

NCL Library

Awarded PhD

Entered in 25/11/88

✓
VERIFIED
INL *SL*

g/ kabi
12.9.95

TH-749

COMPUTERISED

COMPUTERISED

VERIFIED
1977
INL *an*

NATIONAL BIODIVERSITY LABORATORY
LIBRARY
Acc. No. *5166f*
Call. No.

VERIFIED
1983
INL *an*

VERIFIED
1981
INL *an*

COMPUTERISED

**NMR SPECTROSCOPIC AND OTHER
STUDIES ON
CONJUGATED SYSTEMS**

COMPUTERISED

COMPUTERISED

A THESIS SUBMITTED TO THE UNIVERSITY OF POONA
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

by

T. FAIRWELL, M. Sc.

04-547-1
FAI

TH-7299

UNIVERSITY OF POONA
LIBRARY
Acc. No. 51661
Call. No.

NATIONAL CHEMICAL LABORATORY
POONA
1967

PREFACE

The importance of conjugation and hyperconjugation in unsaturated systems, like butadiene and propylene, i.e. systems for which only one classical resonance structure can be written, is now a controversial matter. The larger part of this thesis represents an effort to obtain further evidence related to this general problem by the application of NMR spectroscopy. Although some excellent reviews on the problem have appeared over the past decade, a brief re-survey of it is made here, to furnish the necessary background for the work described. The information that can be gleaned from the PMR methyl band width data for some substituted aromatic compounds is dealt with first. The results, in addition to giving valuable information on the effects of conjugation of COOMe and NO₂ groups with the benzene ring, raise the question of their interaction with the methyl group. The use of proton chemical shifts of disubstituted aromatic compounds, in the study of mutual interaction between groups across the aromatic ring is considered next and the rule of additivity is re-examined. The difficulty regarding the use of chemical shifts for studying the problem is then overcome, by the technique of employing suitably chosen sterically hindered systems. The significance of the results is evaluated.

Also included in this thesis is a study of the preparation of a certain class of carbonium salts, the further study of which can furnish a proper resolution of the effects of substituents into, those due to conjugation and those due to inductive effects.

I wish to record my deep sense of gratitude to Dr. P. MADHAVAN NAIR, Scientist, National Chemical Laboratory, Poona, for suggesting this problem and for his inspiring guidance and supervision during the course of this investigation. I am also grateful to Dr. N.P. Damodaran for kindly going through the manuscript and helpful suggestions.

My thanks are also due to the Director, National Chemical Laboratory, for permission to submit this thesis and to the Council of Scientific and Industrial Research, New Delhi, for the award of a Junior Research Fellowship for part of the period of this investigation.

Fairwell

(T. Fairwell)

NCL, Poona 8

18 March 1967.

C O N T E N T S

	<u>Page</u>
PART I - CONJUGATION AND HYPERCONJUGATION	1 – 142
CHAPTER I Conjugation and Hyperconjugation - A Review	1
References	28
CHAPTER II NMR Methyl Bandwidths of some substituted Aromatic compounds.	32 - 64
Introduction	32
Results and Discussion	40
Experimental	56
References	63
CHAPTER III Disubstituted Benzenes	65 – 87
Introduction	65
Results and Discussion	71
Experimental	84
References	87
CHAPTER IV Chemical Shifts in some sub- stituted benzoic esters.	88 - 142
Introduction	88
Results and Discussion	90
Experimental	120
References	141

	Page
PART II - STABLE ACERTOXYPHENYL CARBONIUM SALS	143 - 201
Introduction	143
Results and Discussion	149
Experimental	185
References	200
SUMMARY	202

PART I

CONJUGATION AND HYPERCONJUGATION

CHAPTER I

CONJUGATION AND HYPERCONJUGATION
-A REVIEW

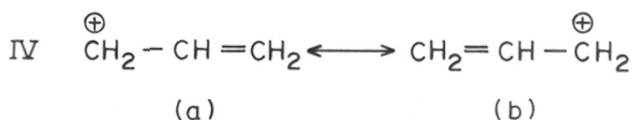
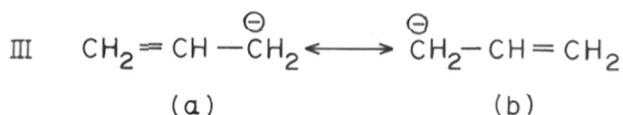
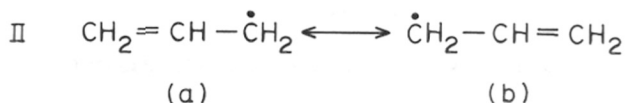
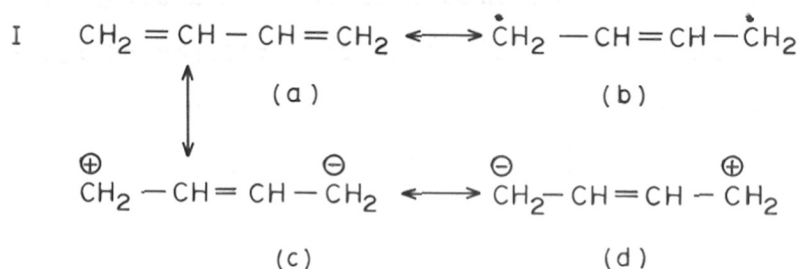
CONJUGATION AND HYPERCONJUGATION

The concept of conjugation was introduced many years ago to account for the special properties shown by certain types of unsaturated compounds, in which two or more multiple bonds are present. Although this concept can be traced back to the work of Michael¹, Thiele², Flurscheim^{3,4} and others, it was clearly formulated in electronic terms for the first time by Robinson⁵, Ingold^{6,7} and their co-workers. Later with the advent of quantum chemistry, this notion was laid on a firmer theoretical foundation. It became clear that the special properties of conjugated systems were attributable to the presence of 'delocalized' π -electrons in 'molecular' orbitals; or speaking in terms of the valence bond description of molecules, these were traceable to resonance between various canonical structures, that may be written for these systems⁸.

The accepted position in the nineteen thirties regarding the concept of conjugation and effects of polar groups in conjugated systems may be stated as follows:

When the principal classical structure contains single bonds, each interposed between two multiple bonds,

or one side having a π -electron, a π -electron pair or quartet or at least a π -electron vacancy and a multiple bond on the other, the species is said to be conjugated⁹. This can be illustrated by the following structures, which are stabilized by resonance between the various structures as shown:

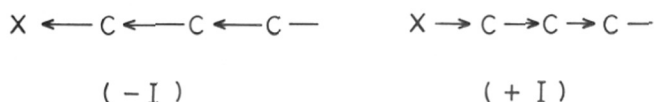


The difficulties that conjugated systems always presented

when their properties were considered from the view point of the classical valence theory, disappeared in the light of this formulation. These properties could not be uniquely represented by a conventional valency structure, in which each carbon atom forms two single bonds and one double bond. But when all the valency structures were taken into account, the physical and chemical behaviours of these systems could be readily rationalized. In the ordinary double bond, the overlap between the orbitals of the π -electrons on the adjacent carbon atoms provides both the extra strength of the double bond and also its resistance to free rotation. In a conjugated system, since the smearing out or 'delocalization' of π -electrons would result in bonds of intermediate character, the barriers to rotation about bonds, which are single in the classical formulation, could be explained readily⁸.

The 'inductive effect' of a polar group was defined as a permanent polarization arising from the unequal sharing of the bonding electrons between two atoms of different nuclear charge, and it was thought to be relayed through a saturated chain of atoms by electrostatic induction⁸. This can be illustrated by

a system of the type $-C_2-C_1-Br$, where the electrons of the covalent bond between the bromine and the carbon will be displaced towards the bromine atom, resulting in a small negative charge on the bromine and a small positive charge on the carbon C_1 . This positive charge on C_1 would make it more electronegative than C_2 , and this electronegativity difference in turn polarizes the C_2-C_1 bond. Thus, C_2 also acquires a positive charge which is smaller than that at C_1 . This effect would be transmitted further and would become weaker and weaker. Considering conjugated systems alone, the standard of reference was the carbon atom of the conjugated hydrocarbons. Substitution at the carbon by a group X , more electronegative than carbon would have a $-I$ effect (negative inductive effect) on the system. On the other hand, when X is more electropositive, the effect would be positive ($+I$).

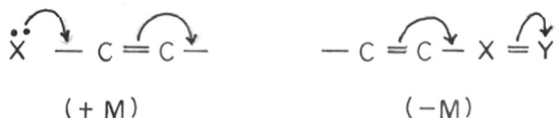


Most of the common substituents have hetero-atoms, which are more electronegative than carbon and hence inductive effects of substituents would be more

frequently negative than positive. Among the most common substituents, the alkyl groups are the only ones which come in the +I class. The methyl in a $\text{CH}_3\text{-C}$ group was considered to repel the bonding electrons more than a hydrogen in a corresponding H-C- bond. This electron repelling power of a methyl group could be expected to increase on replacement of its hydrogen atoms by methyl groups successively, so that the +I effect of a series of alkyl groups would decrease in the order $\text{Bu}^1 > \text{pr}^1 > \text{Et} > \text{Me}$. This expected inductive order was indeed obtained in a large number of studies on chemical reactivity.

The 'mesomeric effect' of a polar group was defined as the permanent polarization of the molecule, which arises from the delocalization of electron pairs conjugated with an attached unsaturated system, due to quantum mechanical resonance present in the ground state of an ion or molecule⁸. The effect was called +M, when the electronic displacement is away from the group and towards the unsaturated system, and -M when it is in the opposite direction. It was suggested that the mesomeric effect may be represented by a curved arrow (\curvearrowright) which indicates the direction

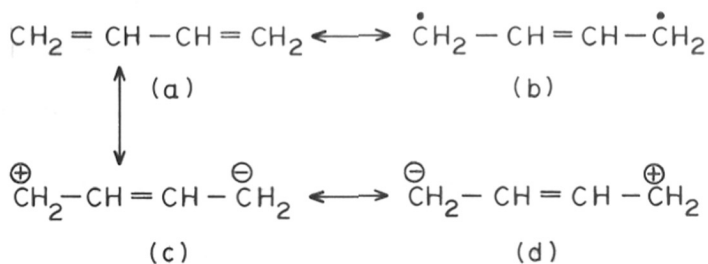
of the electron pair displacement, which must be applied to a single structure in order to obtain a closer approximation of the true electron distribution. The mesomeric displacement of electrons



in a substrate that is brought out by the attack of a reagent in a chemical reaction was designated as 'electromeric effect'. In other words, electromeric effects are mesomeric effects in transition states. A further term 'inductoelectromeric' or 'inductomeric' effect was defined for indicating the mutual interaction between inductive and electromeric effects. The ~~inductomeric~~ effect is a polarizability effect occurring by the inductive mechanism of electron displacement.

In the flush of the success of the resonance theory, its application was grossly oversimplified. The number of resonance structures, that one could write for a system was often used, without any clear reference to their contributions, as a measure of resonance energy. Actually resonance theory requires

that, in order for resonance stabilization to be appreciable, the contributing structures should not differ very much from one another in energy. Also, it was often difficult to guess correctly the relative magnitude of the energies of the contributing structures, so that inferences on resonance stabilization did not have proper foundations. For example, in the case of butadiene, the shortening of the C₂-C₃ bond was attributed to resonance between structures like (a to d).



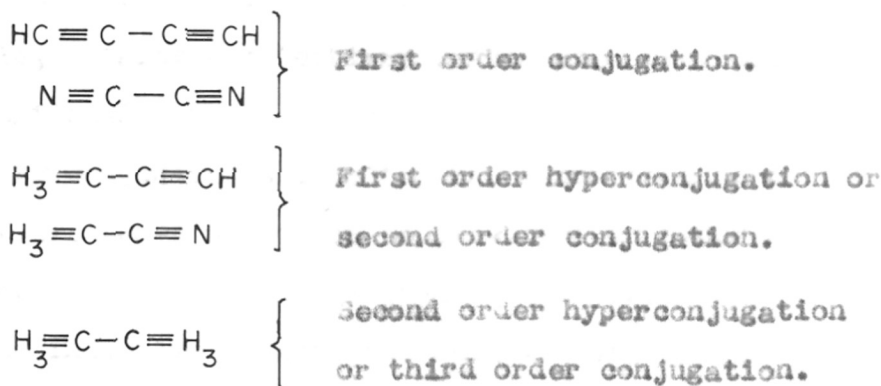
It was not until the end of nineteen forties that doubts were raised on the validity of such naive interpretations. The work of Hans Kuha¹⁰ and others¹¹ on the absorption spectra of polyenes during this period showed the necessity for the alternation of single and double bonds. The importance of conjugation was thus found to be less than that assumed from empirical considerations.

may be even marked in the passage from $\text{CH}_3\text{-C}=\text{C}$ to $\text{CH}_3\text{-C}\equiv\text{C}$ for similar reasons.

In 1935, Baker and Nathan¹⁷ found that the alkyl substituents in the para-position increased the reactivity of benzylbromide with pyridine in acetone solution. The rate of reaction decreased in the order, $\text{Me} > \text{Et} > \text{Pr}^1 > \text{Bu}^t$, which is exactly the reverse of what one would expect, if the electron release were entirely by an inductive mechanism. This means that an accelerating effect of a new and different type is in operation.

Mulliken¹⁸ studied the absorption spectra of cyclopentadiene and a number of related compounds. He found that there is a displacement of the absorption towards longer wavelengths in the case of cyclopentadiene compared to the open-chain conjugated dienes. He found that the abnormal behaviour can be satisfactorily accounted for, if the methylene group can be treated as a system having one σ bond and one quasi π -bond in the molecular orbital descriptions of these systems. In the context of his own observations and those of the others mentioned above, Mulliken designated such interactions of methyl and methylene groups as "hyperconjugation", accepting a

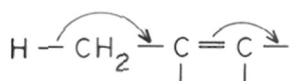
suggestion from Brown. In Mulliken's description, the methyl group is to be regarded as composed of one σ and two quasi π -bonds. "First order hyperconjugation can be said to exist, when the principal classical structure or structures contain single bonds, each interposed between one quasi multiple bond and either an ordinary multiple bond, a lone π -electron, a π -electron pair or quartet or even a π -electron vacancy"³. However, second order hyperconjugation involves two quasi multiple bonds. The groups which conjugate with unsaturated systems act as electron donors. The three cases can be represented by the following examples.



Second order hyperconjugation may be expected to be weak and is generally ignored.

Hyperconjugation can be defined in a rather

simple way as the power of alkyl groups to conjugate with multiple bonds. Considering the Baker-Nathan order in the light of this definition, the methyl group attached to an unsaturated system, permits electron release by what is essentially a type of electromeric effect.



Such electron release will facilitate or retard a reaction depending on whether it is electron accession to or electron recession from the reaction center that facilitate the reaction. Although the inductive effect of the t-butyl group is more than that of a methyl group, the new mode of electron release is no longer possible, because the tertiary carbon atom prevents the additional methyl groups from being part of the necessary conjugated system¹⁹. The assumption here is that C-C bonds would not be effective in hyperconjugation. If the Baker-Nathan effect predominates over the inductive effect, the relative stabilities of p-alkylbenzaldehydes in relation to their cyanohydrins would be expected to diminish in the order Me > Et > Prⁱ > Bu^t, because in the free aldehydes, conjugation extends to the side chain carbonyl group, so that

the new effect stabilizes the free aldehyde to a greater extent than it would the cyanohydrin²⁰.

The application of the notion of hyperconjugation to a variety of chemical problems was discussed by Mulliken, Keike and Brown²¹. Ordinary conjugation causes shortening of single bonds and hyperconjugation should also change the length of C-C bonds that attach the alkyl groups to the unsaturated system. But, since hyperconjugation is weaker than ordinary conjugation, appreciable changes are not likely to be produced. Benzene is the simplest case of bond shortening due to conjugation, in which all bonds are identical (1.39 Å). The shortening of bonds due to hyperconjugation may be well within the limits of experimental error, because electron delocalization occurs to a smaller extent only.

Since conjugation as well as hyperconjugation alters the electron distribution in a molecule, it would also affect its dipole moment. Whether the moment is increased or decreased depends on whether the conjugation or resonance moment is in the same or opposite direction to the normal moment. In *t*-butylbenzene the observed dipole moment arises largely from

the inductive effect of the t-butyl group, which has been assumed to exhibit no hyperconjugation²². Hyperconjugation is probably less in olefins than in aldehydes, because of the smaller polarization of the ethylenic bonds.

Alkyl groups on unsaturated carbon atoms reduce the heat of hydrogenation of an olefin. Delocalization, whenever it occurs, stabilizes the system and hence less heat will be evolved in the hydrogenation process, than in the corresponding system, which is not stabilized by conjugation. The observed progressive diminution of the heat of hydrogenation would therefore be consistent with the notion of hyperconjugation. As may be expected, the heat of hydrogenation of cyclopentadiene was found to be lower than that of butadiene¹⁸. Similarly, small variations were noticed in the heats of hydrogenation of alkylbenzenes.

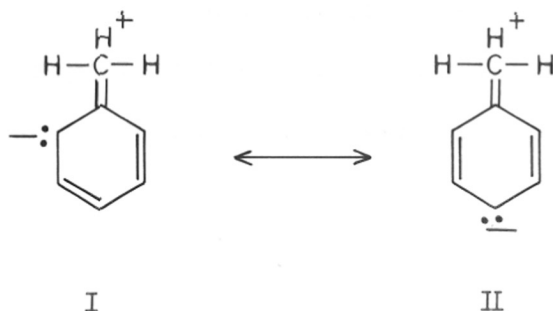
Ordinary conjugation is expected to result in displacement of absorption bands toward longer wavelengths and so is hyperconjugation. Effects of hyperconjugation, though small in the ground state may be expected to be much more pronounced in the excited state of a molecule or in the transition state

of a reaction^{19,23}. Mulliken suggested that about 0.14 ev of the total 0.8 ev decrease in the ionisation potential in passing from ethylene to propylene is attributable to hyperconjugation.

The concept of hyperconjugation was found to be useful in discussing a large number of physical and chemical properties of aromatic and unsaturated systems, a few of which are considered below.

In toluene, the length of the C-H bonds of the methyl group is increased by 0.001\AA , while the length of the C-Me bond is decreased appreciably (1.51\AA) compared to the normal C-C bond length of 1.54\AA . It was assumed that atleast half of the bond shortenings in toluene, methylacetylene and acetonitrile were due to hyperconjugation²⁴.

The dipole moment of toluene is 0.4D and the methyl group is positive with respect to the benzene ring²³. So, it was assumed that the electrons released by the alkyl groups are delocalized and that resonance between structures I and II stabilizes the molecule²⁵.



Mayrot et al.²⁶ assumed that the larger value for the dipole moment of methylchloroform, compared to chloroform, is due to hyperconjugation. In the case of trans-crotonaldehyde, there is an increase in the dipole moment (0.6D), compared to acrolein^{27,28}. Crawford²⁵ cited the case of methylbutadienes as further evidence of the polarity resulting from hyperconjugation.

Hyperconjugation should be more important in a positive ion than in the neutral molecule, from which it is derived, and it should reduce the energy of the positive ion more than that of the parent molecule. Ionisation potential, absorption spectra and chemical reactivity deal, both with the ground and excited states of molecules. Moore et al.²⁹ studied the absorption spectra of benzocycloalkanes and solvolysis rates of benzhydrylhalides. The data seem to suggest the importance of hyperconjugation and an explanation has been offered in terms of the Frank-Condon principle.

Streitweiser and Hair³⁰ indicated by a simple modified Hückel molecular orbital treatment that ionisation potentials of methyl substituted aromatic compounds cannot be properly rationalized if only inductive effects are taken into account. They were able to account for

the same data when proper allowance was made for the effects of hyperconjugation. In their treatment, the methyl group was regarded as a hetero atom having a lone pair of electrons in a p-orbital that is part of the conjugated system.

Substituents capable of donating electrons to a conjugated system by resonance interaction shift the $n \rightarrow \pi^*$ transition to lower wavelengths^{31,32}. In aliphatic carbonyl compounds of the type $RCOR'$, Rao et al.³³ found a large decrease in the wavelength in going from $R'=H$ to $R'=CH_3$. But a progressive increase in the wavelength was observed in the series Me, Et, Pr^i , Pr^t , suggesting electron release in the Baker-Nathan order and by implication hyperconjugation.

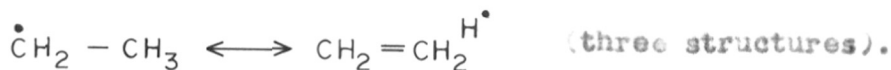
On the basis of a study on the protonation of 1,3,5-trialkylbenzenes in BF_3-HF solution, McCaulay and Lein³⁴ came to the conclusion that C-H hyperconjugation is an important mode of electron release in the cations produced.

