XIV) the four bond coupling, J_{ab}, decreases as the equilibrium shifts toward (XIII). Whipple did not draw his conformations as indicated below, but had them rotated 30° about the α-carbon-trigonal carbon bond. Later evidence (17,18) has

Table VII. Ultraviolet Absorption Maxima and Extinction Coefficients (ε) of Some N-Methylphenylhydrazones.

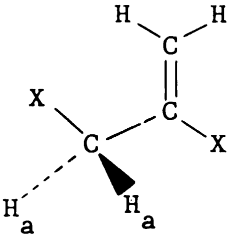


					plateau[a]	
R_1	R_2	Solvent	λmax	ε	λmax	ε
Methyl	H	Ethanol	278	$1.84\text{x}10^4$		
		Cyclohexane	277	$1.3\ \text{x}10^4$		
Ethyl	H	Ethanol	278	$1.84\text{x}10^4$		
		Cyclohexane	278	$1.4\ \text{x}10^4$		
n-Propyl	H	Ethanol	279	$2.23\text{x}10^4$		
3-Pentyl	H	Ethanol	279	$2.21\text{x}10^4$		
Methyl	Methyl	Ethanol	250	$9.51\text{x}10^3$	288	$2.97\text{x}10^3$
		Cyclohexane	249	$5.87\text{x}10^3$	280	$\sim10^3$
Ethyl	Methyl	Ethanol	250	$1.03\text{x}10^4$	277	$3.51\text{x}10^3$
		Cyclohexane	250	$4.45\text{x}10^3$	-	-

[a] The aldehyde derivatives show a single peak whereas the ketone derivatives show a peak and a shoulder. The shoulder was broad and flat and the λmax was difficult to assign accurately.



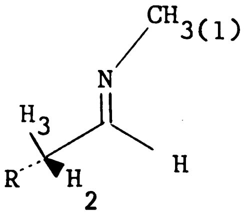
XIII



XIV

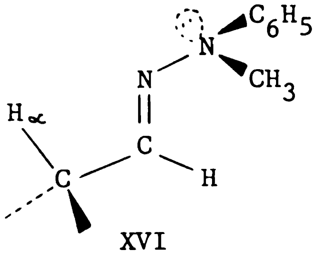
indicated that the above conformations are favored and these will be discussed more fully in the next section.

Karabatsos and Lande (19) have also observed that J_{12} is large and J_{13} is small in XV.

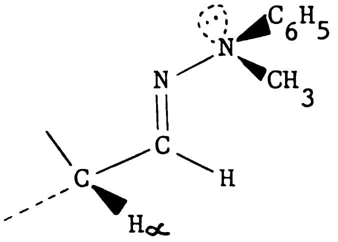


XV

If the observed six bond coupling constants were to follow the same trend, then XVI would contribute much less than XVII to the coupling. This can be tested as follows: The relative populations of XVI and XVII depend on the alkyl groups attached to the α-carbon. As the size of the alkyl groups increases, the ratio



XVI

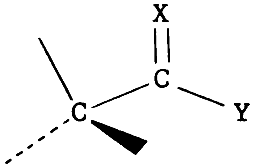


XVII

of XVI/XVII increases. Consequently, $J_{H_N H_\alpha}$ should decrease and the data in Table V support this contention.

Rotational Isomerism

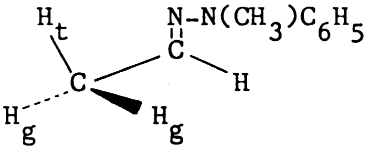
Several studies have shown (15-30) that the stable conformation of a tetrahedral carbon bonded to a trigonal carbon has a single bond eclipsing the double bond (XVIII). Assuming this to be the case for N-methylphenylhydrazones, the relative stabilities



XVIII

of the various conformations of aldehyde N-methylphenylhydrazones can be calculated from studies of spin-spin coupling constants. Table VIII summarizes the pertinent coupling constants that are precise to ± 0.04 c.p.s.