The Baker-Nathan order was found in a number of reactions¹⁹. Among the explanations offered for this, hyperconjugation was generally preferred to the others. Berliner³⁵ discussed the present status of the Baker-Nathan order in terms of the current interpretations and suggested

that hyperconjugation of the C-H bonds provides the most satisfactory general explanation for the behaviour of alkyl groups on benzene ring. Brown et al.³⁶ points out the importance of C-C hyperconjugation in the solvolysis of p-t-butylbenzylhalides. The relative importance of C-C and C-H hyperconjugation in the aliphatic and aromatic series was studied by Taft et al.^{37,38}.

The time honoured classical organic chemical method of comparing the secondary isotope rate effects in a number of different reactions was applied by Shiner³⁹ for studying hyperconjugation. The isotope effects thus measured seem to be traceable to hyperconjugation. Similar results were also obtained by Taft³⁸ and Lewis⁴⁰.

One of the clearest pieces of evidence for hyperconjugation came from the hyperfine splittings observed in the electron spin resonance spectra of radicals⁴¹. For the ethyl radical, for example, the hyperfine coupling constant for the β -protons were found to be of the same magnitude as for the α -protons. This result is consistent with the "no bond" type of resonance first postulated by Wheland⁴².



Similar results were obtained in a number of other systems also^{43,44}. Symons⁴⁵ recently reviewed the esr

04:597-1
FAI

51661

evidence for hyperconjugation and expressed the opinion that hyperconjugation involving bonds other than C-H is also important.

A related piece of evidence is the observation of long-range spin-spin coupling between vinylic (or aromatic) protons and protons of vinylic (or aromatic) methyl groups. In 1958, Hoffman⁴⁶ reported that the methyl groups of m-xylene and mesitylene are coupled to the ring protons with $J = 0.45$ and 0.62 cps respectively and suggested that this long range spin-spin coupling is due to hyperconjugation between the π -orbitals of the benzene ring and the C-H bond orbitals of the methyl group. However, he could not satisfactorily account for the relatively large coupling constant for m-xylene.

Hoffman and Gronowitz⁴⁷ showed that the interactions of a π -electron on an unsaturated carbon atom, with the protons of an attached methyl group is approx. equal to its interaction with a proton directly bound to the unsaturated carbon atom. In view of the approximate equality of the hyperfine coupling constants for the fragments \dot{C} -H and \dot{C} -CH₃ and also the molecular orbital⁴⁸⁻⁵¹ description of the coupling in systems such as those studied by these workers, we now know that this result is only to be expected. Gronowitz extended this work on

long-range spin-spin coupling to methyl thiophenes and thiophenethiols⁵². He has argued that, hyperconjugation is more in methylthiophenes than in the benzene analogues. This statement is apparently made on the basis of the magnitudes of the long range coupling constants and is misleading. There is no reason why hyperconjugation energy - the stabilization resulting from hyperconjugation - is greater for a methylthiophene than for toluene. Long range coupling of the δ -H group of thiophenethiols with the ring protons was found to vary as expected from a conjugative mechanism⁵².

Kowalewski and Kowalewski^{53,54} proposed that a significant part of the long range coupling (0.4 to 0.9 cps) in *N*-methyl- and *N,N*-dimethylformamides involves hyperconjugation, since the long range spin-spin coupling in the *N*-methyl⁵⁵ and *N,N*-dimethyl acetamides⁵⁴ is not much smaller, having a value of 0.4 cps. Hyperconjugation for *N*-methyl groups was also studied by McLachlan⁵⁶.

Whipple et al.⁵⁷ studied the long range couplings in haloallenes and found that, both the non-equivalence of the protons and the non-planar structure of the molecules should favour hyperconjugation in these systems. Pritchard and Sumner⁵⁸ assumed that hyperconjugation is quite appreciable in allene.

Thus, until a few years ago, the concept of hyperconjugation was well accepted. But even during the period of its greatest popularity, it was not universally accepted⁵⁹. With the passage of time it became increasingly apparent that the phenomena that were explained earlier on the basis of hyperconjugation could be rationalized equally well by alternative considerations. We may consider for example, the bond contractions in some systems that should be hyperconjugated according to the generally accepted view.

In methylacetylene⁶⁰ and derivatives of acetonitrile^{61,62}, the C-C single bonds show a length of 1.46 \AA , which is not dependent on the substituents on the sp^3 carbon atom, even though simple electronegativity considerations would predict a variation of the bond lengths with the substituents. In malononitrile⁶³, the C-C bond length is 1.46 \AA and if the π -bonding caused by hyperconjugation were important, each C-C single bond should possess considerably less double bond character than in acetonitrile. So the observed shortening of carbon $sp-sp^3$ bonds may not be the result of any kind of conjugation and it is quite likely that these bond contractions are entirely due to changes in covalent radius as

a function of 's' character. Coulson^{64,65} suggested that about half of the shortening in bond lengths can be ascribed to changes in bond lengths with hybridisation.

In a recent reconsideration of the importance of conjugation and hyperconjugation, Dewar and Schemissing⁶³ came to the conclusion, that they are insignificant in the ground states of molecules, for which only one classical (unexcited) resonance structure can be written. They showed that C-C bond lengths in these systems are determined by the state of hybridisation of the carbon atoms. The observed stabilization of such molecules is attributable to changes in bond energy associated with hybridisation changes rather than to resonance. Dewar and Schemissing⁶⁶ found that resonance stabilization plays a very minor role even in benzene. If the π -electron resonance is unimportant in ordinary conjugation (as in butadiene) it should be much more so in hyperconjugation.

Simultaneously, Brown⁶⁷ presented similar views on the basis of a study on bond lengths in unsaturated systems.

Bartell^{68,69} studied the effects of intramolecular Van der Waals' forces and found that the

shortening of carbon-carbon single bonds in unsaturated hydrocarbons may be attributable principally to the relaxation of non-bonded repulsions that results when tetrahedrally hybridised carbon atoms are replaced by carbons with trigonal or digonal hybridisation. It was conceivable that the effects of hybridisation, conjugation and hyperconjugation may be less significant than the intramolecular Van der Waals' forces; that is, the effects which are usually attributed to conjugation, hybridisation etc. can be rationalized to a great extent, in terms of non-bonded interactions.

Dewar^{59,73} pointed out that the evidence for hyperconjugation from dipole moments is inconclusive and needs reinterpretation. Since the electronegativity of an sp or sp^2 carbon is different from that of an sp^3 carbon, the $Csp^2 - Csp^3$ and $Csp - Csp^3$ bonds should have characteristic dipole moments, the latter being larger than the former. The dipole moment of toluene can arise, on the basis of this view, from the electronegativity difference between the methyl and aromatic carbons. Petro⁷⁰ actually showed that hyperconjugated structures do not explain the non-zero dipole moment of toluene.

From a study of the electronic spectra of para-alkyl nitrobenzenes in the gas phase and in inert solvents,

Schubert et al.^{71,72} found that the inherent order of electron release from the alkyl groups is in the order $\text{Bu}^t > \text{Pr}^i > \text{Et} > \text{Me}$. A Baker-Nathan order was reported earlier for the energies of the first transitions of this series as well as for a similar set of *p*-alkyl acetophenones in basic solvents. The behaviour in the basic solvents was therefore attributed to solvation of electron deficient sites in the near vicinity of the alkyl substituents.

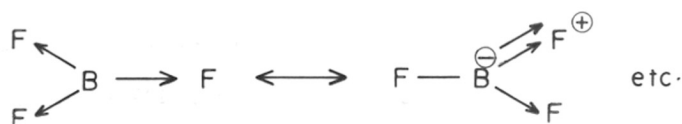
Dewar⁵⁹ has disagreed with McCaulay and Lein's³⁴ view that hyperconjugation is an important factor determining the stability of positive ions obtained by protonation of 1,3,5-trialkylbenzenes. The Baker-Nathan order shown by the uncorrected equilibrium constants for the protonation reaction disappears when proper allowance is made for the differences in the activity of the neutral hydrocarbons in the hydrogenfluoride and heptane solutions involved in the study.

Dewar has pointed out that even the strongest piece of evidence so far produced for hyperconjugation namely, hyperfine coupling in esr spectra, does not have any significance for 'even' systems⁵⁹. Radicals are systems for which the equivalent orbital representation does not hold and hyperconjugation is expected to be

significant in such species. Jewar has also expressed doubts about the admissibility of long range spin-spin coupling between protons, discussed earlier, as evidence for hyperconjugation, since the coupling arises by interaction of molecules with the applied magnetic field. We may state here the nature of this objection a little more explicitly. The coupling with which we are concerned, proceeds through π -electrons and is dependent on the mixing of triplet configurations into the ground state electronic configuration as a result of the interaction with the magnetic field. In other words the coupling is due to the radical character induced. The same objections that have been raised in regard to radicals would therefore be applicable here also. Evidence from chemical shift would be more reliable but no such data have been reported until this investigation was undertaken.

In view of the present controversy over the concepts of conjugation and hyperconjugation Mulliken³, and Muller and Mulliken⁷⁴ have suggested that it would be desirable to classify them into three types; isovalent, sacrificial (ordinary) and polyvalent. Isovalent conjugation and hyperconjugation can be divided further into three sub-types: dative, non-dative and homodative,

in order of increasing conjugative stabilization. Sacrificial conjugation and hyperconjugation has been suggested to be more important than ordinary hyperconjugation and the Baker-Nathan order has been described as differential hyperconjugation. Ordinary conjugation and hyperconjugation are sacrificial in the sense that π -electron stabilization is effected only by structures in which one π -bond is lost, as compared with classical valence bond structures. When the secondary structure involved in resonance has one more bond than the main valence bond structure, the conjugation we have is of the plivalent type. It is illustrated by the example of boronfluoride.



Plivalent conjugation and hyperconjugation are of course always dative. However, electron release is not an essential or important feature of the delocalization theory of ordinary hyperconjugation and so it (ordinary hyperconjugation) is quite different from dative conjugation and hyperconjugation, where electron release is essential.

Although there are apparently no theoretical

reasons for expecting differences between C-C and C-H hyperconjugation, Mulliken has expressed the opinion that the Baker-Nathan order, in harmony with other data, does seem to support the idea that C-H hyperconjugation is a stronger effect than C-C hyperconjugation⁷⁵. Although Mulliken has acknowledged the substance of Dewar's criticism, he has given reasons why he feels that Dewar has overstated his case⁷⁶.

Even though most of the effects attributed to hyperconjugation can be explained in alternative terms, "most of the effects claimed for hyperconjugation seem to exist"⁷⁷ for carbonium ions and carbanions. Coulson⁷⁷ has pointed out that part of the confusion regarding hyperconjugation is probably semantic in nature. The steric repulsion theory has been ruled out by Bright Wilson⁷⁸, because it cannot account for the barriers to rotation well known for unsaturated systems like butadiene.⁷⁹ The hybridisation theory cannot be ruled out, but it is not possible to find any testable predictions from it as far as rotational barriers are concerned. These may have their origin in dispersion and other Van der Waals' forces or in conjugation.

It is thus seen that inspite of the tremendous effort spread over three decades, hyperconjugation and

and to a smaller extent, conjugation have
remained controversial.

REFERENCES

- 1 A. Michael, J. Prakt. Chem. 46, 204(1892);
50, 286 (1899).
- 2 J. Thiele, Ann. 306, 67 (1898).
- 3 B. Flürscheim, J. Prakt. Chem. 66, 321 (1902).
- 4 B. Flürscheim, J. Chem. Soc. 95, 722 (1909);
97, 91 (1910).
- 5 R. Robinson et al. ibid. 401 (1926).
- 6 C.K. Ingold and B.H. Ingold, ibid. 1310 (1926).
- 7 C.K. Ingold, Chem. Revs. 15, 265 (1934).
- 8 C.K. Ingold "Structure and Mechanism in Organic Chemistry", Cornell University Press 1953.
- 9 R.S. Mulliken, Tetrahedron 5, 253 (1959).
- 10 Hans Kuhn, J. Chem. Phys. 16, 840 (1948);
11, 1198 (1949).
- 11 A. McColl, Quart. Revs. 1, 16 (1947).
- 12 G. Herzberg et al. J. Phys. Chem. 41, 123 (1937).
- 13 R.M. Badger and J.H. Baner, J. Chem. Phys. 5, 559(1937).
- 14 L. Pauling et al. J. Am. Chem. Soc. 61, 927 (1939).
- 15 L. Pauling and Brockway ibid. 59, 1223 (1937).
- 16 A.D. Walsh, Ann. Rep. of the Chem. Soc. London 44,
36 (1947).
- 17 J.W. Baker and W.S. Nathan, J. Chem. Soc. 1844 (1935).
- 18 R.S. Mulliken, J. Chem. Phys. 7, 339 (1939).
- 19 J.W. Baker, "Hyperconjugation" Oxford 1952.
- 20 J.W. Baker and M.L. Hemming, J. Chem. Soc. 191 (1942).
- 21 R.S. Mulliken et al. J. Am. Chem. Soc. 63, 41 (1941).

- 22 C.K. Ingold, J. Chem. Soc. 909 (1940).
- 23 J.W. Baker and L.G. Groves, J. Chem. Soc. 1144(1939).
- 24 C.A. Coulson "Valence" Clarendon Press, Oxford 1952.
- 25 U.A. Crawford, Quart. Revs. 3, 226 (1949).
- 26 A.A. Mayrot et al. J. Am. Chem. Soc. 63, 659 (1941).
- 27 E.C. Hurdis and C.P. Smyth, ibid. 65, 89 (1943).
- 28 N.B. Dunning and C.P. Smyth, ibid. 65, 1931 (1943).
- 29 W. Moore et al. Tetrahedron 5, 179 (1959).
- 30 A. Streiweiser Jr. and P.M. Nair, Tetrahearon 5, 149 (1959).
- 31 J.W. Sidman, Chem. Revs. 58, 689 (1958).
- 32 A. Burawoy, J. Chem. Soc. 1177 (1939).
- 33 C.N.R. Rao et al. Tetrahedron Letters No.2, 1(1960).
- 34 J.C. McCaulay and A.P. Lien, Tetrahearon 5, 186(1959).
- 35 E. Berliner, Tetrahearon 5, 202 (1959).
- 36 H.C. Brown et al. J. Am. Chem. Soc. 79, 1897(1957).
- 37 M.M. Kreevoy and R.W. Taft, ibid. 77, 5590 (1955).
- 38 R.W. Taft and I.C. Lewis, Tetrahedron 5, 210 (1959).
- ✓ 39 V.J. Shiner, Tetrahedron 5, 248 (1959).
- X 40 E.C. Lewis, Tetrahearon 5, 149 (1959).
- 41 J.J.E. Ingram "Free Radicals as Studied by ESR" Butterworth and Co. Ltd. London 1958.
- 42 G.W. Wheland, J. Chem. Phys. 2, 474 (1934).
- 43 J.R. Tuttle, J. Chem. Phys. 30, 331 (1959).
- 44 B. Venkataraman et al. J. Chem. Phys. 30, 1006(1959).

- 45 M.C.R. Symons, Tetrahedron 18, 333 (1962).
- 46 R.A. Hoffman, Mol. Phys. 1, 326 (1958).
- 47 a) R.A.Hoffman and J. Gronowitz, Arkiv. Kemi 16,
471 (1961).
b) R.A.Hoffman and J. Gronowitz, Acta. Chem. Scan.
13, 1477 (1959).
- 48 M. Karplus et al. J. Chem. Phys. 27, 597 (1957).
- 49 a) H.M. McConnell, ibid. 24, 460 (1956).
b) H.M. McConnell, J. Mol.Spec. 1, 11 (1957).
- 50 P.M. Nair and G. Gopakumar, Symposium on "Physical
Methods in Structure Determination", National
Chemical Laboratory, Poona, India (1963).
- 51 P.M. Nair and G. Gopakumar, Tetrahedron Letters
709 (1964).
- 52 J. Gronowitz, Arkiv. Kemi 13, 295, 817 (1958).
- 53 V.J. Kowalewski and J.G. Kowalewski, J. Chem. Phys.
32, 1272 (1960).
- 54 V.J. Kowalewski and J.G. Kowalewski, Arkiv. Kemi
16, 373 (1960).
- 55 S. Meiboom et al. J. Am. Chem. Soc. 81, 62 (1959).
- 56 A.D. McLachlan, Mol. Phys. 1, 233 (1958).
- 57 E.B. Whipple et al. J. Chem. Phys. 30, 1109 (1959).
- 58 H.O. Pritchard and E.H. Sumner, Proc. Roy. Soc.
A235, 136 (1956).
- 59 M.J.S. Dewar, "Hyperconjugation" Ronald Press Co.
New York, 1962.
- 60 A. Trambarulo and W. Gordy, J. Chem. Phys. 18,
1613 (1950).
- 61 M.D. Danford and R.L. Livingstone, J. Am. Chem. Soc.
77, 2944 (1955).

- 62 W. Kessler et al. Phys. Rev. 79, 54 (1950).
- 63 N. Muller and D.E. Pritchard, J. Am. Chem. Soc. 80, 3482 (1958).
- 64 C.A. Coulson, Victor Henri Vol. Deoser Liege 15 (1948).
- ✓ 65 C.A. Coulson, Proc. Roy. Soc. A207, 91 (1951).
- 66 M.J.S. Dewar and H.M. Schemissing, Tetrahedron 5, 166 (1959).
- 67 M.G. Brown, Trans. Faraday Soc. 55, 694 (1959).
- 68 L.S. Bartell, J. Chem. Phys. 32, 827 (1960).
- 69 L.S. Bartell, Tetrahedron 17, 186 (1962).
- 70 A.J. Petro, J. Am. Chem. Soc. 80, 4230 (1958).
- 71 W.M. Schubert and W.A. Sweeny, J. Org. Chem. 21, 119 (1956).
- 72 W.M. Schubert et al. Tetrahedron 5, 194 (1959).
- 73 M.J.S. Dewar and H.M. Schemissing, Tetrahedron 11, 96 (1960).
- 74 N. Muller and R.S. Mulliken, J. Am. Chem. Soc. 80, 3489 (1958).
- 75 R.S. Mulliken, Tetrahedron 6, 68 (1959).
- 76 R.S. Mulliken, Tetrahedron 17, 249 (1962).
- 77 C.A. Coulson "Mol. orbitals in Phys. Chem. and Biology".
- 78 E. Bright Wilson Jr. Tetrahedron 17, 191 (1962).
- 79 W.T. Simpson, J. Am. Chem. Soc. 73, 5363 (1951).

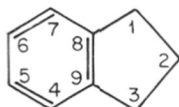
CHAPTER II

NMR METHYL BAND WIDTHS OF SOME
SUBSTITUTED AROMATIC COMPOUNDS

NMR METHYL BAND WIDTHS OF SOME
SUBSTITUTED AROMATIC COMPOUNDS

I N T R O D U C T I O N

It has been shown recently that measurements of long range spin-spin coupling between sp^3 benzylic and aromatic protons, which has been called "benzylic" coupling, can be of considerable value in the study of π -electron distribution in aromatic compounds¹. It has been pointed out that this coupling proceeds mostly through π -electrons and that it is proportional to the square of the mobile bond order between the aromatic carbon atoms involved. This was demonstrated qualitatively for sets of closely related methyl substituted compounds. The methyl group has also been employed as an element for probing π -electron distribution in indane (I) i.e. for a re-examination of the Mills-Nixon effect^{1b}. It has been shown that C_4 - C_5 bond of the molecule has a larger mobile bond order than the C_5 - C_6



(I)

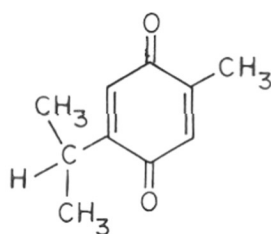
bond. In the present study, we shall be concerned with

the application of the same technique for sensing the changes in π -electron distribution brought about by the substitution of strongly interacting groups. But, before going into the details of this study, we shall very briefly survey the work on long range spin-spin coupling leading upto the developments just mentioned.