The average coupling constant of acetaldehyde N-methylphenylhydrazone (XIX) is expressed by equation 1, where J_g is the gauche coupling and J_t is the trans coupling.

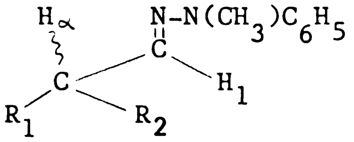


XIX

$$J_{HH} = 1/3(2J_g + J_t) \qquad \underline{1}$$

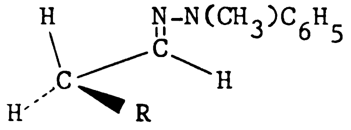
The average coupling constant of monosubstituted acetaldehyde N-methylphenylhydrazones is expressed by equation 2, where Y is the

Table VIII. Spin-Spin Coupling Constants of Aldehyde N-Methylphenylhydrazones.

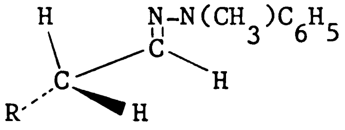


R_1	R_2	$J_{H_\alpha H_1}$ (c.p.s.)
H	H	5.06
Methyl	H	4.76
Ethyl	H	5.10
_i_-Propyl	H	5.33
_t_-butyl	H	5.98
Phenyl	H	5.40
Methyl	Methyl	4.60
Ethyl	Methyl	5.24
Ethyl	Ethyl	5.91
_n_-butyl	Ethyl	5.97
_i_-Propyl	_i_-Propyl	6.27
$-(CH_2)_5-$		4.41

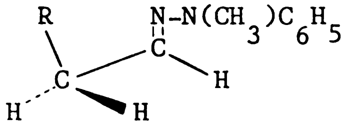
fractional population of XX + XXI, and 1-Y the fractional population of XXII.



XX



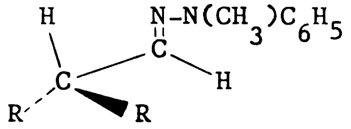
XXI



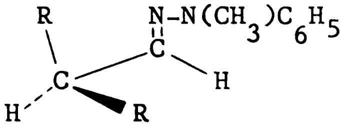
XXII

$$J_{HH} = \tfrac{1}{2}Y(J_g + J_t) + (1-Y)J_g \qquad \underline{2}$$

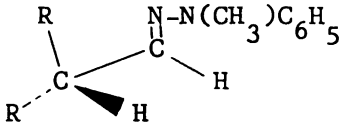
The average coupling constant of disubstituted acetaldehyde N-methylphenylhydrazones is expressed by equation $\underline{3}$ where Y is the fractional population of XXIII and 1-Y the fractional population of XXIV and XXV.



XXIII



XXIV



XXV

$$J_{HH} = YJ_t + (1-Y)J_g \qquad \underline{3}$$

Making the reasonable assumption (17) that <u>tert</u>-butylacetaldehyde N-methylphenylhydrazone exists exclusively in conformation XX, its average coupling constant is expressed by equation $\underline{4}$. From equations

$$J_{HH} = \tfrac{1}{2}(J_g + J_t) \qquad \underline{4}$$

$\underline{1}$ and $\underline{4}$, values for J_t and J_g can be obtained. In turn, when these values are used in equations $\underline{2}$ and $\underline{3}$, the populations of the various rotamers can be calculated.