Long range spin-spin interactions between methyl protons and aromatic or olefinic protons were first observed by Hoffman^{2,3} in 1958, in a number of aromatic, olefinic and heterocyclic compounds. He observed a distinct quartet for the methyl protons and a multiplet for the aromatic ring protons of mesitylene and interpreted his data on the basis of hyperconjugation between the C-H bond orbitals of the methyl group and π -electron orbitals of the unsaturated systems. In the case of ortho-substituted toluenes the long range coupling was found to depend on the nature of the substituent. The splitting of the methyl signals of 2,2'-dimethyldiphenyl ether was mistaken to be the result of non-equivalence of the methyl groups arising from restricted rotation⁴. Tiers et al.⁵ showed that it is due to benzylic coupling. It was found that the separation between the two methyl signals is temperature independent and also that the gross peak half-width

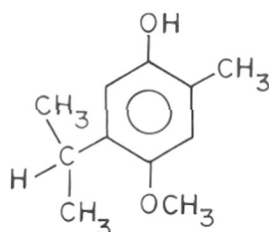
does not change as the radio-frequency of the spectrometer is varied from 60 Mc to 40 Mc. Rottendorf and Sternhell⁶ made a systematic study of the para-substituted alkylbenzenes and showed that in these compounds the benzylic protons are coupled to the ring protons in the ortho positions. The signals of the A_2B_2 pattern representing the protons ortho to the methyl, methylene and methine group were broader than the signals of the other two.

The coupling constant J , for this kind of interaction through four bonds, was shown to be dependent on the type of double bond involved, through the example of thymolquinone (II) and the monomethyl ether (III) of the corresponding quinol^{7,8}.



(II)

$$J_{\text{CH}_2-\text{H}} = 1.5 \text{ cps}$$



(III)

$$J_{\text{CH}_2-\text{H}} = 0 \text{ cps}$$

While in (II), where the C_2-C_3 bond is very much like an ethylenic double bond, there is observable splitting

of the methyl, in (III), where the ring is fully aromatic in nature, the interaction between the aromatic protons and the side chain protons is much less. Considerable work has been done on benzylic and other types of long range coupling³ and reviews on these have appeared^{9,10,11}.

Long range spin-spin coupling through π -electrons was treated theoretically for both aromatic and unsaturated systems¹²⁻¹⁵. McConnell¹⁴ studied the long range nuclear spin-spin coupling through π -electrons for the case of aromatic protons and showed that π -contribution to the coupling between protons attached to carbon atoms N and N' is given by the equation:

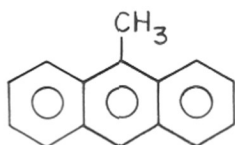
$$J_{NN'}^{\pi} = (BQ)^2 P^2_{NN'} / h \Delta E \dots\dots(1)$$

where ΔE is an average (singlet-triplet, electronic excitation energy (taken as 4 eV); $P_{NN'}$ is the mobile bond order between the carbon atoms N and N'; Q is the effective isotropic hyperfine splitting constant and B is the Bohr magneton.

It was pointed out by Nair and Gopakumar^{1b} and simultaneously by Dewar and Fahey¹⁶, that this equation derived by McConnell could be made applicable to benzylic coupling also, if one of the Q's is replaced by the

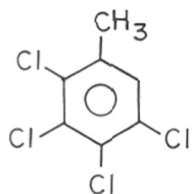
hyperfine splitting constant (Q') for the C-X fragment, where X is the benzylic carbon atom bearing protons. Making allowance for a possible σ -contribution, benzylic coupling may therefore be expected to be linearly related to the square of the mobile bond order (P). Measurements of the coupling were made for a number of closely related compounds, in which the methyls are freely rotating and for which the same Q' values would therefore apply. When the coupling constants obtained for *o*-bromotoluene, 2-methylnaphthalene, 2-methylanthracene and 9-methylphenanthrene were plotted against the p^2 values calculated for the parent hydrocarbons from simple Hückel molecular orbital theory, a good straightline was obtained^{1a}. The assumption that ΔE is roughly constant for this series seems to be valid and the data may be regarded as providing adequate evidence for the p^2 dependence of benzylic coupling. The importance of ΔE term has been illustrated by the example of 9-methylanthracene (IV) for which $J_{\text{CH}_3-\text{H}_{10}}$ is as high as 0.625 cps, although the P value is only -0.4. The large J value becomes readily understandable in the light of the fact that anthracene has a low lying triplet state in which the spin densities are largely concentrated at the 9- and 10-

positions. Here ΔE is only 1.8 eV and a rough calculation for J gives a value quite close to that experimentally observed^{1a}.

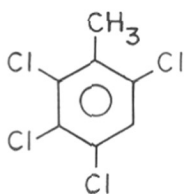


(IV)

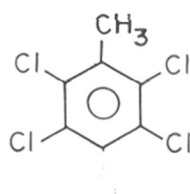
Another instructive example that may be mentioned in this connection is the effort made by Rottendorf and Sternhell¹⁷ to see if long range coupling in benzene derivatives could be related to structure by the substitution technique. They prepared all the three isomeric tetrachlorotoluenes (V-VII), and measured the benzylic coupling in each. The ortho and para couplings



(V)



(VI)



(VII)

were found to be the same (0.63 ± 0.01 cps) and $J_{\text{CH}_3\text{-H meta}}$ was 0.36 cps. The equality of the methyl coupling to the ortho and para protons indicated that it is difficult to relate these data to π -electron distribution.

Since substitution of strongly interacting groups alter the π -electron distributions of aromatic rings quite appreciably, the substitution method for isolating spin-spin interactions has serious limitations, particularly when multiple substitution is involved. Secondly, any inference regarding relative magnitudes of bond orders from benzylic coupling constants can be made, only if one can be sure that the corresponding ΔE values are comparable. These factors have clearly conspired to make any deduction from measurements of tetrachlorotoluenes impossible.

It is thus clear that one has to be very careful in making deductions from measurements of benzylic coupling regarding bond orders. In spite of the limitations of the method, it is still of considerable value, since there are no convenient and reliable methods available to the chemist for the determination of relative magnitudes of π -bond orders, except X-ray crystallographic analysis. For the sake of comparison, mention may be made here of the attempt of Hunsberger et al.^{18,19} to measure bond orders from the lowering of carbonyl stretching frequency, that results from hydrogen bonding with OH groups, when these groups (CO and OH) are connected through the bonds of interest. The complicating

feature here is the steric factor^{20,21}, the correction for which cannot be ascertained very readily. We may also remember in this connection that Jonathan et al.²² have shown that the vicinal coupling constants in aromatic systems is linearly related to the mobile bond order. But vicinal coupling is largely due to coupling that proceeds entirely through σ bonds, the π -contribution being very small. The margin of uncertainty for the large component is so high when compared to the magnitude of the smaller part, that it is difficult to use vicinal coupling constants for measuring bond orders²³. The study of benzylic coupling, inspite of its small magnitude, would therefore appear to be of considerable importance in ascertaining bond order variations.

In the application^{1b} that has been made using the methyl group as a sensing element, it is assumed that the interaction of this group with π -electrons may be ignored as a first approximation. It should be possible to study the effects of strongly interacting groups like carboxyl and nitro, on the benzene ring geometry by extending the same technique and making the same assumption. Carboxyl and nitro derivatives of aromatic compounds are of special interest in this

connection, because X-ray studies of such systems have given results that are difficult to rationalize in terms of the widely accepted current notions of the electronic effects of the substituents²⁴⁻²⁶ involved. It has been even suggested that the carboxyl and nitro groups in these systems are not conjugated to the aromatic moieties. In this background it was considered that measurements of methyl bandwidths in the PMR spectra of the isomeric toluic esters and nitrotoluenes would give results of considerable interest.

RESULTS AND DISCUSSION

The methyl band width data for the isomeric methyl and sodium toluates and the nitrotoluenes are collected in Table I, and the PMR absorptions themselves are shown in Figs. I and II. Although the values for the ortho isomers are indicated in the Table for purposes of information and comparison, the discussion is restricted to the data for the meta and para-isomers. In the case of the ortho-isomers, the steric effect comes into play and the COOMe and NO₂ groups will be rotated from the mean molecular plane. The changes in the conformation of these groups imply, changes in their electronic effects as well and there is no easy way of estimating their effects on the benzylic coupling constants.

TABLE I

Compound	Methyl band-width in cps	Coupling constant (J in cps)
1 Methyl <u>m</u> -toluate	1.54	
2 Methyl <u>p</u> -toluate	2.01	
3 Sodium <u>m</u> -toluate	1.61	
4 Sodium <u>p</u> -toluate	1.77	
5 <u>m</u> -Nitrotoluene	1.61	
6 <u>p</u> -Nitrotoluene	1.86	
7 3-Methylacetophenone	1.49	
8 4-Methylacetophenone	1.70	
9 1-Bromo-2-methylnaphthalene	1.2	
10 1-Deuterio-2-methylnaphthalene*	1.2	
11 Methyl 2-methyl-1-naphthoate	1.03	
12 Methyl 1-methyl-4-naphthoate	1.78	0.77
13 1-Methylnaphthalene*	0.70
14 Methyl <u>o</u> -toluate	1.42	
15 Sodium <u>o</u> -toluate	1.18	
16 <u>o</u> -Nitrotoluene	1.50	
17 2-Methylacetophenone	1.28	
18 Toluene	1.50	

*G. Gopakumar, Ph.D Thesis, Univ. of Poona (1966).

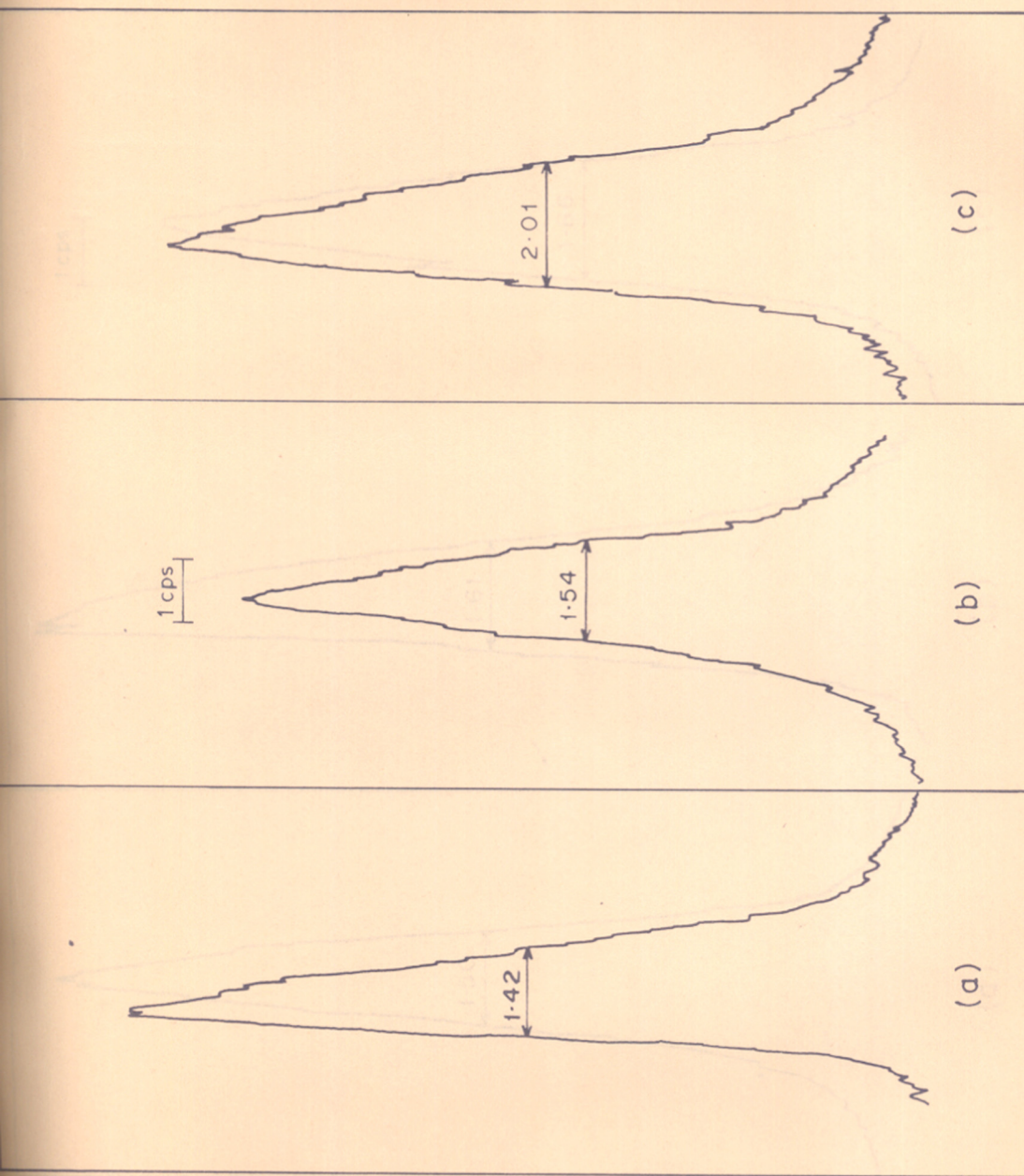


FIG. I. METHYL SIGNALS OF: (a) METHYL *o*-TOLUATE (b) METHYL *m*-TOLUATE AND (c) METHYL *p*-TOLUATE

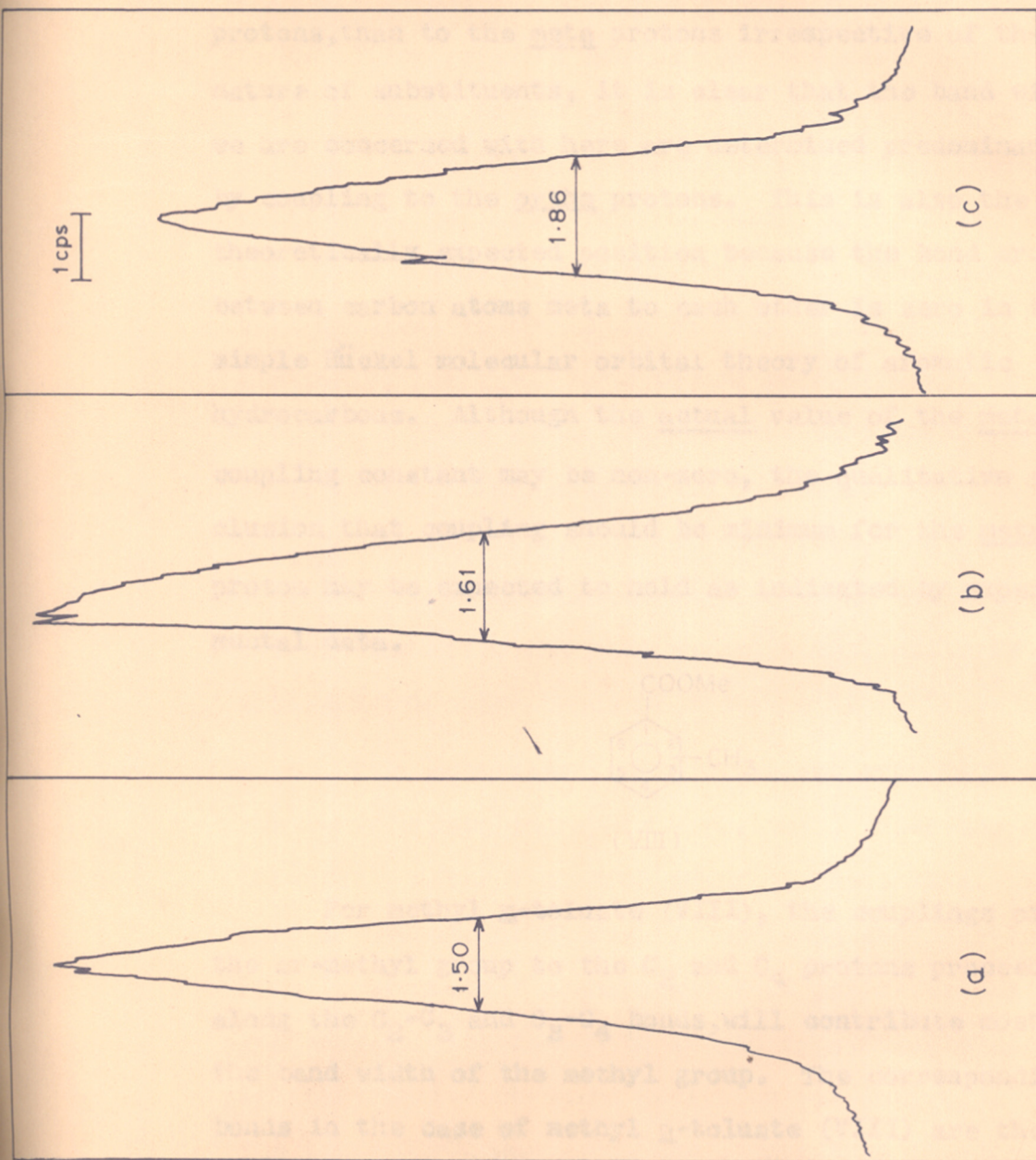
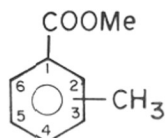


FIG. II. METHYL SIGNALS OF: (a) o-NITROTOLUENE (b) m-NITROTOLUENE AND (c) p-NITROTOLUENE

Since it is known that in p-substituted toluenes, the methyl group is coupled more strongly to the ortho protons, than to the meta protons irrespective of the nature of substituents, it is clear that the band widths we are concerned with here are determined predominantly by coupling to the ortho protons. This is also the theoretically expected position because the bond order between carbon atoms meta to each other is zero in the simple Hückel molecular orbital theory of aromatic hydrocarbons. Although the actual value of the meta coupling constant may be non-zero, the qualitative conclusion that coupling should be minimum for the meta-proton may be expected to hold as indicated by experimental data.



(VIII)

For methyl m-toluate (VIII), the couplings of the ar-methyl group to the C_2 and C_4 protons proceeding along the C_2-C_3 and C_3-C_4 bonds, will contribute most to the band width of the methyl group. The corresponding bonds in the case of methyl p-toluate (VIII) are the equivalent ones in the C_3-C_4 and C_4-C_5 positions. The

larger band width for the p-toluic ester implies that C_4-C_5 bond has a larger P value than the C_2-C_3 bond. Since we are assuming that the nature of these bonds, is predominantly determined by the carbo-methoxy group, which interacts strongly with the aromatic ring, and also that the methyl group functions merely as a sensing element, the C_4-C_5 bond should be equivalent to the C_2-C_4 bond by symmetry and, similarly, the C_2-C_3 bond should be equivalent to C_5-C_6 . In other words the relative bond order magnitudes indicated are applicable to benzoic acid itself. The conclusion arrived at is, therefore, that carboxyl substitution in a benzene ring lengthens the bonds between the ortho and meta carbon atoms, while it shortens the other bonds of the ring^{1a}.

This conclusion is in excellent agreement with the X-ray crystallographic data. Sim, Robertson and Goodwin²⁴, after a careful study of the crystal structure of benzoic acid (Fig.3) concluded that the benzene ring is accurately planar, and that the C-C bonds in the benzene ring varied in length by 0.05\AA , while the total estimated standard deviation was only 0.017\AA . The bonds C_2-C_3 and C_5-C_6 are longer than the C_3-C_4 and C_4-C_5 bonds by an average value of 0.051\AA and

they felt that this difference is quite significant. Actually, the bond length difference mentioned is almost the same as the shortening observed, for the bond connecting the carboxyl carbon and C₁ of the benzene ring, when compared to a pure C-C single bond.

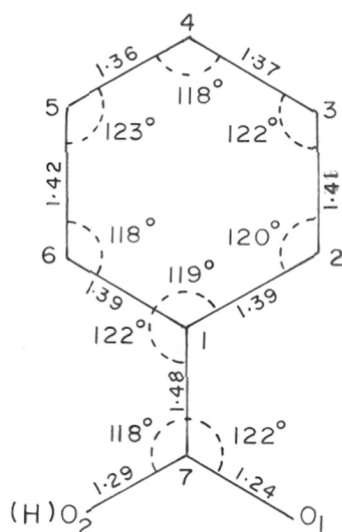


Fig.III - Bond lengths and Bond angles in benzoic acid (Ref.24).

The difference noticed for the meta- and para-esters almost disappears in the corresponding sodium salts. While it is of the order of 0.47 cps in the

former, in the latter it is only 0.16 cps. The band width of meta-methyl shows a tendency to increase in going from the ester to the sodium salt; while the reverse is true for the p-methyl compound. This suggests that we are in fact dealing with the effects of conjugation in the esters. Since the carboxylate ion is a poor electron withdrawing function, the effects on the benzene ring are apparently weaker^{1a}.

In the case of the nitrotoluenes the band widths follow the same sequence, but the variation was not as large. The meta- and para-isomers showed band widths of 1.61 and 1.86 cps respectively. The band width difference between the meta- and para- isomers here is only 0.25 cps, while it is 0.47 cps for the methyl toluates.