A serious error arises from the assumption that J_t and J_g will be the same for acetaldehyde, monosubstituted acetaldehyde and disubstituted acetaldehyde N-methylphenylhydrazones. There is ample evidence in the literature that substitution of an alkyl group for a hydrogen decreases the coupling. For example, whereas the coupling of ethane (31) is 8.0 c.p.s., those of propane (32) and isobutane (33) are 7.3 and 6.8 c.p.s. respectively. From electronegativity considerations (34,35) substitution of an alkyl group for a hydrogen should decrease the coupling by about 0.3 c.p.s. Karabatsos and co-workers have shown (36) that the best correction for aldehydes and their derivatives is 0.4 c.p.s. per alkyl group. The rotamer percentages, therefore, summarized in Tables IX and X, were calculated from equations 1, 5, 6, and 7 (J_g = 2.44 c.p.s. and J_t = 10.30 c.p.s.) instead of equations 1, 2, 3, and 4. The free energy differences, ΔF^o between the individual rotamers were calculated from equation 8.

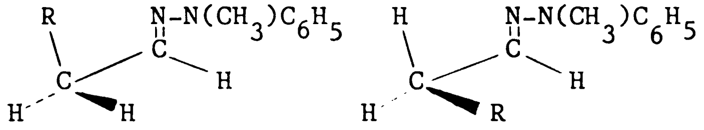
$$J_{HH} + 0.4 \text{ (monosubstituted)} = \frac{Y}{2}(J_g + J_t) + (1-Y) J_g \qquad \underline{5}$$

$$J_{HH} + 0.8 \text{ (disubstituted)} = YJ_t + (1-Y) J_g \qquad \underline{6}$$

$$J_{HH} + 0.4 \left(\begin{array}{l}\underline{\text{tert}}\text{-butylacetaldehyde} \\ \text{N-methylphenylhydrazone}\end{array}\right) = \tfrac{1}{2}(J_g + J_t) \qquad \underline{7}$$

$$\Delta F^o = -RT\ln K \qquad \underline{8}$$

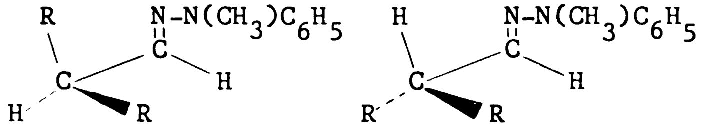
Table IX. Conformer Percentages and ΔF^{o} Values for Monosubstituted Acetaldehyde N-Methylphenylhydrazones.



R	A	B	$\Delta F^{o}_{36^{o}C}$ [a] (Kcal/mole)
Methyl	31%	69%	-0.06
Ethyl	22%	78%	-0.28
_i_-Propyl	16%	84%	-0.59
Phenyl	14%	86%	-0.69

[a] ΔF^{o} was calculated from: $\Delta F^{o} = -RT\ln(\frac{1}{2}B/A)$

Table X. Conformer Percentages and ΔF^{o} Values for Disubstituted Acetaldehyde N-Methylphenylhydrazones.



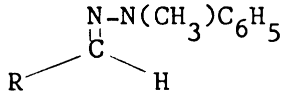
R	A	B	$\Delta F^{o}_{36^{o}C}$ [a] (Kcal/mole
Methyl	62%	38%	-0.13
Ethyl	54%	46%	-0.33
_i_-Propyl	41%	59%	-0.66
$-(CH_2)_5-$	65%	35%	-0.05

[a] ΔF^{o} was calculated from $\Delta F^{o} = -RT\ln(B/\frac{1}{2}A)$

From the negative ΔF^{o} values in Tables IX and X, it is apparent that the more stable conformation for substituted acetaldehyde N-methylphenylhydrazones has a hydrogen eclipsing the double bond as in XX, XXI, and XXIII.

The dependence of the coupling constants on temperature is summarized in Table XI. Heating a compound increases the probability that the rotamers will become more equally populated. Therefore, the coupling constants of those compounds whose conformations are almost energetically equivalent, *i.e.*, A, B, and E, should change only slightly on heating. On the other hand, the coupling constants of those compounds whose conformations are energetically nonequivalent, *i.e.*, C and D, should change appreciably. The data in Table XI support these conclusions.

Table XI. Effect of Changing Temperature on $J_{H_{\alpha}H_{1}}$ (XVI and XVII) (c.p.s.)[a]



	R	J (0°)	J (36°)	J (65°)	J (95°)
A	Methyl	5.06	5.10	5.10	5.08
B	Ethyl	4.82	4.80	4.71	-
C	*neo*-Pentyl	-	6.05	5.90	5.59
D	3-Pentyl	-	5.91	5.83	5.60
E	Cyclohexyl	-	4.48	-	4.50

[a] The coupling constants are accurate to ± 0.05 c.p.s. and are uncorrected.

EXPERIMENTAL

General Procedure for the Preparation of N-Methylphenylhydrazones.

The N-methylphenylhydrazones were prepared by placing 0.05 moles of 1-methyl-1-phenylhydrazine in ten-ml. of water, adding enough glacial acetic acid to dissolve the 1-methyl-1-phenylhydrazine, and then adding the appropriate aldehyde or ketone (0.05 moles) dropwise. The mixture was stirred for thirty minutes at room temperature. The organic layer was separated, dried over potassium carbonate, and fractionated. All of the products were oils whose boiling points are listed in Table XII.

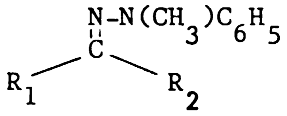
N.M.R. Spectra.

All n.m.r. spectra were taken at about 36°, except where noted otherwise, using a Varian A-60 spectrometer. Undegassed samples were placed in thin-walled tubes. Each compound was studied neat, 10% in carbon tetrachloride, and 10% in benzene, using tetramethylsilane as an internal reference standard.

Ultraviolet Spectra.

The ultraviolet spectra were taken at 25° using a Beckman D.U. and a Beckman D.B. spectrophotometer.

Table XII. Boiling Points of N-Methylphenylhydrazones.



R_1	R_2	Boiling Point
H	H	66-69°/ 1mm.
Methyl	H	120-1° / 13mm.
Ethyl	H	148-9° / 30mm.
n-Propyl	H	113-5° / 1mm.
i-Butyl	H	104-6° / 1mm.
neo-Pentyl	H	105-6° / 1mm.
Benzyl	H	170-3° / 2mm.
i-Propyl	H	135-7° / 14mm.
sec-Butyl	H	105-7° / 1mm.
3-Pentyl	H	118-9° / 1mm.
3-Heptyl	H	121-3° / 1mm.
2,4-Dimethyl-3-pentyl	H	115-9° / 1mm.
Cyclohexyl	H	163-4° / 4mm.
Methyl	Methyl	90-3° / 7mm.
Ethyl	Methyl	103-6° / 6mm.
i-Propyl	Methyl	108-9° / 6mm.
tert-Butyl	Methyl	77-9° / 1mm.
Phenyl	Methyl	135-7° / 1mm.
neo-Pentyl	Methyl	112-4° / 1mm.
Benzyl	Methyl	146-9° / 1mm.

LITERATURE CITED

Part I

1) C. H. DePuy and R. W. King, Chem. Rev., 60, 431(1960).

2) A. Maccoll in "Theoretical Organic Chemistry," papers presented to the Kekule Symposium, London, 1958, p. 230. Butterworths Scientific Publications, London, 1959.

3) J. M. Corbett, M.S. Thesis, Michigan State University, 1963.

4) R. Taylor, G. G. Smith and W. H. Wetzel, J. Am. Chem. Soc., 84 4817(1962).

5) G. G. Smith, F. D. Bagley and R. Taylor, ibid, 83, 3647(1961).

6) G. G. Smith, D. A. K. Jones and D. F. Brown, J. Org. Chem., 27, 403(1963).

7) J. C. Scheer, E. C. Kooyman and F. L. J. Sixman, Rec. Trav. Chim., 82, 1123(1963); Chem. Abs. 60:6715a.

8) C. H. DePuy, R. W. King and D. H. Froensdorf, Tet., 7, 123(1959).