X-ray crystallographic studies on the crystal structure of nitrobenzene at -5°C by Trotter²⁵ shows that the nitrobenzene molecule is completely planar and that the bonds $\text{C}_2\text{-C}_3$ and $\text{C}_5\text{-C}_6$ are larger than the other bonds by an average value of 0.061\AA , whereas the estimated standard deviation is only 0.014\AA . The difference observed is as pronounced as, or even more than, for benzoic acid²⁴. The other bonds are all

approximately of the same length.

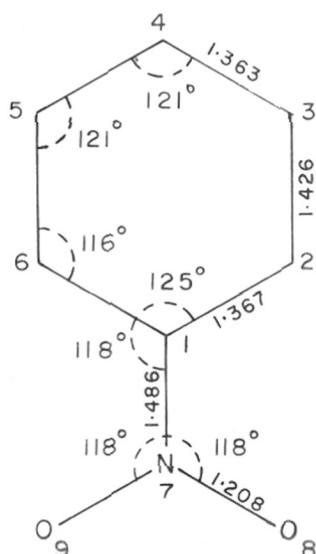
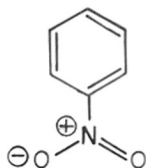


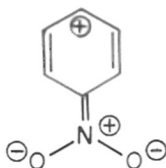
Fig.IV - Bondlengths and Bond angles in nitrobenzene at -5°C (Ref.25).

Trotter²⁶ has observed that these variations in bond lengths are inconsistent with the changes predicted by resonance theory. They are large and in the wrong direction. The $\text{C}_2\text{-C}_3$ and $\text{C}_5\text{-C}_6$ bonds would be expected to be shorter than the benzene bonds on the basis of resonance theory. Further the C-N bond distance is found to be 1.486\AA , while the value usually quoted for C-N single bond is 1.475\AA . Thus, again the expected shortening from resonance (IX and X) is

not found.



IX



X

From this observation Trotter concluded that the nitro group is not conjugated with the aromatic ring. From a consideration of bond angles, he suggested that the changes observed, result from changes in hybridisation of the aromatic carbon atoms when compared with that prevailing in benzene (sp^2). If the variations in bond length were entirely due to changes in hybridisation, on putting another similar strongly interacting group in the para-position, one would expect a further increase in the bond lengths for the C_2-C_3 and C_5-C_6 bonds. But in p-dinitrobenzene²⁷ and p-nitrobenzoic²⁸ acid, no such changes are observed and in fact the ring geometry is just the same as for benzene. The conclusion that the nitro group is not conjugated to the benzene ring, would thus appear to be hasty.

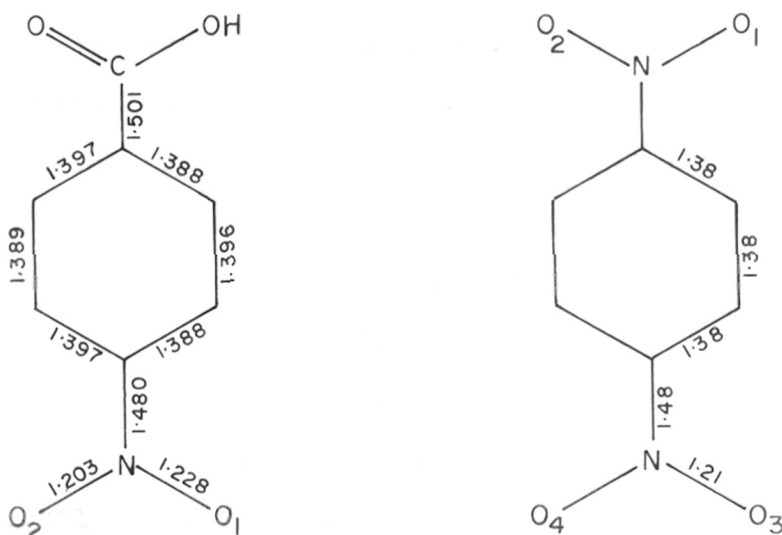


Fig.V - Bond lengths in (a) p-nitrobenzoic acid and (b) p-dinitrobenzene (in Å).

Molecular orbital calculations that have so far been done for nitrobenzene²⁹ and benzoic acid³⁰ do not fare better than the resonance theory in rationalizing the observed bond lengths. The calculations have been of the simpler types, which do not take into account inter-electronic repulsions. Thus, in the calculations done by Trotter²⁹ for nitrobenzene, the P value of the C₂-C₃ bond is found to be 0.675 as compared with 0.667 for benzene. A very appreciable amount of double bond character is indicated for the C-N bond by the calculated P value of 0.322.

Goodwin³¹ made calculations of the π -electron distribution in benzoic acid using three slightly different approximations. In the first two (1 and 2) different values were used for the coulomb integrals α , but the same resonance (exchange) integrals 'H' were used and overlap integrals 'S' were neglected; while in the third method, the α 's were given the same value as in method (2), but H's were modified slightly in the light of the results of method (2) and overlap integrals were included. The bond orders obtained and the expected bond lengths are given in Fig.VI a-c.

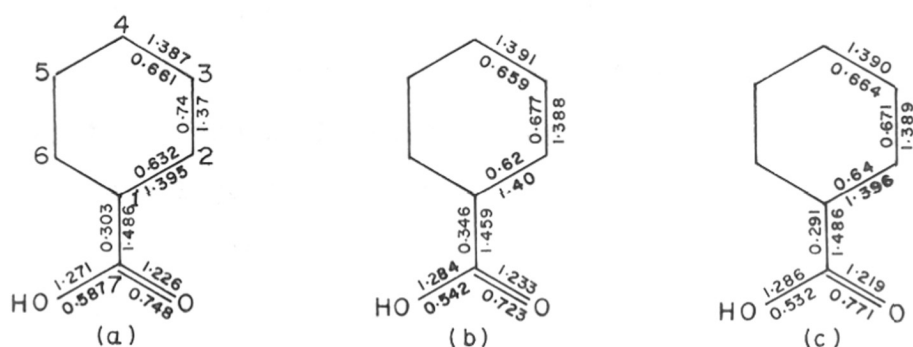


Fig.IV - Calculated bond orders and expected bond lengths in benzoic acid (Ref.30).

As in the case of nitrobenzene, a shortening of the C_2-C_3 and C_5-C_6 bonds is predicted by the calculations. The experimentally observed bond lengths indicate, that

these calculations are entirely too crude. There is probably no hope of getting anywhere near the correct results unless repulsions between electrons are taken into account.

While the X-ray evidence does help us to realize the unsatisfactory nature of the customary representations of conjugative interactions, the evidence presented is by no means to be taken as disproving conjugation of the nitro and carboxyl groups with the benzene ring. In fact it has been established by X-ray evidence that there is conjugative interaction between nitro and hydroxyl (or amino) groups across the aromatic ring^{31,32}. The difference noticed here between the toluic esters and nitrotoluenes may therefore imply, that the approximation assumed for the methyl group may not be fully operative, particularly in the case of the nitro derivatives. The nitro group is a much more powerful electron withdrawing group than the carboxyl and the possibility that nitro and methyl groups may be mutually interacting, when they are para to one another, is very real. Electron donor action from the methyl to the nitro via the aromatic ring would tend to shorten the C₂-C₃ and C₅-C₆ bonds, counteracting the observed effects

in nitrobenzene. This interaction, if it is present, can be of the 'hyperconjugative' or the 'inducto-mesomeric' type and is dealt with in detail in Chapter IV of this thesis.

In the context of the behaviour observed for the toluic acids, it is of interest to see if similar effects can be seen in carboxyl derivatives of naphthalene. This would involve a comparison of the methyl band widths for the three isomeric methyl derivatives of α -naphthoic acid and also 4-methyl-2-naphthoic acid. In this investigation, only two of the required compounds have been prepared, namely, the methyl esters of 2-methyl-1-naphthoic and 1-methyl-4-naphthoic acids. The band width data for these compounds as well as a few other naphthalene derivatives are given in Table I. 1-Bromo-2-methylnaphthalene shows a band width of 1.2 cps for the methyl signal which is not altered on replacing of the bromine by deuterium. But the replacement of bromine by a carbomethoxy group lowers the band width value to 1.03 cps. Similarly methyl 1-methyl-4-naphthoate shows a benzylic coupling of 0.77 cps compared to 0.7 cps for α -methylnaphthalene. But it is not possible to make any comment on these data,

unless the data for methyl 3-methyl-1-naphthoate and methyl 1-methyl-3-naphthoate are also obtained. However, the X-ray results³³ show several interesting features (Fig.VII) other than the elongation of the C_2-C_3 bond. There is a lengthening of bonds C_1-C_2 and C_3-C_4 which cannot be explained in simple terms. Also, the C_1-C_9 bond is long while the C_4-C_{10} and C_8-C_9 bonds are short. The reason for this is also not clear.

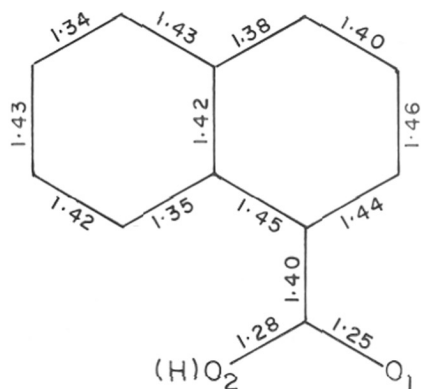


Fig.VII - Bond lengths and Bond angles in α -naphthoic acid (in \AA).

In the case of methylacetophenones the band widths for the ar-methyls are 1.28, 1.49 and 1.70 cps for the 1:2, 1:3 and 1:4 isomers respectively. Here again, it is seen that the band widths vary, in the same manner as in the earlier cases. But the values are smaller compared to those for methyltoluates or

even the nitrotoluenes. It would have been instructive to see, if the bond length data for these compounds would agree with the expectations based on the NMR band width values. But the required data are not available. Here again, the small difference for the bandwidths of the meta and para isomers is suggestive of an interaction between the acyl and methyl groups across the ring as in the case of p-nitrotoluene.

CONCLUSION

The attempt that has been made here, to determine the changes in π -electron distributions in aromatic compounds using the methyl group as a sensing element, has given valuable results. The NMR methyl bandwidths generally support the conclusions of X-ray studies on carboxyl and nitroderivatives. Further, in the case of the nitro derivatives, the data obtained suggest the possibility of an interaction between the nitro and methyl groups para to each other. This interaction can possibly involve hyperconjugation. Although hyperconjugation in p-nitrotoluene has been often discussed earlier, the immediate reason for the investigations described in Chapter IV was the nature of the results obtained here.

E X P E R I M E N T A L

NMR Measurements: All spectra were recorded on a Varian A-60 NMR spectrometer operating at 60 Mc. Solutions (10-20%) were prepared in carbon tetrachloride or deuterium oxide (99.4%) for recording the spectra. Tetramethylsilane was used as a standard in all band width measurements; i.e. comparison of band widths were made at identical spectrometer conditions, which gave the same band width for TMS reference signal. Calibration of the chart was made using TMS in deuterated chloroform (436 cps).

All methyl signals were recorded at 100 as well as 50 cps sweep width at 500 seconds sweep time, so that the sweep rates were 0.2 and 0.1 cps/sec. The band widths reported are averages obtained from 20-25 independent scannings of the methyl signal in each case. R_f and filter band widths were adjusted so as to obtain optimum conditions i.e. the best resolution and sufficiently low noise level.

Materials: Preparation and/or purification of the materials used are described below. Melting points and boiling points are uncorrected.

Carbon tetrachloride of C.P. grade was washed

first with sulfuric acid and then with water; finally it was dried over anhydrous sodium sulfate, distilled and fractionated.

Methyl o-toluate: *o*-Toluic acid (m.p. 104°) was esterified with methanol using a little conc. sulfuric acid as catalyst and the product worked up in the usual way by pouring into cold water and separating the oily liquid. This crude product was further purified by distillation. Pure methyl *o*-toluate distilled over at $96^{\circ}/15$ mm (Lit. $213^{\circ}/760$ mm). This was found to be quite pure from its NMR spectrum.

Methyl m- and p-toluates: *m*- and *p*-toluic acids were converted to their methyl esters in the same way as described above and the products were purified by distillation (b.p.s. 212° and $214^{\circ}/710$ mm respectively).

Sodium salts: All the three salts, i.e. the sodium *o*, *m* and *p*-toluates were prepared by exactly neutralising the pure acids with solutions of analar grade sodium hydroxide and removing the water by slow evaporation. Sodium *o*-toluate was obtained as white glistening plates (m.p. $226-7^{\circ}$). Sodium *m*- and *p*-toluates did not melt upto 300°C .

Nitrotoluenes: The commercially available *o* and *p*-

nitrotoluenes were purified by steam-distillation. The ortho-isomer was further purified by fractionation and the pure material distilling over in the range 217-218° was collected. The para-isomer was further purified by recrystallisation from ethanol and was obtained as pale yellow needles which melted at 54°C.

m-Nitrotoluene is ordinarily prepared from o-toluidine³⁴, which is first converted to 3-nitro-4-aminotoluene³⁵, the nitration being done after protecting the amino group by acetylation. The latter is then subjected to reductive deamination. m-Nitrotoluene for this investigation was prepared from o-toluidine, the choice being necessitated by the immediate availability. It was found that the nitration of o-acetaminotoluene proceeds quite smoothly and in better yields than in the case of the para-isomer. The product, which is 2-acetamino-5-nitrotoluene is first hydrolysed to the amine and then reductively deaminated by the procedure described for 3-nitro-4-aminotoluene³⁴. The yields are comparable. The details of the procedure are described below.

o-Acetaminotoluene (42.5 g) was dissolved in glacial acetic acid (45 ml) in a three-necked round bottomed flask fitted with a mechanical stirrer, a

thermometer and a dropping funnel. Conc. sulfuric acid (75 ml) was added slowly and the mixture cooled externally using a freezing mixture. Fuming nitric acid (24 g, d. 1.5) was added drop by drop keeping the temperature below 25° and stirring the solution mechanically. After the addition was over, stirring was continued for another hour. The reaction mixture was then poured on to a mixture of water (100 ml) and crushed ice (100 g). The mixture was allowed to stand for half an hour, during which time the product crystallised, filtered, washed with a little cold water and dried. It was hydrolysed to the nitroamine with conc. HCl (38 g HCl for 15 g of the anilide). The free base was liberated with excess ammonia. After cooling it was filtered, washed with cold water and dried. The yield of the product melting at $112-113^{\circ}$ was 39 g (86%).

The sample of 5-nitro-2-aminotoluene was deaminated by the method of Clarke and Taylor³⁴ and the product was isolated by steam distillation. It was further purified by distillation (b.p. $111-112^{\circ}/15$ mm).

2-Methylacetophenone: 2-Methylacetophenone was prepared by converting *o*-tolunitrile to the ketimine-

hydrochloride, which was then hydrolysed^{35,36}.

Methyl magnesium iodide was prepared from clean grignard magnesium (3.2 g) and methyl iodide (17.2 g) in absolute ether. To this *o*-tolunitrile (11.7 g) was added slowly during 30 minutes. The solution was kept stirred for 6 hours and then allowed to stand overnight. The mixture was then poured on to crushed ice (100 g) containing conc. HCl (30 ml). The ether was removed and the aq. layer was refluxed for an hour to hydrolyse the ketimine hydrochloride. It was then extracted with ether thrice and the ether layer was washed first with sodium carbonate solution to remove any *o*-toluic acid, and then with water. The ether extract was dried with anhydrous sodium sulfate and the solvent removed. The residue was distilled under reduced pressure (b.p. 67°/3.5 mm). Yield = 3.2 g (about 70% of the theory).

3-Methylacetophenone: This was prepared from *m*-tolunitrile in exactly the same way as described above. It was obtained as a colorless liquid distilling over at 65-66°/3 mm). Yield = 10.4 g (77% of the theory).

4-Methylacetophenone: It was prepared by the Friedel-Craft's acylation of toluene³⁷ with acetic anhydride and anhydrous aluminium chloride. The product distilled

over at 93-94°/7 mm.

1-Bromo-2-methylnaphthalene: 2-Methylnaphthalene was brominated according to the method of Adams Binder³⁸. The crude material was purified by distillation and the fraction boiling at 94-95°/3 mm was collected.

Methyl 2-methyl-1-naphthoate^{38,39}: 1-Bromo-2-methylnaphthalene (24 g) was converted to its Grignard compound by treating with clean magnesium turnings (2.6 g) in absolute ether. The white precipitate was formed/dissolved in dry benzene (25 ml) and the mixture was cooled. It was then poured on to dry ice (70 g) and stirred. When the mass became semisolid dil. HCl was added to dissolve the entire material. The ether-benzene layer was extracted with dilute sodium hydroxide solution. On acidification of the alkaline extract, the acid separated as an oil, which crystallised slowly. The crude product was filtered, washed and dried. It was then recrystallised from benzene. The product (13.5 g, about 70%) melted at 125-6°.

This acid was then converted to its acid chloride with phosphorus oxychloride and then esterified with methanol. The pure ester was obtained as a colorless liquid (b.p. 68°/1.5 mm).

Methyl 1-methyl-4-naphthoate: 1-Methyl-4-naphthoic acid was prepared exactly in the same way as above from 1-methyl-4-bromonaphthalene. The acid (m.p. 174°) was then converted to its methyl ester in the usual way with a little sulfuric acid as catalyst. The product melted at $38-39^{\circ}$ after recrystallisation from benzene.

REFERENCES

- 1 a) P.M. Nair, G. Gopakumar and T. Fairwell,
Preliminary Report, International Symposium
on NMR, Tokyo, 1965, N-3-7.
- b) P.M. Nair and G. Gopakumar, Tetrahedron Letters
749 (1964).
- c) G. Gopakumar, Ph.D Thesis, Univ. of Poona, 1966.
- 2 R.A. Hoffman, Mol. Phys. 1, 326 (1958).
- 3 R.A. Hoffman and S. Gronowitz, Arkiv Kemie 16, 471,
501, 515, 539, 563 (1961).
- 4 H. Shimizu et al. J. Chem. Phys. 34, 1467 (1961).
37, 1565 (1962).
- 5 G.V.D. Tiers et al. ibid. 37, 1564 (1962).
- 6 H. Roltendorf and S. Sternhell, Tetrahedron Letters
1289 (1963).
- 7 J.N. Shoolery, Varian Tech. Bull. 2, 8 (1957).
- 8 J.D. Roberts "Nuclear Magnetic Resonance" McGraw Hill
1959, p.54.
- 9 E.O. Bishop, Ann. Rep. Prog. Chem. 58, 55,(1961) and
references therein.
- 10 C.N. Banwell and N. Sheppard, Disc. Fara. Soc. 34,
115 (1962).
- 11 S. Sternhell, Rev. Pure and Applied Chem. 14, 15(1964).
- 12 M. Karplus, J. Chem. Phys. 32, 1842 (1960).
- 13 M. Karplus, ibid. 30, 11 (1959).
- 14 H.M. McConnell, J. Mol. Spec. 1, 11 (1957).
- 15 H.M. McConnell, J. Chem. Phys. 24, 460 (1956).
- 16 M.J.S. Dewar and R.C. Fahey, J. Am. Chem. Soc. 85,
2704 (1963).

- 17 H. Roltendorf and S. Sternhell, Aus. J. Chem. 17, 1315 (1964).
- 18 I.M. Hunsberger, J. Am. Chem. Soc. 72, 5626 (1950).
- 19 I.M. Hunsberger et al. ibid. 74, 4839 (1952).
- 20 H.S. Gutowsky et al. ibid. 77, 2466 (1955).
- 21 H.S. Gutowsky "Hydrogen bonding" Hadzi, Pergamon Press, London (1959), p.461.
- 22 N. Jonathal et al. J. Chem. Phys. 36, 2443 (1962).
- 23 H.M. McConnel, ibid. 30, 126 (1959).
- 24 G.A. Sim et al. Acta Cryst. 8, 157 (1955).
- 25 J. Trotter, ibid. 12, 884 (1959).
- 26 J. Trotter, Tetrahedron 8, 13 (1960).
- 27 S.C. Abrahams, ibid. 3, 194 (1950).
- 28 T.D. Sakore and L.M. Pant, ibid. 21, 755 (1966).
- 29 J. Trotter, Can. J. Chem. 37, 905 (1959).
- 30 T.H. Goodman, J. Chem. Soc. 4453 (1955).
- 31 K.N. Trueblood, Acta. Cryst. 14, 1009 (1961).
- 32 P. Koppens and G.M.J. Schmidt, ibid. 18, 62, 654(1965).
- 33 J. Trotter, ibid. 13, 732 (1960).
- 34 Org. Synthesis Coll. Vol. I, p.415.
J. Am. Chem. Soc. 41, 1565 (1919).
- 35 S.F. Birchell et al. J. Am. Chem. Soc. 71, 1363 (1949).
- 36 M.S. Kharash "Grignard Reactions of Non-Metallic substances, p.714.
- 37 A.I. Vogel, "Practical Organic Chemistry" p.730.
- 38 Adams Binder, J. Am. Chem. Soc. 63, 2773 (1941).
- 39 R.C. Fuson et al. ibid. 63, 2648 (1941).