9) P. S. Skell and W. L. Hall, J. Am. Chem. Soc., 86, 1557(1964).

10) K. B. Wiberg, Chem. Rev., 55, 713(1955).

11) D. H. R. Barton, A. J. Head and R. J. Williams, J. Chem. Soc., 1952, (453).

12) A. T. Blades, Can. J. Chem., 36, 1043(1958).

13) G. L. O'Conner and H. R. Nace, J. Am. Chem. Soc., 77, 1578(1958).

14) O. L. Chapman and G. W. Borden, J. Org. Chem., 26, 4193(1961).

15) V. J. Traynellis, W. H. Hergenrother, J. R. Livingston and J. A. Valicenti, ibid, 27, 2377(1962).

16) G. J. Karabatsos, J. M. Corbett and K. L. Krumel, ibid, 29, 689(1965).

17) R. Fittig and E. Erdmann, Ann, 216, 194(1882).

18) H. Felkin and G. LeNy, Bull. Soc. Chim. France, 1957, (1169).

19) P. D. Bartlett, W. D. Closson and T. J. Cogdill, J. Am. Chem. Soc., 87, 1308(1965).

20) J. Berson in "Molecular Rearrangements-Part I" edited by P. DeMayo, Interscience Publishers, J. Wiley and Sons, New York, 1963, Chapter 3.

21) P. von R. Schleyer, J. Am. Chem. Soc., 86, 1856(1964).

22) J. Berson in "Molecular Rearrangements-Part I," loc. cit., p. 143.

23) P. D. Bartlett and S. Bank, J. Am. Chem. Soc., 83, 2591(1961).

24) P. D. Bartlett, S. Bank, R. J. Crawford and G. H. Schmid, ibid, 87, 1288(1965).

25) J. D. Roberts and J. A. Yancey, ibid, 77, 5558(1955).

26) D. H. Froensdorf, C. H. Collins, G. S. Hammond and C. H. DePuy, ibid, 81, 643(1959).

27) D. Y. Curtin and D. B. Kellom, ibid, 75, 6011(1953).

28) E. L. Eliel,"Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., New York, 1962, p. 236.

29) C. H. DePuy and R. W. King, J. Am. Chem. Soc., 83, 2743(1961).

30) M. L. Bouveault, Bull. Soc. Chim. France, 3, 29, 1049(1903).

31) N. Zelinsky, Chem. Ber., 41, 2629(1908).

32) R. Adams and J. R. Johnson, "Laboratory Experiments in Organic Chemistry," 4th edition, The MacMillan Co., New York, 1953, p. 417.

33) P. D. Bartlett, S. Bank, R. J. Crawford and G. H. Schmid, J. Am. Chem. Soc., 87, 1288(1965).

34) G. Komppa and S. Beckmann, Ann., 512, 177(1934).

35) P. D. Bartlett and M. Rice, J. Org. Chem., 27, 3351(1963).

36) R. G. Lawton, J. Am. Chem. Soc., 83, 2399(1961).

37) W. H. Perkin and K. Matsubara, J. Chem. Soc., 87, 668(1905).

38) Beilstein, 1, 418, I, 207, II, 446.

39) G. S. Hammond and C. H. Collins, J. Am. Chem. Soc., 82, 4323(1960).

40) Organic Syntheses Coll. Vol. 4, N. Rabjohn, editor, John Wiley & Sons, Inc., New York, 1963, p. 860.

41) P. D. Bartlett and E. B. Lefferts, J. Am. Chem. Soc., 77, 2804(1955).

42) L. Bateman and H. P. Koch, J. Chem. Soc., 1944 (600).

Part II

1) G. J. Karabatsos and R. A. Taller, J. Am. Chem. Soc., 85, 3624 (1963).

2) G. J. Karabatsos, F. M. Vane and J. Graham, ibid, 84, 753(1962).

3) G. J. Karabatsos, R. A. Taller, F. M. Vane and N. Hsi, ibid, 86, 3351(1964).

4) G. J. Karabatsos, N. Hsi, C. Osborne, and S. Lande, private communication.

5) G. J. Karabatsos, R. A. Taller and F. M. Vane, Tet. Let., 18, 1081 (1964).

6) C. E. Looney, W. D. Phillips and E. L. Reilly, J. Am. Chem. Soc., 79, 6136(1957).

7) W. D. Phillips, C. E. Looney, C. P. Spaeth, J. Mol. Spec., 1, 35(1957).

8) W. D. Phillips, Ann. N.Y. Acad. Sci., 70, 817(1958).

9) G. J. Karabatsos, R. A. Taller and F. M. Vane, J. Am. Chem. Soc., 85, 2326, 2327(1963).

10) J. Hatton and R. Richards, Mol. Phys., 3, 253(1960).
5, 153,193(1962).

11) H. S. Gutowsky and C. S. Juan, J. Am. Chem. Soc., 84, 307(1962).

12) G. J. Karabatsos and C. E. Orzech, ibid, 86, 3574(1964).

13) G. Stork, A. Brizzolara, H. Landesman, S. Szmuskovicz and R. Terrell, ibid, 85, 207(1963).

14) R. O'Conner, J. Org. Chem., 26, 4375(1961).

15) E. B. Whipple, J. H. Goldstein and G. R. McClure, J. Am. Chem. Soc., 82, 3811(1960).

16) E. B. Whipple, J. Chem. Phys., 35, 1039(1961).

17) A. A. Bothner-By, C. Naar-Colin, and H. Gunther, J. Am. Chem. Soc., 84, 2748(1962).

18) G. J. Karabatsos and N. Hsi, private communication.

19) G. J. Karabatsos and S. Lande, private communication.

20) S. Mizushima, T. Shimanouchi, T. Miyazawa, I. Ichishima, K. Kuratani, I. Nakagawa and N. Shido, J. Chem. Phys., 21, 815(1953).

21) I. Nakagawa, I. Ichishima, K. Kuratani, T. Miyazawa, T. Shimanouchi and S. Mizushima, ibid, 20, 1720(1952).

22) S. Mizushima, T. Shimanouchi, I. Ichishima, T. Miyazawa, I. Nakagawa and T. Araki, J. Am. Chem. Soc., 78, 2038(1956).

23) R. W. Kolb, C. C. Lin, and E. B. Wilson, Jr., J. Chem. Phys. 26, 1695(1957).

24) S. S. Butcher and E. B. Wilson, Jr., ibid, 40, 1971(1964).

25) K. M. Sinnott, ibid, 34, 851(1961).

26) C. Romers and J. E. G. Creutzberg, Rec. Trav. Chim., 75, 331(1956).

27) L. S. Bartell, B. L. Carroll and J. P. Guillory, Tet. Let., 13, 705(1964).

28) R. J. Abraham and J. A. Pople, Mol. Phys., 3, 609(1960).

29) A. A. Bothner-By and C. Naar-Colin, J. Am. Chem. Soc., 83, 231 (1961).

30) A. A. Bothner-By and H. Gunther, Disc. Faraday Soc., 34, 127(1962).

31) R. M. Lyndon-Bell and N. Sheppard, Proc. Roy. Soc., Ser. A., 269, 385(1962).

32) D. R. Whitman, L. Onsager, M. Saunders and H. E. Dubb, J. Chem. Phys., 32, 67(1960).

33) J. S. Waugh and F. W. Dobbs, ibid, 31, 1235(1959).

34) R. J. Abraham and K. G. R. Pachler, Mol. Phys., 7, 165(1963-64).

35) R. Glick and A. A. Bothner-By, J. Chem. Phys., 25, 362(1956).

36) G. J. Karabatsos, N. Hsi and S. Lande, private communication.