CHAPTER III

DISUBSTITUTED BENZENES

DISUBSTITUTED BENZENES

Introduction:

Different types of additivity rules have been proposed for the effects of substituents on the chemical shifts of aromatic ring protons. A reassessment of the present position in this regard is made in this Chapter with the help of additional data. Such a reassessment became absolutely necessary in the context of the work to be described in the next Chapter regarding the interaction between the methyl and nitro groups. Special attention is given to a series of derivatives of toluene and t-butylbenzene. The background of the earlier work on substituted benzenes is briefly described below.

Gutowsky et al.¹ studied the influence of different substituents on the fluorine resonance of substituted fluorebenzenes. They found an empirical correlation of chemical shift values for meta- and para-derivatives with corresponding Hammett σ constants, which implied that the shift differences were attributable to the nature of electronic interactions of the substituent. It was found that the effects are additive, except in few cases where there is interaction

between the substituents.

Bothner-By and Glick² measured the para-proton chemical shift in a number of mono-substituted benzenes and found that the variation in chemical shift on extrapolation to infinite dilution is related to the Hammett para-substituent constant. Corio and Dailey³ in a study on mono-substituted benzenes made an attempt to analyse the effect of various functional groups on the chemical shifts of the ring protons. The chemical shifts seemed to indicate the electron densities at the various positions compared to benzene. Taft⁴ correlated Gutowsky's shielding constants with σ_I and σ_R (the inductive and resonance parameters). Richards and Schaefer⁵ suggested from a study on para-disubstituted benzenes that a very roughly additive effect for each group is possible, if it is assumed that the chemical shifts of a proton is most affected by the substituent in the ortho-position. In some trisubstituted benzenes, it was found that the chemical shifts of the protons could be written as the sum of the effects of the various groups⁶. But in compounds having NO_2 and NH_2 groups ortho- or para to each other, there may be variations which can be attributed to the mesomeric interactions between the groups.

Buckingham⁷ showed that the shielding constants in polar mono- and polysubstituted benzenes can be explained in terms of the polarization induced by the electric fields of the dipoles present. His calculations seemed to fit in well with the shifts observed for nitrobenzene. A number of 2-substituted *m*-xylenes were studied by Fraser⁸, who found that the chemical shifts of the ring protons is dependent on the electron withdrawing or electron donating power of the substituent. Fraser found that his results cannot be explained by Buckingham's electric field theory. On the contrary, the results agree with Taft's view, that the chemical shifts of the meta- and para-protons are determined by both inductive and resonance effects of substituents.

Diehl⁹, in 1961, made a more quantitative study of the influence of various functional groups on the ring proton resonances of benzene derivatives and found that the substituent effects for meta- and para-disubstituted benzenes in dilute hexane solutions are additive. The solvent effect was negligible. The influence of various groups was separated into ρ_o , ρ_m and ρ_p values and these were used to predict chemical shifts. It was found that an electrostatic theory of substitution is a good approximation, as long as resonance contribution to

the chemical shift is low. The substituent constants for eleven groups were determined. He also found that the effects of benzene and acetone as solvents, on the meta- and para- protons are proportional to the Hammett σ -constants of the corresponding substituents¹⁰.

Martin and Dailey¹¹ found that in disubstituted benzenes, the J values remain roughly the same irrespective of the substituents, with most of the values falling within the range 8.4 to 9.0 cps. The proton chemical shifts appear to arise primarily from changes in π -electron density in the ring resulting from substituent perturbation. These shifts could be expressed with an average accuracy of about 0.1 PPM as sums of the substituent constants except in the case of ortho-disubstituted compounds¹². The deviations from simple additivity rule showed a trend suggesting the presence of a polarizability effect. A new equation, which takes into consideration this effect, was proposed for the chemical shifts of para-disubstituted derivatives. The root mean square (rms) deviation in the new correlation is only 0.015 PPM. The deviations of the calculated chemical shifts for compounds like p-nitroaniline and p-nitroanisole from the observed values were not large, even though deviations from additivity in the case of

dipole moments are known to be very pronounced^{12,13}. The deviations from the modified additivity rule did not show any systematic trend with changes in structure.

The PMR spectra of a number of para-substituted phenols were studied by Patterson and Tipman¹⁴, who found that at infinite dilutions in benzene and in carbontetrachloride, the -OH chemical shift is independent of the ring substituent. No correlation between the internal ring proton shift and group electronegativity was found and they suggested that this indicates that the shifts are due both to inductive and resonance effects.

In para-disubstituted benzenes, although the spin coupling constants do not vary widely, there is a definite relationship between the electronegativity of the groups and the coupling constants¹⁵. Ohinishi and Kawazoe¹⁶ found that the large low field shifts for the ortho-protons in iodo and bromobenzenes cannot be accounted for on the basis of inductive or resonance effects. This is attributed to the anisotropy of the C-X bond. In the case of non-halogen substituents, the anisotropic effects are still there, but they are overshadowed by the electronic effects arising from

γ -electron resonance of the substituent. They determined the S_o , S_m and S_p values for a number of groups.

Smith¹⁷ studied a fairly large number of para-disubstituted benzenes and showed that the measured line positions and the substituent constants computed from them depend on the choice of the standardisation method employed. Substituent constants for about fifty groups were determined in addition to those of Diehl and others. These substituent constants were correlated to the Hammett σ parameter and also with electric dipole moments. There is fairly good agreement between the values observed and those calculated using Smith's substituent constants. Unlike in the work of Martin and Dailey no correction is introduced for polarizability or any other factor.

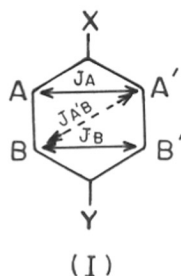
It would thus seem that there is considerable disagreement between the results obtained by Smith on the one hand and Martin and Dailey on the other. A re-examination of the additivity rules has therefore been undertaken. Additional data for some twenty compounds have been obtained. What we shall attempt is to find out whether the simpler rule of additivity is a satisfactory approximation and also, whether the more refined

one proposed offers any substantial advantage.

RESULTS AND DISCUSSION

The new data obtained for thirteen para-disubstituted benzenes are collected in Table I along with those for twenty-six similar compounds reported by Smith¹⁷. Chemical shifts of the protons ortho to the substituents X and Y in $p\text{-XC}_6\text{H}_4\text{Y}$ are designated by δ_{OX} and δ_{OY} respectively and are referred to benzene as standard.

For the additional compounds studied, the solvent used was carbontetrachloride and the spectra were super positions of two identical AB systems to a very good approximation. In a few cases, in which the A_2B_2 multiplet patterns were more or less clearly indicated, although they were not completely resolved, the spectra were analyzed as A_2B_2 systems (I) under the approximation¹² $J_A = J_B$ and $J_{A'B} = 0$ cps. The results were



almost the same as when the spectra were regarded as arising from identical isolated AB systems in each compound.

TABLE I - COMPARISON OF CHEMICAL SHIFT DATA FOR PARA-SUBSTITUTED BENZONES
 CHEMICAL SHIFTS IN cps RELATIVE TO BENZENE (436 cps).

X	Y	Solvent	$\delta_{\alpha X}$		$\delta_{\beta Y}$		
			Observed	Calculated	Observed	Calculated	
1	F	CHO	CCl ₄	+2	+2	-38	-34
2	Br	CHO	"	-26	-24	-26	-28
3	I	CHO	"	-31	-35	-22	-22
4	CH ₃	CHO	"	+2	-2	-24	-27
5	F	COOMe	"	+9	+9	-47	-48
6	Cl	COOMe	"	-7	-8	-42	-45
7	Br	COOMe	"	-18	-16	-37	-41
8	I	COOMe	"	-26	-27	-26	-34
9	CH ₃	COOMe	"	+6	+6	-36	-40
10	NO ₂	COOMe	"	-65	-61	-65	-63
11	t-Bu	COOMe	"	-7	-9	-41	-46
12	t-Bu	NO ₂	"	-18	-17	-52	-56
13	NH ₂	COOMe	CCl ₃	+37	+36	-36	-38
14	Br	Me	CCl ₄	-4	-3	+16	+18
15	I	Me	"	-15	-14	+24	+24

TABLE I (Contd.)

X	Y	Solvent	δ_{OX}		δ_{OY}		
			Observed	Calculated	Observed	Calculated	
16	Cl	Me	CCl ₄	+4	+5	+13	+14
17	OMe	CHO	"	+15	+15	-33	-28
18	Cl	CHO	"	-14	-15	-32	-32
19	NMe ₂	CHO	"	+36	+36	-23	-24
20	CH ₃	COMe	"	+4	0.0	-32	-32
21	CH ₃	NO ₂	"	-2	-2	-48	-51
22	CH ₃	CH ₃	"	+18	+19	+18	+19
23	NO ₂	OMe	"	-32	-51	+22	+15
24	Et	OMe	"	+17	+14	+34	+31
25	F	CH ₃	"	+21	+22	+14	+12
26	CHO	CHO	"	-45	-48	-45	-48
27	CHO	CHMe ₂	"	-28	-30	-3	-6
28	t-Bu	CH ₃	"	+6	+4	+16	+13
29	OH	COOBu	"	+24	+21	-37	-42
30	Et	COMe	"	-18	-18	-30	-33

TABLE I (Contd.)

X	Y	Solvent	δ_{OX}		δ_{OY}		
			Observed	Calculated	Observed	Calculated	
31	OMe	COOMe	CCl ₄	+26	+23	-38	-40
32	OH	CHO	Acetone	+23	+15	-29	-30
33	OH	COOH	"	+24	+20	-36	-42
34	H ₂	NO ₂	"	+26	+31	-40	-42
35	COCl	NO ₂	"	-64	-61	-64	-60
36	OH	NO ₂	CDCl ₃	+15	+18	-48	-48
37	OMe	COOH	"	+23	+13	-42	-46
38	CHMe ₂	CH ₃	"	+17	+14	+17	+14
39	OCOMe	Me	CCl ₄	+24	+21	+14	+11

Data for compounds 23 to 39 are taken from the work of Smith¹⁷.

In these systems each proton is coming under the influence of one substituent ortho to it and another one meta to it. According to the simple rule of additivity⁹, the chemical shifts of these protons are made up of additive contributions representing the effects of the substituents in the ortho and meta positions. The chemical shifts of all the compounds in Table I, have been calculated using the δ_o and δ_m values computed by Smith¹⁵ and the values thus calculated are shown side by side with observed values.

The data of Table I show that the agreement between the calculated and observed values is on the whole rather good. The root mean square (rms) deviation of the observed values from the calculated ones is 3.2 cps or 0.053 PPM. The rms deviation rises to only 5.1 cps when the eight compounds showing deviations larger than 4 cps, for either δ_oX or δ_oY are considered. These deviations are less than those observed by Martin and Dailey¹² for a much smaller set of data. These investigators have suggested a modified additivity rule based on the trend they observed in the deviations from the simple rule of Diehl⁹. The data were found to obey the modified rule (eqn. 1), closely, the rms deviation being only 0.015 PPM. In the modified rule,

the $\gamma(R)$'s are parameters representing the polarizability or susceptibility of the positions ortho to R, to perturbations by substituents para to R.

$$\delta_2 = \delta_0 (R_1) + \gamma(R_1) d_m(R_4) \text{ ---- (1)}$$

This interpretation doesn't imply any particular mechanism.

Since the rms deviations from the simple additivity rule is only about half as much in the present investigation, as it was in that of Martin and Dailey, the necessity for introducing a correction factor is not as serious. However, it is of considerable interest to see if there is any trend in the deviations, which is indicative of interactions between the substituents. When the chemical shift values δ_{mX} of a set of compounds $p\text{-XC}_6\text{H}_4\text{CHO}$ are plotted against the similar set for $p\text{-XC}_6\text{H}_4\text{COOMe}$ there is indeed a very definite indication of a linear variation. But, the correlation obtained (Fig. I) is not very satisfactory. This is very much unlike the behaviour seen for $p\text{-XC}_6\text{H}_4\text{OMe}$ and $p\text{-XC}_6\text{H}_4\text{Cl}$ by Martin and Dailey¹². A similar correlation is again indicated (Fig. II) between the sets of data for para-substituted toluenes ($p\text{-XC}_6\text{H}_4\text{CH}_3$) and para-substituted methylbenzoates ($p\text{-XC}_6\text{H}_4\text{COOMe}$). While

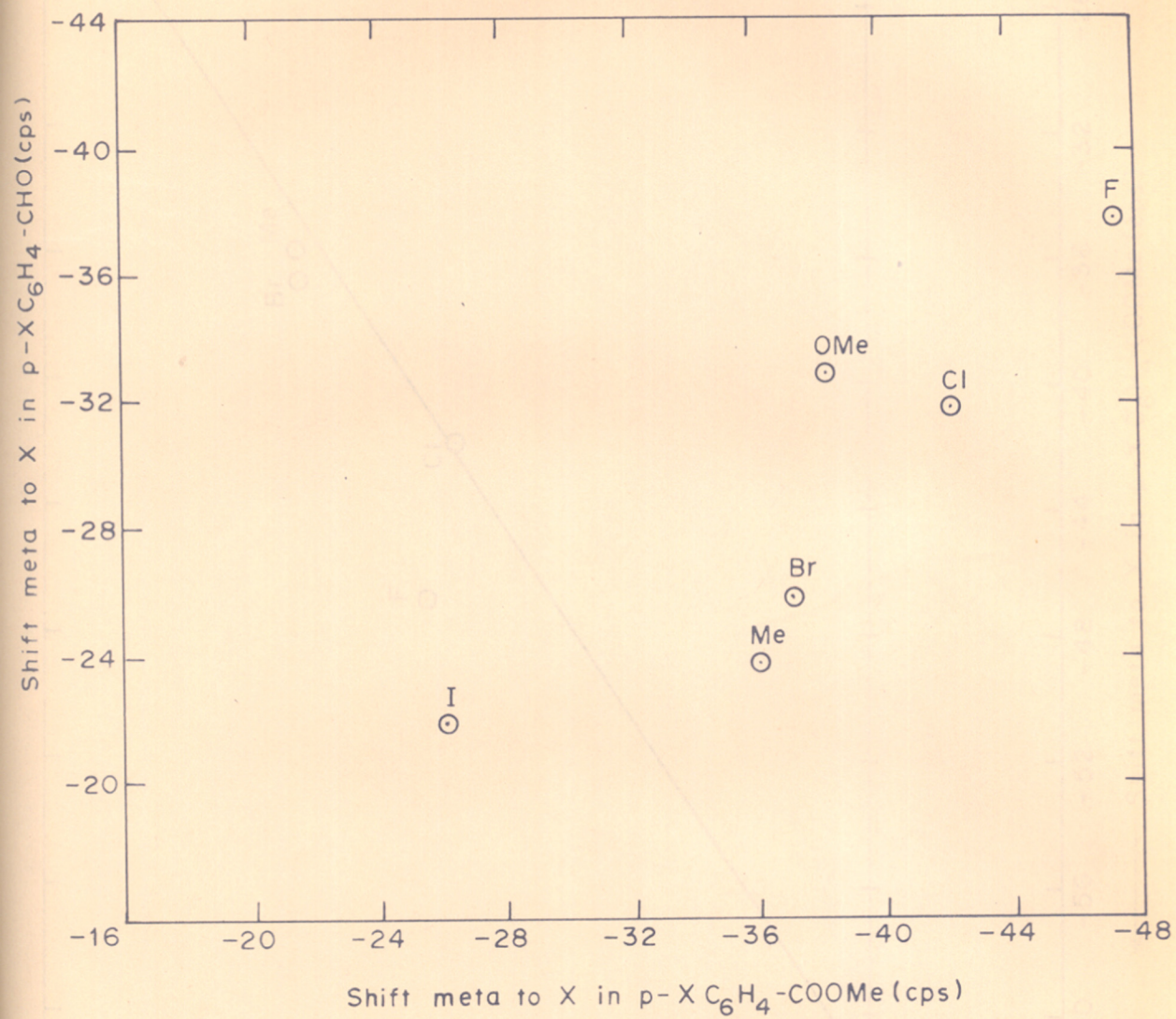


Fig. I META CORRELATIONS: CHO Vs. COOMe

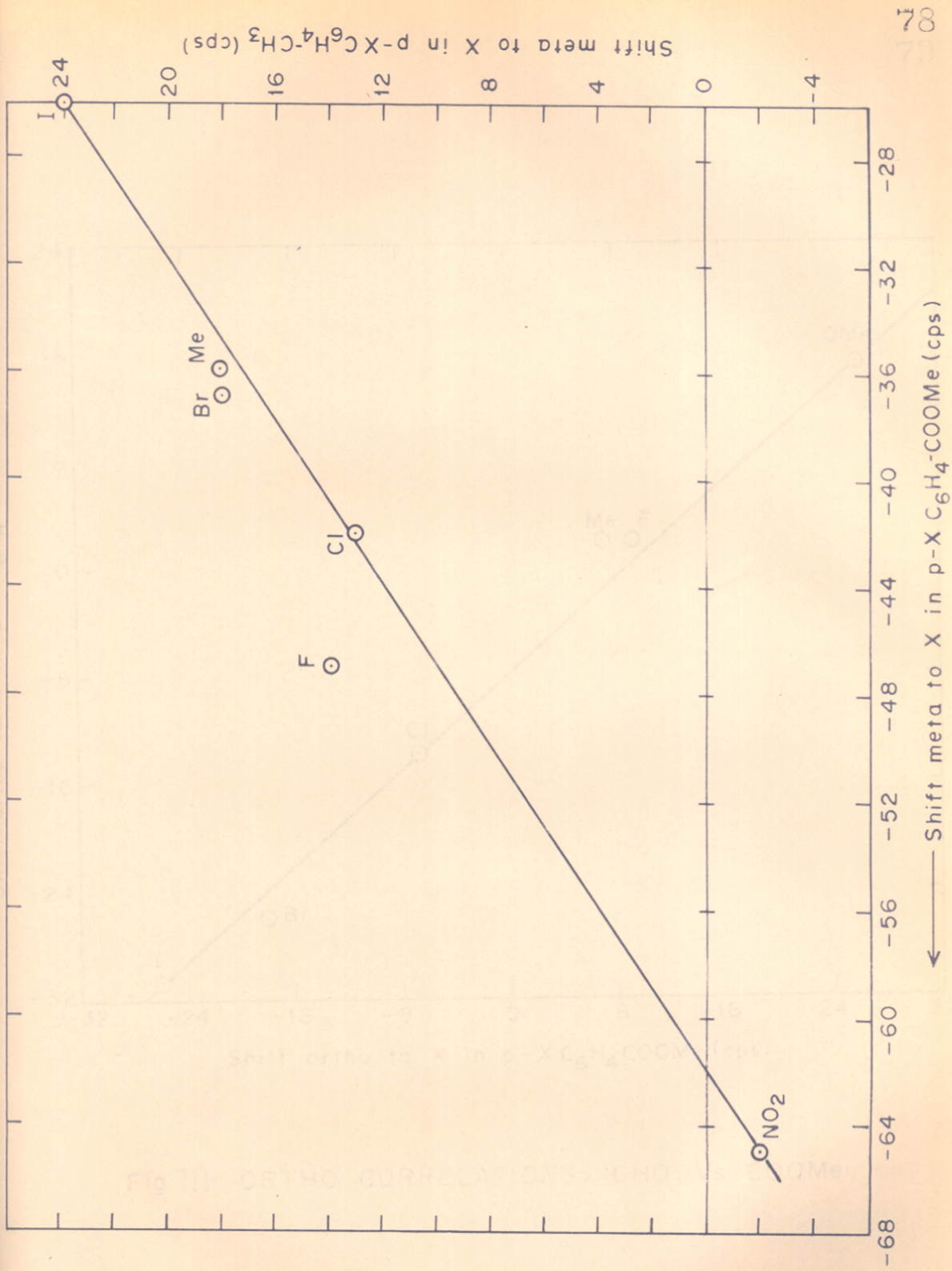


Fig. II META CORRELATIONS: Me Vs. COOMe

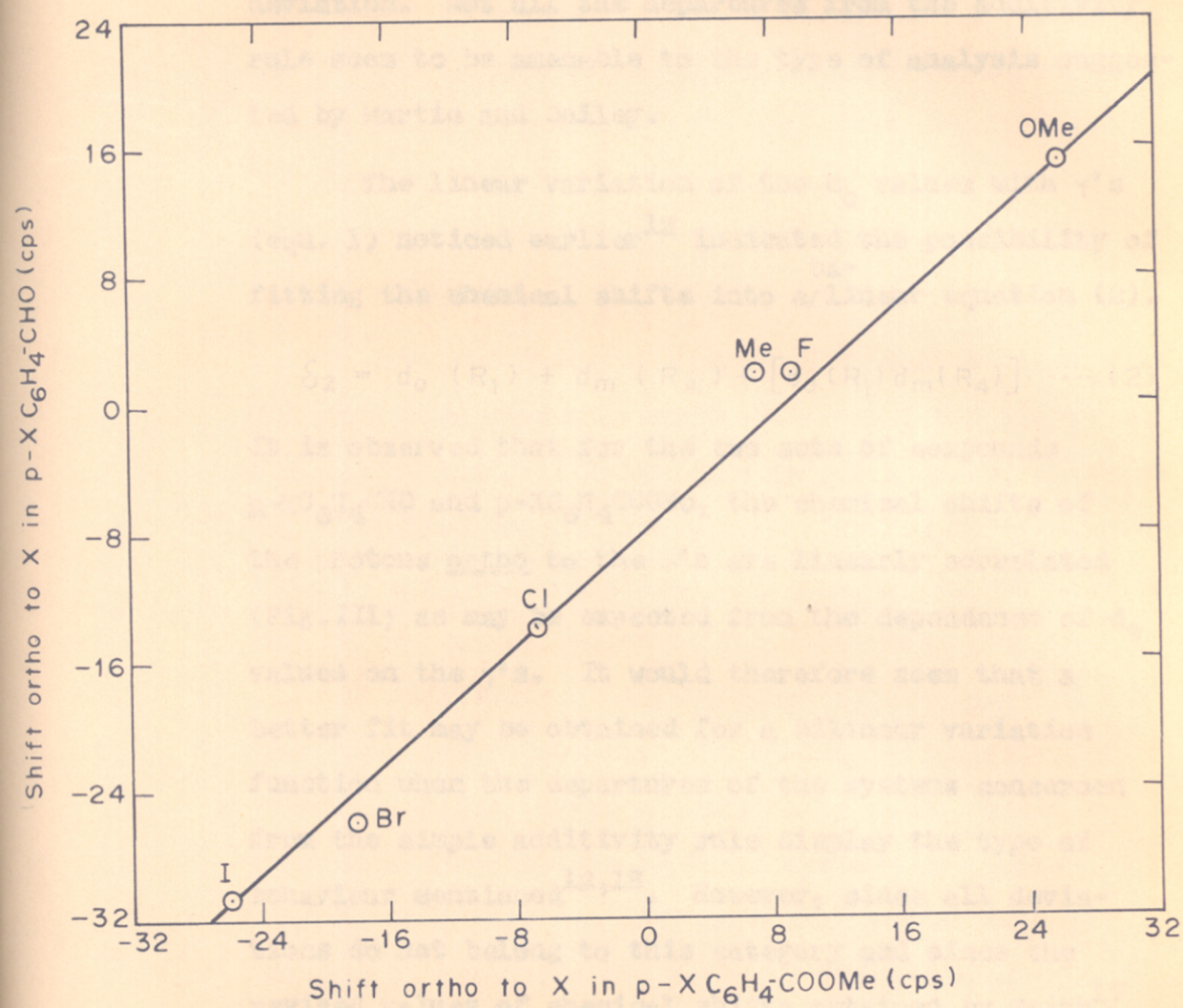


Fig. III ORTHO CORRELATIONS: CHO Vs. COOMe

the data for five compounds fit in a linear correlation very closely, one is showing very pronounced deviation. Not all the departures from the additivity rule seem to be amenable to the type of analysis suggested by Martin and Bailey.

The linear variation of the d_o values with γ 's (eqn. 1) noticed earlier¹² indicated the possibility of fitting the chemical shifts into a ^{bi-}linear equation (2).

$$\delta_2 = d_o (R_1) + d_m (R_4) + [d_o (R_1) d_m (R_4)] \text{ ---- (2)}$$

It is observed that for the two sets of compounds $o\text{-XC}_6\text{H}_4\text{CHO}$ and $p\text{-XC}_6\text{H}_4\text{COOMe}$, the chemical shifts of the protons ortho to the X's are linearly correlated (Fig. III) as may be expected from the dependence of d_o values on the γ 's. It would therefore seem that a better fit may be obtained for a bilinear variation function when the departures of the systems concerned from the simple additivity rule display the type of behaviour mentioned^{12,18}. However, since all deviations do not belong to this category and since the revised values of chemical shifts obtained by Smith¹⁷ and those determined in this investigation do seem to obey the rule of additivity rather well, there is hardly very much to be gained by the sophisticated approach

of Martin and Dailey¹².

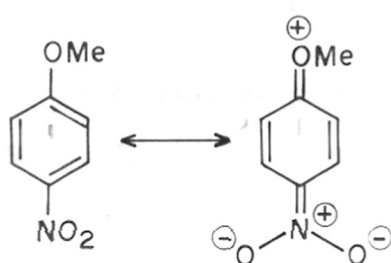
The data obtained for meta-disubstituted benzenes are shown in Table II, along with the chemical shift data calculated using the substituent constants (shown within brackets). The agreement obtained is excellent. This is, but to be, expected in view of the absence of direct resonance interaction between the substituents.

From the point of view of the study of resonance interactions between substituent groups, the significance of the additivity rule is quite clear, although in a negative sense. The chemical shifts for p-nitroanisole and p-nitroaniline, for example, do not disclose any effect corresponding to the departures from the rule of additivity of dipole moments. For p-amino and p-methoxy methylbenzoates the rule of additivity (of chemical shifts) works exceptionally well. Since resonance interactions in these systems are well-established, this can only mean that the electronic effects in the different parts of the π -system that result from resonance (II and III) have nearly compensating magnetic shielding.

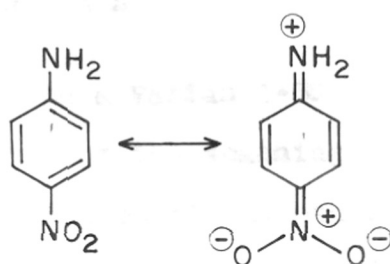
TABLE II - COMPARISON OF CHEMICAL SHIFT DATA FOR 1,3-DISUBSTITUTED BENZENES*
 CHEMICAL SHIFTS IN cps RELATIVE TO BENZENE (436 cps) SOLVENT CCl₄

	X(1)	Y(3)	H ₂	H ₄	H ₅	H ₆
1	CH ₃	CH ₃	+18 (+21)	+18 (+20)	+18 (+12)	+18 (+20)
2	CH ₃	NO ₂	-49 (-48)	-50 (-50)	-10 (-3)	-10 (-8)
3	CH ₃	COOMe	-32 (-33)	-32 (-35)	+3 (0.0)	+3 (-2)
4	CH ₃	COCH ₃	-26 (-28)	-26 (-29)	-2 (0.0)	-2 (0.0)
5	CH ₃	NH ₂	+59 (+57)	+59 (+62)	+20 (+18)	+49 (+50)
6	CH ₃	CH	-4 (-5)	-4 (-10)	-4 (0.0)	-4 (0.0)
7	CH ₃	H	+9 (+8)	+9 (+9)	+9 (+6)	+9 (+8)
8	COOMe	NO ₂	-98 (-102)	-73 (-63)	-29 (-18)	-73 (-62)
9	COOMe	NH ₂	+1 (+1)	+33 (+34)	+11 (+10)	-4 (-4)
10	t-Bu	NO ₂	-57 (-55)	-43 (-)	-10 (-9)	-26 (-24)
11	t-Bu	COOMe	-48 (-49)	-34 (-)	-2 (-3)	-18 (-16)

*Calculated shifts are given within brackets.



II



III

There is thus no possibility of using chemical shifts for studying resonance in the derivatives considered. In the context of the study described in the next Chapter, it may further be noted that the effects of the substituent alkyl groups are particularly well described by the additivity rule.

EXPERIMENTAL

All spectra were recorded on a Varian A-60 NMR Spectrometer. Details regarding the scanning of the spectrum, calibration of the chart and other experimental details are as described in Chapter II. For all compounds tetramethylsilane was used as an internal reference. But the line position of benzene in carbontetrachloride (5%) was taken as the ultimate reference for computation of the shifts discussed. Sample concentrations were 5-10% (w/v) to minimize intermolecular interactions.

Most of the compounds used in this study were available from the work done in connection with other studies described in this thesis. The methods of preparation are given in Chapter II of this Part and in Part II.

The *p*-halobenzoic acids were obtained as by-products in the preparations of the corresponding aldehydes from the halotoluenes by chromic anhydride oxidation. These acids were converted to their methylesters in the usual way with methanol and a little sulfuric acid as catalyst.

1. Methyl *p*-nitrobenzoate

p-Nitrotoluene was oxidised with alkaline potassium

permanganate and the resulting acid isolated. The *p*-nitrobenzoic acid thus obtained was converted into its methyl ester by refluxing with methanol and a little sulfuric acid as catalyst. Pure methyl *p*-nitrobenzoate was obtained as fine pale yellow needles, which melted at $95-96^{\circ}$ (lit. 96°).

2. Methyl *m*-nitrobenzoate

Methylbenzoate was nitrated with a nitrating mixture of conc. HNO_3 and conc. H_2SO_4 . The pure methyl ester was isolated in the usual way as colorless needles melting at 78° .

3. Methyl *p*-*t*-butylbenzoate

4-Amino-*t*-butylbenzene which was prepared from 4-nitro-*t*-butylbenzene by reduction with iron and hydrochloric acid, was converted to its nitrile, by a method analogous to that employed for the preparation of *p*-tolunitrile using cuprous cyanide. The nitrile was isolated by steam distillation. It was then hydrolysed to the acid with 10% sodium hydroxide solution. The acid was isolated and purified by recrystallising from alcohol. Pure 4-*t*-butylbenzoic acid was obtained as snow white glistening crystals, which melts at 143° . This acid was then converted to its methyl ester in the usual way. Pure methyl

4-t-butylbenzoate was obtained as a colorless liquid, which distilled over at 117°/2.5 mm.

4. Methyl m-t-butylbenzoate

It was prepared by the hydrolysis of the corresponding nitrile with 10% sodium hydroxide solution as in the above case (The preparation of the nitrile is described in detail in Chapter IV). Pure m-t-butylbenzoic acid was obtained as a snow white solid (m.p. 119-20°) in 95-6% yield. This acid was converted to its methyl ester. Pure methyl m-t-butylbenzoate was obtained as a colorless liquid, distilling at 113-14°/2.5 mm.

5. Methyl Aminobenzoates

Both m- and p-aminobenzoic acids (commercial samples) were converted to their methyl esters in the usual way. Methyl m-aminobenzoate was obtained as a colorless liquid, distilling at 121-22°/2.5 mm, while the methyl p-aminobenzoate was obtained as colorless needle shaped crystals, melting at 111° (lit. 112°).

6. Nitro-t-butylbenzenes

Both m- and p-nitro-t-butylbenzenes were prepared starting with t-butylbenzene. The methods of preparation of both compounds are described in detail in Chapter IV.

REFERENCES

- 1 H.S. Gutowsky et al. J. Am. Chem. Soc. **74**, 4809 (1952).
- 2 A.A. Bothner-by and R.E. Glick, ibid. **78**, 1071(1956).
- 3 P.L. Corio and B.P. Dailey, ibid. **78**, 3043 (1956).
- 4 R.W. Tart et al. ibid. **72**, 1045 (1957).
- 5 R.E. Richards and T. Schaefer, Trans Fara. Soc. **54**, 1280 (1958).
- 6 R.E. Richards and J.B. Lean, ibid. **55**, 707 (1959).
- 7 A.D. Buckingham, Can. J. Chem. **38**, 360 (1960).
- 8 R.R. Fraser, Can. J. Chem. **38**, 2226 (1960).
- 9 P. Diehl, Helv. Chim. Acta **44**, 829 (1961).
- 10 P. Diehl, ibid. **45**, 568 (1962).
- 11 J. Martin and B.P. Dailey, J. Chem. Phys. **37**, 2594 (1962).
- 12 J. Martin and B.P. Dailey, ibid. **39**, 1722 (1963).
- 13 C.P. Smyth "Dielectric Behaviour and Structure" McGraw-Hill Book Co. Inc. New York 1955, Chapter 10.
- 14 W.G. Patterson and N.R. Tipman, Can. J. Chem. **40**, 2122 (1962).
- 15 P.F. Cox, J. Am. Chem. Soc. **85**, 380 (1963).
- 16 M. Ohinishi and Y. Kawazoe, Chem. Pharm. Bull.(Jap) **12**, 938 (1964).
- 17 G.W. Smith, J. Mol. Spec. **12**, 146 (1964).
- 18 S.I. Miller, J. Am. Chem. Soc. **81**, 101 (1959).

CHAPTER IV

CHEMICAL SHIFTS IN SOME SUBSTITUTED
BENZOIC ESTERS

CHEMICAL SHIFTS IN SOME SUBSTITUTED
BENZOIC ESTERS

Introduction

The main evidence so far put forward from NMR spectroscopic studies in support of hyperconjugation comes from the observation of long range spin-spin coupling in alkyl substituted unsaturated systems¹. In view of the small magnitude of this interaction and the fact that the coupling arises from the perturbation of the ground state by interaction with the higher energy triplet configurations of the π -electrons, the admissibility of such evidence for hyperconjugation, in the case of even systems is indeed doubtful as Dewar² has pointed out. Chemical shift evidence would be free from this difficulty. Although there has been no determined effort to study hyperconjugation with the aid of chemical shifts, a few observations have indeed been made in this regard.

Corio and Weinberg³, who studied the methyl resonances of some substituted thiophenes, found that the signals of 2- and 3-methylthiophenes are at lower field than those of 2,3-dimethylthiophene. They suggested that if hyperconjugation is important in these

systems, one might expect the methyl groups to be shifted to lower fields, and on this account since the electron release per methyl group would be smaller in the dimethyl derivative than in the mono-methyl derivatives. But this low field shift may not be genuine, since the data have not been corrected for bulk susceptibility. Even if it turns out to be genuine, it can be readily accounted for, on the basis of the inductive effect of the methyl group and the anisotropy of the C-Me bond.

Reddy and Goldstein⁴ studied the effect of methyl substitution on the chemical shift of substituted ethylenes. The effect of methyl substitution is ascribed to hyperconjugation, since the β -proton shift is a long range effect and also since it is roughly independent of the variations in the polarity of the other substituent. This interpretation is quite uncertain, since the inductive effect of the methyl group has been ignored.

In Chapter II, an indication was obtained that the methyl group may be involved in a hyperconjugative interaction with a p-nitro group and that its interaction with the carboxyl group may be weaker. In view of the fact that all the effects attributed to hyper-

conjugation can be explained in other ways^{2,5}, it looked attractive to see if clear cut chemical shift evidence can be obtained, which would resolve the ambiguity. The conclusion of the previous Chapter was not helpful from this point of view. However, it is shown here, that the difficulty regarding the use of chemical shifts of benzene derivatives for studying the problem at hand, can be solved by using suitably chosen sterically hindered systems.

Results and Discussion

The aromatic region of the NMR spectra (Fig. Ia and b) of methyl *o*-nitrobenzoate (I) and dimethylphthalate (II), show that the C₃ and C₆-protons, which are ortho to the nitro and carbomethoxy groups do not show the usual downfield shifts observed for similar protons of carboxyl and nitro derivatives. The absence of the usual paramagnetic shift clearly arises from the magnetic anisotropy of the NO₂⁶ and COOMe groups, which are rotated in these derivatives from the normally more favourable conformation coplanar with the aromatic ring. In these systems, if a substituent that can enter into resonance interaction with the NO₂ or carboxyl group is introduced, we may expect the latter to rotate and come nearer to the coplanar conformation. A

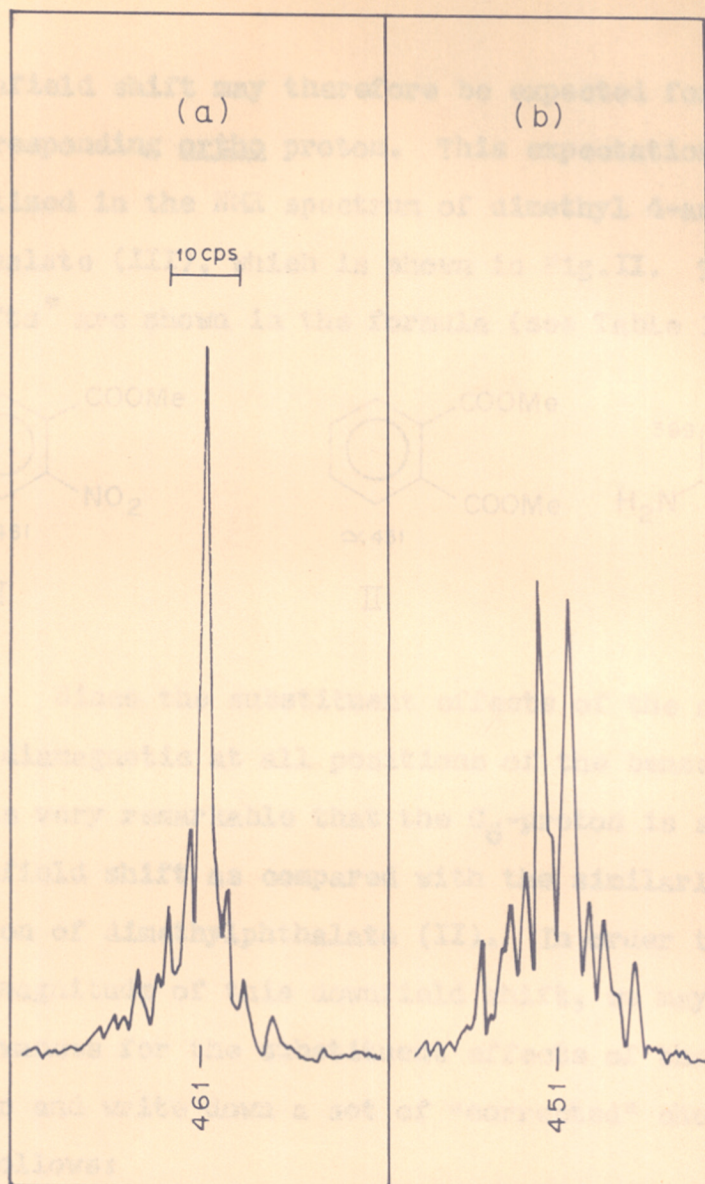
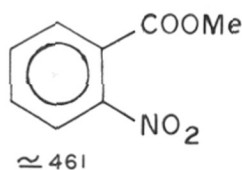
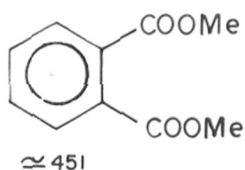


FIG. I. AROMATIC REGION OF THE NMR SPECTRA OF: (a) Methyl o-nitrobenzoate and (b) Dimethyl phthalate.

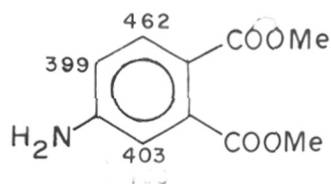
downfield shift may therefore be expected for the corresponding ortho proton. This expectation is realized in the NMR spectrum of dimethyl 4-amino-phthalate (III), which is shown in Fig. II. The chemical shifts* are shown in the formula (see Table I also).



I



II



III

Since the substituent effects of the amino group are diamagnetic at all positions of the benzene ring, it is very remarkable that the C_6 -proton is showing a downfield shift as compared with the similarly placed proton of dimethylphthalate (II). In order to estimate the magnitude of this downfield shift, we may make allowances for the substituent effects of the amino group and write down a set of "corrected" chemical shifts as follows:

*The NMR spectra were taken in CCl_4 on a Varian A-60 NMR spectrometer. Tetramethylsilane was used as internal reference, unless otherwise stated. Chemical shifts (δ) are expressed in cps downfield from TMS.

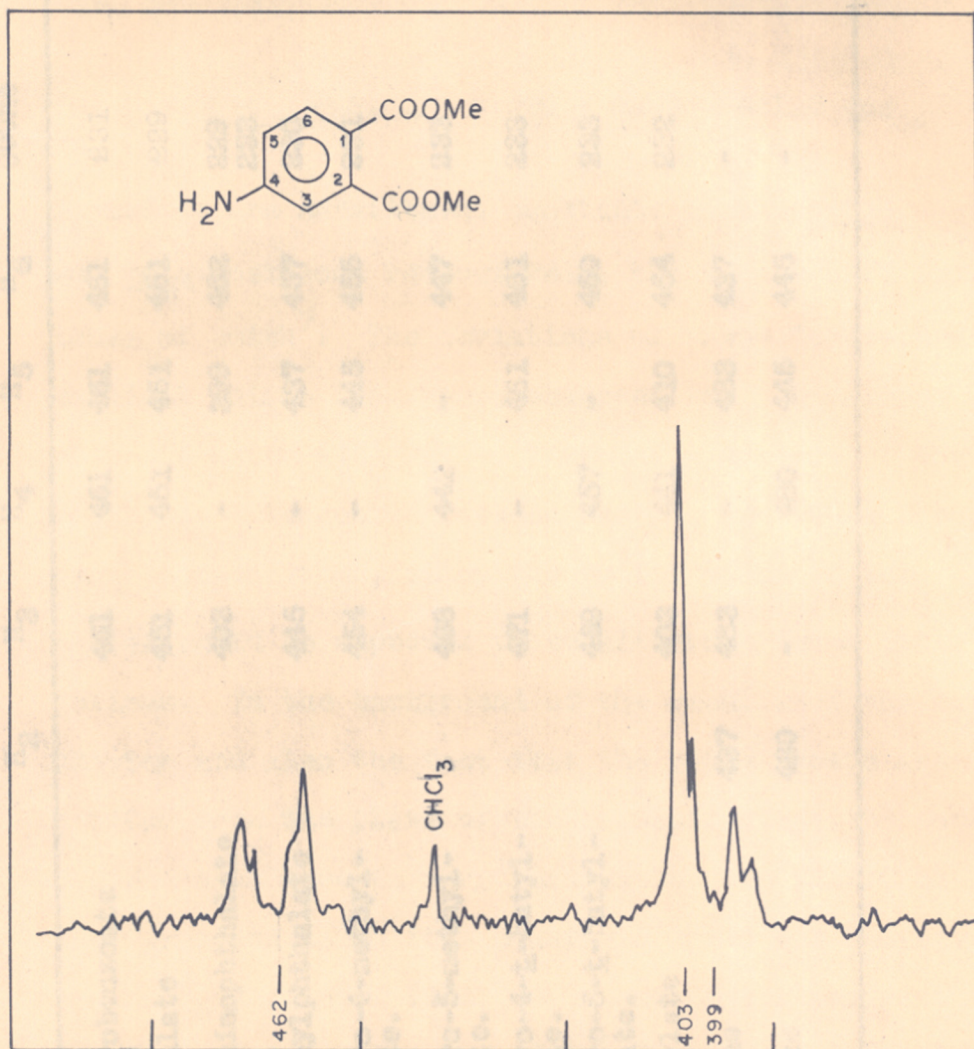


FIG. II. AROMATIC REGION OF THE NMR SPECTRA OF DIMETHYL 4-AMINOPHTHALATE

TABLE I - PROTON CHEMICAL SHIFTS IN cps (8) SOLVENT:CCl₄ (Ref. TMS INTERNAL)

No.		H ₂	H ₃	H ₄	H ₅	H ₆	COOMe	Other groups
1	Methyl <i>o</i> -nitrobenzoate	461	461	461	461	461	231	-
2	Dimethylphthalate	451	451	451	451	451	229	-
3	Dimethyl 4-aminophthalate	403	403	-	399	462	229 233	260 (NH ₂)
4	Methyl 4-methylphthalate	445	445	-	437	457	230	144 (Me)
5	Methyl 2-nitro-4-methylbenzoate.	454	454	-	445	455	231	147 (Me)
6	Methyl 2-nitro-5-methylbenzoate.	468	468	442	-	447	233	148 (Me)
7	Methyl 2-nitro-4- <i>t</i> -butylbenzoate.	471	471	-	461	461	233	83 (CMe ₃)
8	Methyl 2-nitro-5- <i>t</i> -butylbenzoate.	469	469	457	-	460	233	82 (CMe ₃)
9	Methyl Salicylate	403	403	441	410	464	232	638 (OH)
10	<i>o</i> -Nitrotoluene	487	483	-	483	437	-	147 (Me)
11	<i>m</i> -Nitrotoluene	480	-	480	445	445	-	148 (Me)

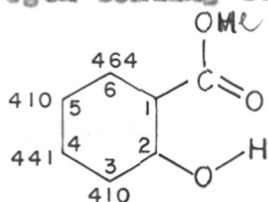
$$\delta_{H_6}^{\text{Cor.}} = \delta_{H_6}^{\text{Obs}} + S_{m, \text{NH}_2} = 462 + 12.6 = 474.6 \text{ cps}$$

$$\delta_{H_3}^{\text{Cor.}} = \delta_{H_3}^{\text{Obs}} + S_{o, \text{NH}_2} = 403 + 42.6 = 445.6 \text{ cps}$$

$$\delta_{H_5}^{\text{Cor.}} = \delta_{H_5}^{\text{Obs}} + S_{o, \text{NH}_2} = 399 + 42.6 = 441.6 \text{ cps}$$

S_o and S_m are substituent constants at the ortho and meta positions respectively, the values used being those of Smith⁷. The deviations of these "corrected" chemical shifts from those observed for the parent phthalic ester (II) may be taken as a measure of the resonance interaction between the NH_2 and COOMe group para to each other, since the conformation of the latter would be expected to be altered by such interactions. In the background of the results of the last Chapter and also the fact that the COOMe groups are rotated from the plane of the aromatic ring, the comparison made here is very reasonable. We find that the C_6 -proton is shifted downfield by 29 cps relative to the C_3 -proton of (III) and about 24 cps relative to the C_3 - and C_6 -protons of (II). Such a large shift can arise only through the interaction of the 4-amino group with the carbomethoxy group at position 1, which will tend to bring the latter into the same plane as

the aromatic ring. There can be no doubt about the changes in conformation of the COOMe group at position 1, and the interpretation of the spectral differences here is quite unambiguous. There is no necessity at this stage to consider the dispositions of the C=O and C-OMe bonds about the C_1-C_4 axis, since both these components of COOMe group have paramagnetic effects on the C_6 -proton in a planar conformation. The effect of the C-OMe group may be illustrated with the help of the spectrum of methyl salicylate (IV) whose C_6 -proton absorbs at 28 cps downfield from the absorption of benzene. Hydrogen bonding between the OH and C=O



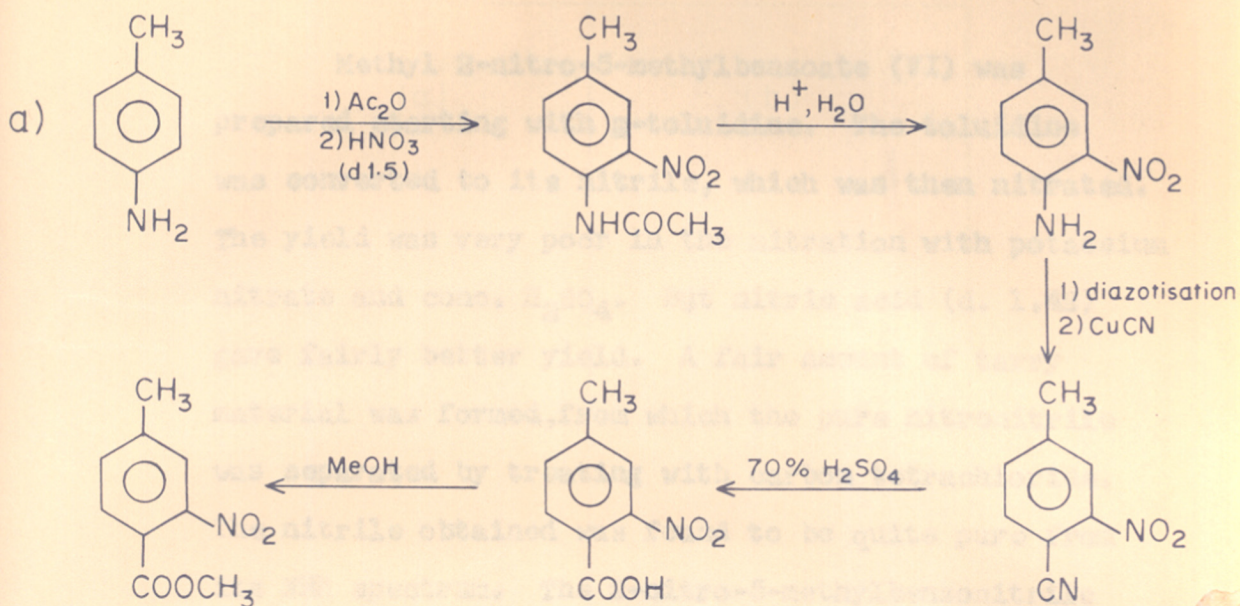
IV

groups holds the COOMe group, in this compound in the required configuration.

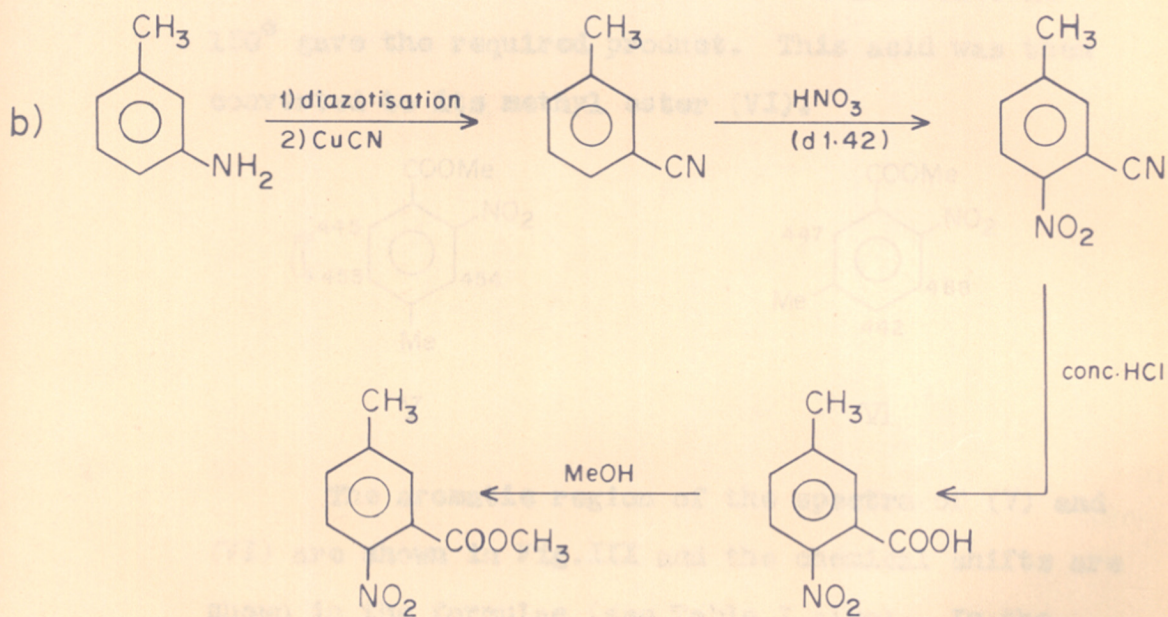
The example of dimethyl 4-aminophthalate shows that an examination of the NMR spectra of methyl 2-nitro-4-methylbenzoate (V) and methyl 2-nitro-5-methylbenzoate (VI) would help us in answering the question posed at the end of Chapter II, regarding the presence

of an interaction between the methyl and nitro groups across an aromatic ring. These compounds (V and VI) were prepared according to the schemes shown in Chart I.

Methyl 2-nitro-4-methylbenzoate was prepared in six steps starting with *p*-toluidine, which was acetylated and nitrated to the 3-nitro-4-acetaminotoluene. The nitration was carried out with fuming nitric acid and a mixture of glacial acetic acid and sulfuric acid was used as solvent. This method had the advantage over the classical methods described by Bigelow⁸ and others⁹, that there was no polynitro compound formed in the reaction and that the yield was excellent. The product was then hydrolysed with conc. HCl and the free amine converted to the nitrile. This nitrile on hydrolysis with 10% alkali gave a mixture of acids with *p*-toluic acid as the major product. However, it was hydrolysed to the required acid, with 70% sulfuric acid, but considerable amount of tarry material was formed, probably due to the high temperature employed for the hydrolysis (180°). The acid obtained was found to be quite pure and was converted to its methyl ester.

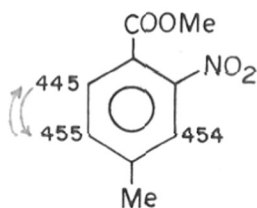


(V)

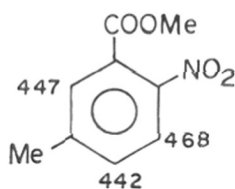


(VI)

Methyl 2-nitro-5-methylbenzoate (VI) was prepared starting with *m*-toluidine. The toluidine was converted to its nitrile, which was then nitrated. The yield was very poor in the nitration with potassium nitrate and conc. H_2SO_4 . But nitric acid (d. 1.42) gave fairly better yield. A fair amount of tarry material was formed, from which the pure nitronitrile was separated by treating with carbon tetrachloride. The nitrile obtained was found to be quite pure from its NMR spectrum. The 2-nitro-5-methylbenzonitrile thus obtained, on hydrolysis with alkali or 70% sulfuric acid gave mixtures containing mainly *m*-toluic acid. But hydrolysis with conc. HCl in a sealed tube at 150° gave the required product. This acid was then converted to its methyl ester (VI).



V



VI

The aromatic region of the spectra of (V) and (VI) are shown in Fig. III and the chemical shifts are shown in the formulae (see Table I also). In the spectrum of (V), the protons at C₃ and C₆ positions

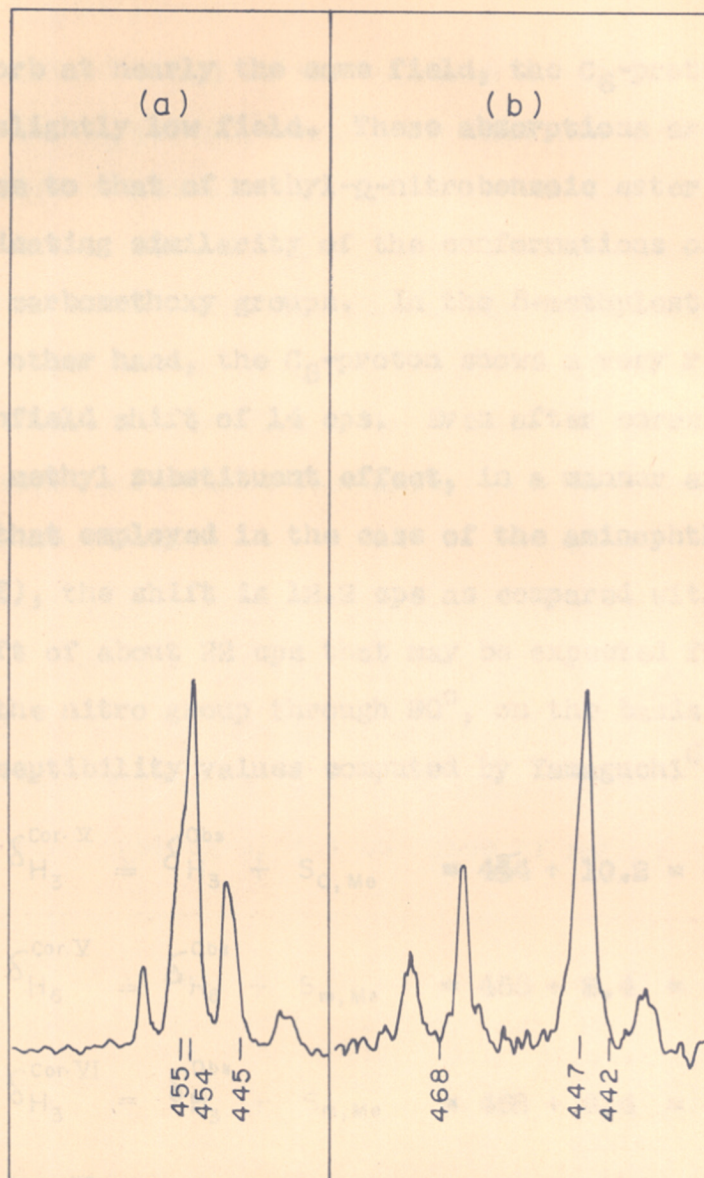


FIG. III. AROMATIC REGION OF THE NMR SPECTRA OF : (a) Methyl 2-nitro-4-methylbenzoate and (b) Methyl 2-nitro-5-methylbenzoate.

absorb at nearly the same field, the C₃-proton being at slightly low field. These absorptions are very close to that of methyl-2-nitrobenzoic ester (I) itself, indicating similarity of the conformations of the nitro and carbomethoxy groups. In the 5-methylester (VI), on the other hand, the C₃-proton shows a very remarkable downfield shift of 14 cps. Even after correcting for the methyl substituent effect, in a manner analogous to that employed in the case of the aminophthalic ester (III), the shift is 12.2 cps as compared with the total shift of about 22 cps that may be expected for rotation of the nitro group through 90°, on the basis of the susceptibility values computed by Yamaguchi⁶.

$$\delta_{H_3}^{\text{Cor. V}} = \delta_{H_3}^{\text{Obs}} + S_{O, Me} = 454 + 10.2 = 464.2 \text{ cps}$$

$$\delta_{H_6}^{\text{Cor. V}} = \delta_{H_6}^{\text{Obs}} + S_{m, Me} = 455 + 8.4 = 463.4 \text{ cps}$$

$$\delta_{H_3}^{\text{Cor. VI}} = \delta_{H_3}^{\text{Obs}} + S_{m, Me} = 468 + 8.4 = 476.4 \text{ cps}$$

$$\delta_{H_6}^{\text{Cor. VI}} = \delta_{H_6}^{\text{Obs}} + S_{O, Me} = 447 + 10.2 = 457.2 \text{ cps}$$

$$\delta_{H_3}^{\text{Cor. V}} - \delta_{H_3}^{\text{Cor. VI}} = -12.2 \text{ cps}$$

$$\delta_{H_6}^{\text{Cor. V}} - \delta_{H_6}^{\text{Cor. VI}} = +6.2 \text{ cps}$$

A shift of 8 cps in the opposite direction is seen for the C_6 -proton, suggesting that the carboxyl group is more out of plane in (VI) than in (V). This is only to be expected, because, when the nitro group comes closer to the aromatic plane, the carbomethoxy group would go further out of the plane. These changes in the conformation of the two groups are proof of the interaction between the nitro and methyl groups para to each other.

At this point one would like to ask, whether the methyl group would not interact with the carboxyl group also, although this interaction might be weaker*. The comparatively close values for the chemical shifts of the ring protons of (V) to those of methyl o-nitrobenzoate

*The Hammett type parameter ($\sigma_p - \sigma'$) defined by Taft²⁶ which may be generally regarded as a measure of resonance interaction has been estimated to be smaller for the nitro group than for the carboxyl group. However, in these cases both the I and M effects are negative in sign and there is little real basis for the procedure employed for the discussion of π -electron polarization into components arising from inductive and resonance effects. These effects interact mutually and the mere subtraction of indirectly computed σ' values from σ_p values would not do for the estimation of resonance.

(I) suggest that the conformations of the two groups in these two compounds are similar. In other words, in (V), the expected paramagnetic shift for the C_6 -proton is not observed. The reason for this becomes clear, when we consider the structure of *o*-nitrobenzoic acid.

X-ray crystallographic studies on *o*-nitrobenzoic acid^{*}, conducted in our laboratory by Pant and coworkers¹⁰, have shown that the nitro group is rotated 54.7° and the carboxyl group 23.4° from the aromatic plane. These rotations help to relieve the intramolecular overcrowding of the nitro and carboxyl groups.

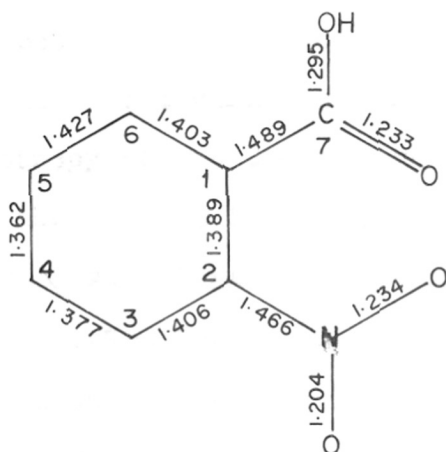


Fig. IV - Bond lengths in *o*-nitrobenzoic acid.

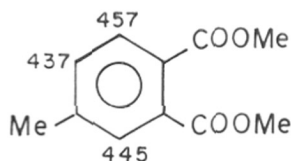
^{*}The author wishes to record his gratitude to Dr. L. M. Pant for making available the X-ray data on *o*-nitrobenzoic acid.

The interesting feature here is that the deformation of the aromatic ring (Fig.IV) from the regular hexagonal geometry is very similar to, that seen in benzoic acid¹¹, as far as the bond lengths are considered.

We have seen in the last Chapter that even when the carboxyl is involved in a resonance interaction with a para substituent, such an interaction is not reflected in the chemical shifts of the aromatic protons. This is true so long as we are dealing with planar systems. In the case of *o*-nitrobenzoic acid, since the departure of the carboxyl group from coplanarity with the aromatic ring is small, it is conceivable that the observable effect on the C₆-proton can be negligible. This will depend on the variation of the effects of magnetic anisotropy of the COOMe group with rotation. The effect of the changes in resonance and of magnetic anisotropy may be such that the chemical shift is not substantially affected for small deviations from planarity. An interaction between the methyl and COOMe in (V) need not therefore show any observable effect. However, if one does take a case, in which the COOMe group is forced very much out of the aromatic plane, the effects of the methyl substitution in the para position should be demonstrable for a COOMe derivative in the same way as

for a nitro derivative.

In view of the nature of the carbomethoxy groups of dimethylphthalate, indicated by its NMR spectrum, which has already been discussed, it was considered that dimethyl 4-methylphthalate (VII) would be a suitable test case. This compound was prepared from isoprene which was condensed with maleic anhydride to give 4-methyl 1,2,3,6-tetrahydrophthalic anhydride. The tetrahydrophthalic anhydride was then dehydrogenated with bromine to get 4-methylphthalic anhydride, which was then esterified with methanol.



VII

The aromatic region of the NMR spectrum is shown in Fig.V. The C_6 -proton is at lower field compared to the C_3 -proton. The chemical shift difference between the two after correcting for the methyl substituent effect is 10.2 cps, as shown below.

$$\delta_{H_3}^{\text{Cor}} = \delta_{H_3}^{\text{Obs}} + S_{O, \text{Me}}^{\text{Me}} = 445 + 10.2 = 455.2 \text{ cps.}$$

$$\delta_{H_6}^{\text{Cor}} = \delta_{H_6}^{\text{Obs}} + S_{M, \text{Me}}^{\text{Me}} = 457 + 8.4 = 465.4 \text{ cps.}$$

$$\delta_{H_5}^{\text{Cor}} = \delta_{H_5}^{\text{Obs}} + S_{O, \text{Me}}^{\text{Me}} = 437 + 10.2 = 447.2 \text{ cps}$$

$$\delta_{H_3}^{\text{Cor}} - \delta_{H_6}^{\text{Cor}} = -10.2 \text{ cps.}$$

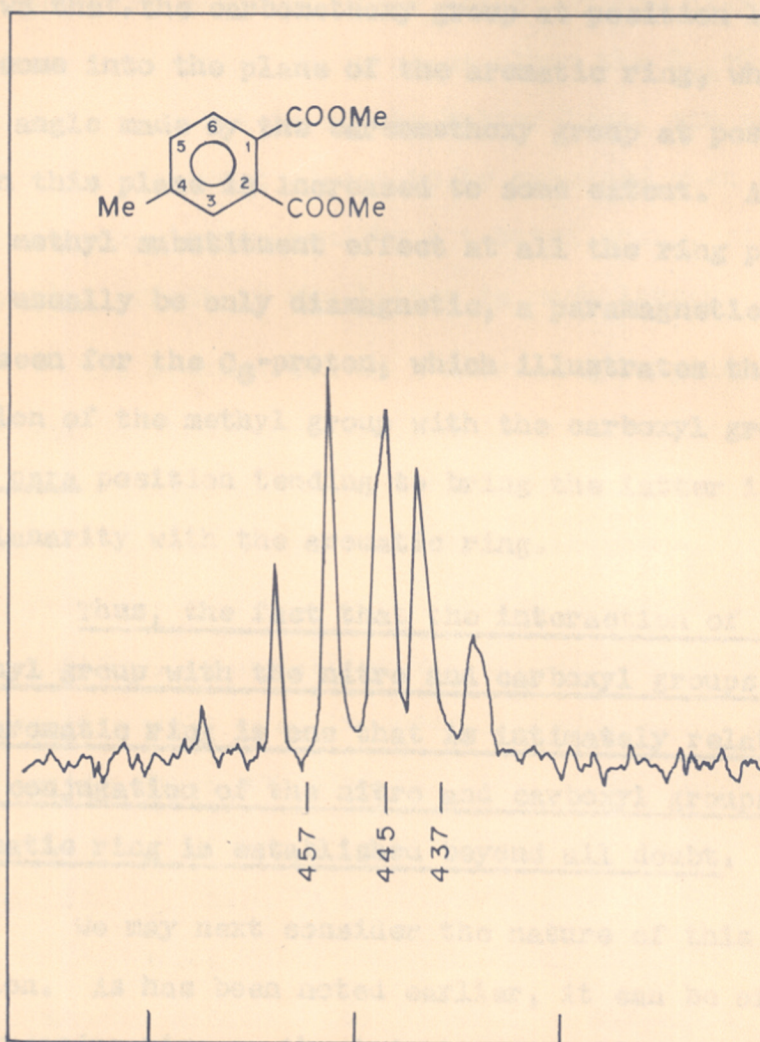
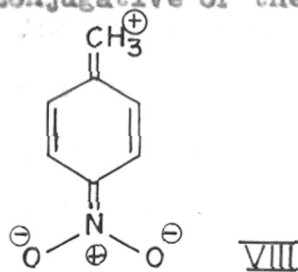


FIG. V. AROMATIC REGION OF THE NMR SPECTRA OF DIMETHYL 4-METHYLPHTHALATE

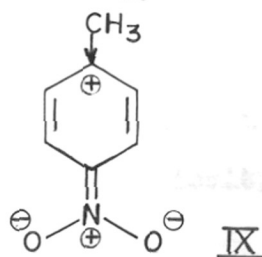
A comparison of these shifts with the chemical shifts for the corresponding protons of dimethylphthalate shows that, the carbomethoxy group at position 1 tends to come into the plane of the aromatic ring, whereas the angle made by the carbomethoxy group at position 2 with this plane is increased to some extent. Although the methyl substituent effect at all the ring positions can usually be only diamagnetic, a paramagnetic shift is seen for the C_6 -proton, which illustrates the interaction of the methyl group with the carboxyl group in the para position tending to bring the latter into coplanarity with the aromatic ring.

Thus, the fact that the interaction of the methyl group with the nitro and carboxyl groups across an aromatic ring is one that is intimately related to the conjugation of the nitro and carboxyl groups with the aromatic ring is established beyond all doubt.

We may next consider the nature of this interaction. As has been noted earlier, it can be of the hyperconjugative or the inducto-mesomeric type.



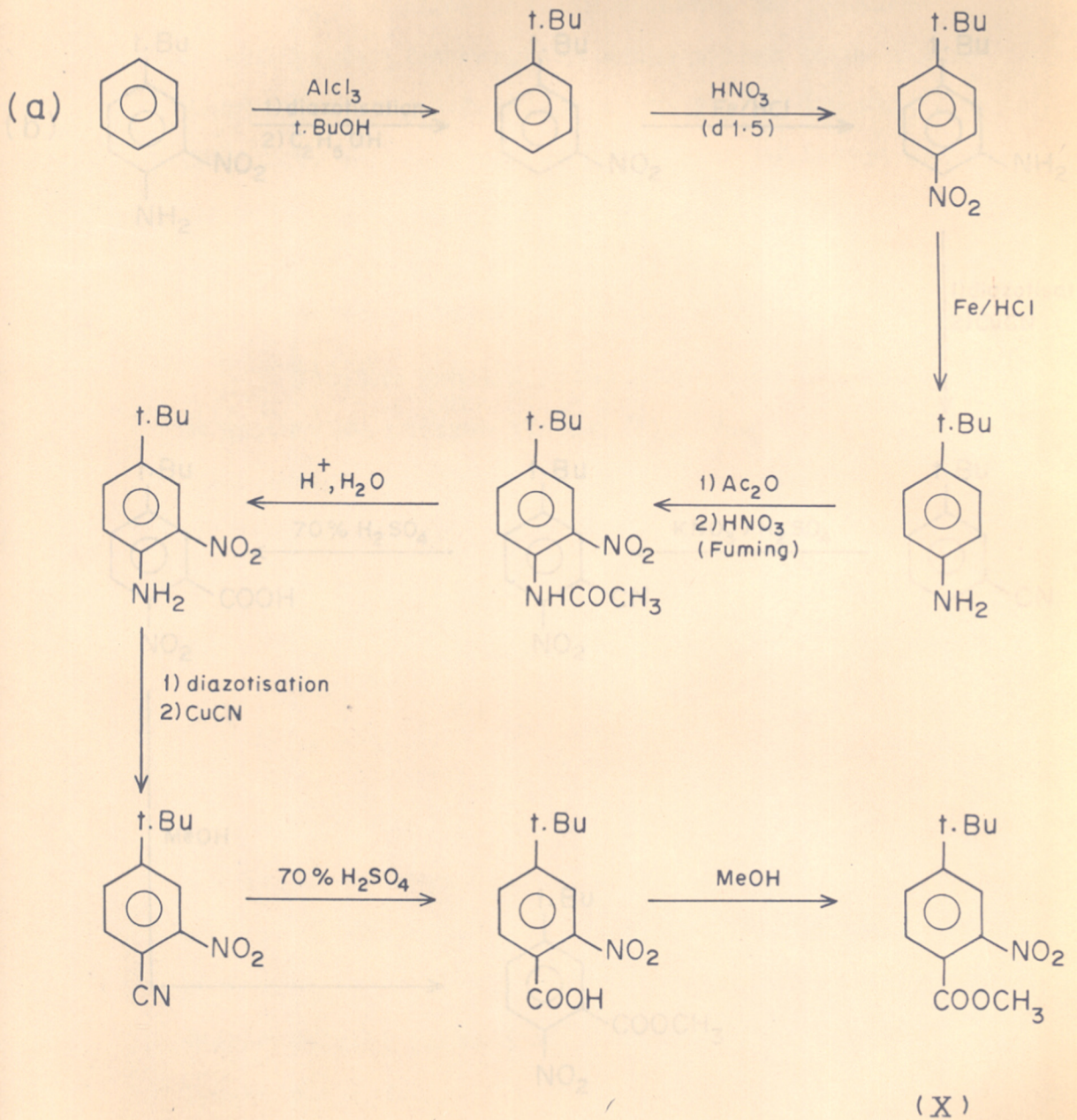
Hyperconjugative

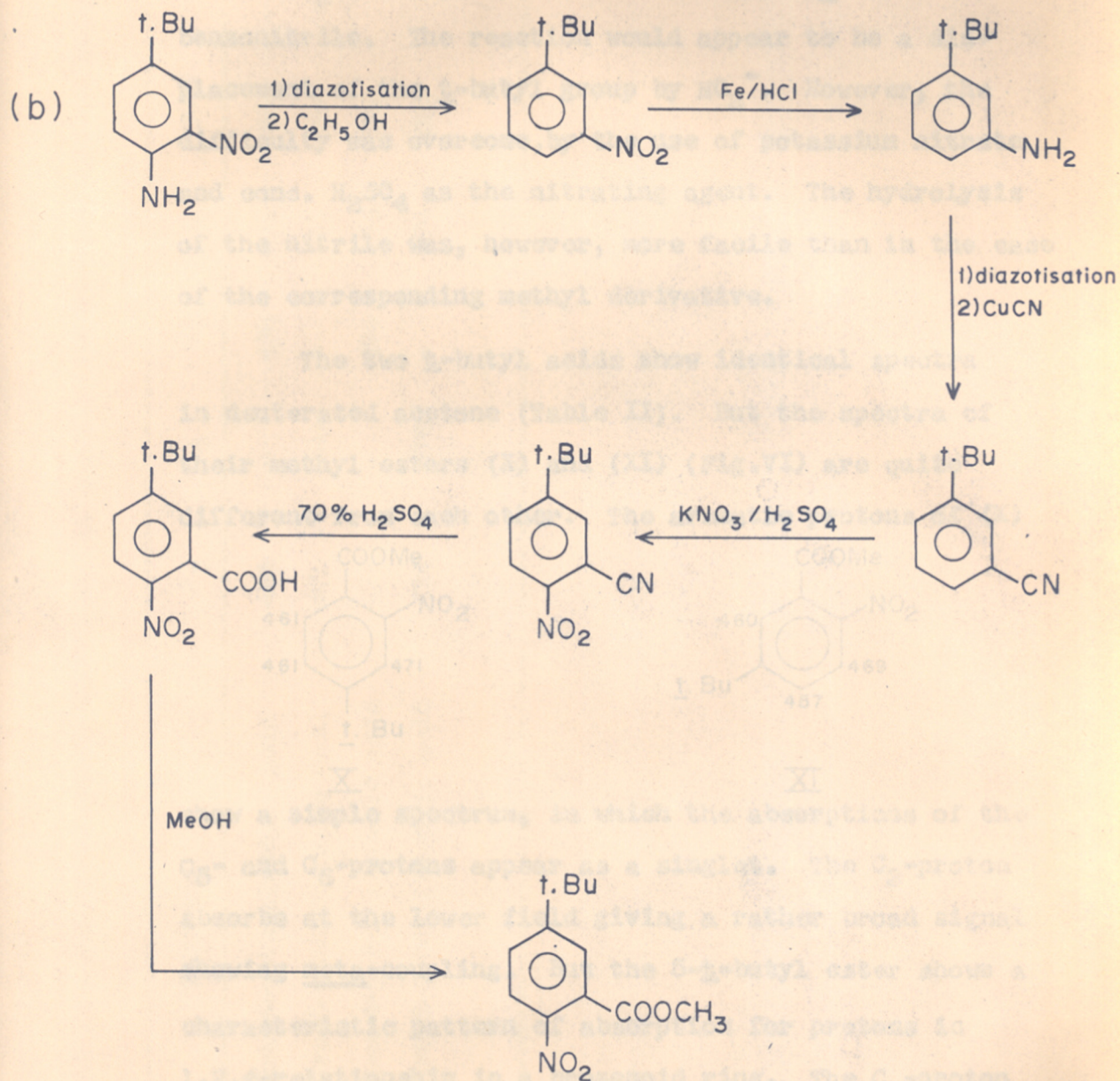


Inducto-mesomeric.

In the latter type of interaction, the resonance of the nitro group with the aromatic ring is enhanced by the inductive electron donor action by the alkyl group, which by definition takes place along the $C_{Me}-C_{Ar}$ bond. If the interaction is of the latter type, one should expect the observed effect to be enhanced when the methyl group is replaced by a *t*-butyl group, since the inductive effect of the latter is much larger.

The preparation of 2-nitro-4-*t*-butylbenzoic acid and 2-nitro-5-*t*-butylbenzoic acid, which are hitherto unknown, was undertaken according to the schemes shown in Charts II and III. *t*-Butylbenzene, which was prepared from benzene, was nitrated and reduced to 4-*t*-butylaniline. The aniline was transformed into 2-nitro-4-*t*-butylbenzoic acid in several steps, which were all similar to those employed for the corresponding methyl derivative. For the 5-*t*-butyl derivative, 2-nitro-4-*t*-butylaniline, which is an intermediate in the synthesis of the 4-*t*-butyl acid, was deaminated and the 3-nitro-*t*-butylbenzene obtained was reduced to the amino compound. The amine was converted to the nitro acid in three steps analogous to those employed in the case of the corresponding methyl derivative. But the nitration of *m-t*-butylbenzotrile was attended with some difficulty. With

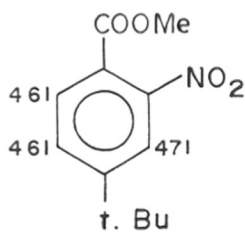




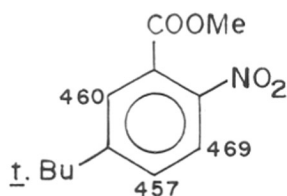
(XI)

conc. HNO_3 the major product obtained was m-nitro-benzonitrile. The reaction would appear to be a displacement of the t-butyl group by NO_2^- . However, the difficulty was overcome, by the use of potassium nitrate and conc. H_2SO_4 as the nitrating agent. The hydrolysis of the nitrile was, however, more facile than in the case of the corresponding methyl derivative.

The two t-butyl acids show identical spectra in deuterated acetone (Table II). But the spectra of their methyl esters (X) and (XI) (Fig.VI) are quite different from each other. The aromatic protons of (X)



X



XI

show a simple spectrum, in which the absorptions of the C_5 - and C_6 -protons appear as a singlet. The C_3 -proton absorbs at the lower field giving a rather broad signal showing meta-coupling. But the 5-t-butyl ester shows a characteristic pattern of absorption for protons in 1,2,4-relationship in a benzenoid ring. The C_3 -proton is slightly upfield compared to the C_3 -proton resonance of (X). On correcting for the substituent effects of the t-butyl group, as in the earlier cases, the C_3 -proton

TABLE II - PROTON CHEMICAL SHIFTS OF THE ACIDS CD_3COCD_3 (Ref. TMS INTERNAL)

No.	Compound	H ₃	H ₄	H ₅	H ₆	COOH	Me
1	2-Nitro-4-methylbenzoic acid	464	-	458	471	353	150
2	2-Nitro-5-methylbenzoic acid	471	459	-	460	359	149
3	2-Nitro-4-t-butylbenzoic acid	474	-	474	474	352	84
4	2-Nitro-5-t-butylbenzoic acid	474	474	-	474	328	84

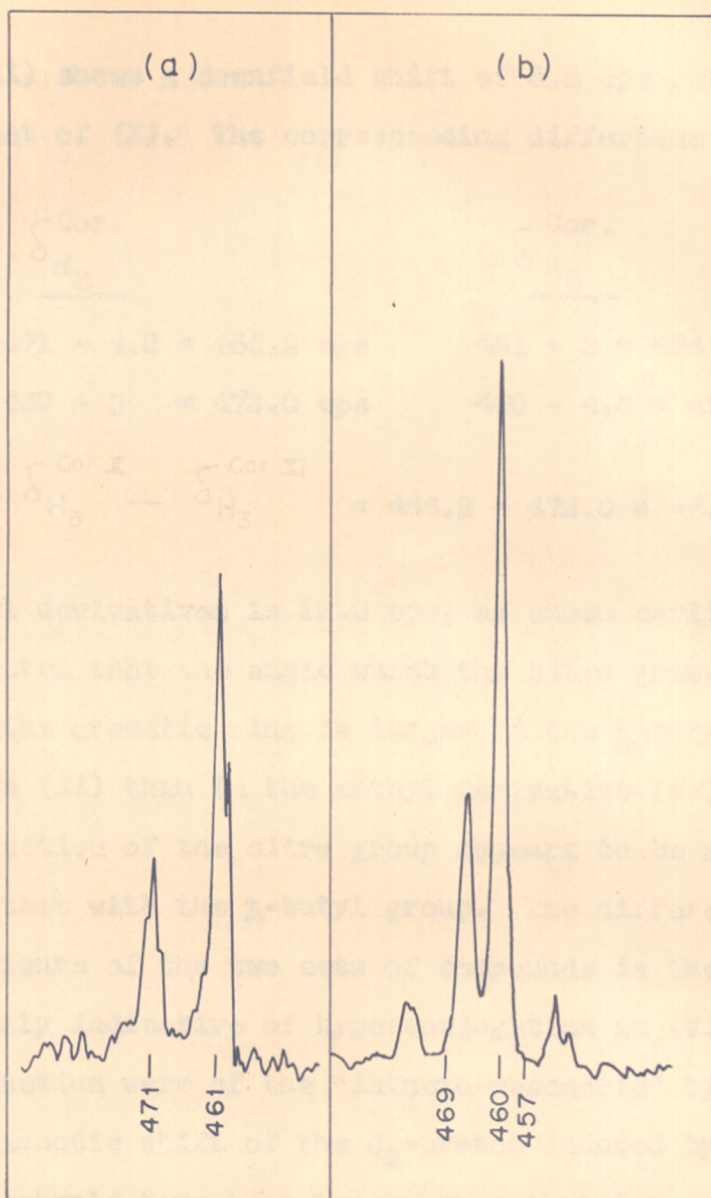


FIG. VI. AROMATIC REGION OF THE NMR SPECTRA OF : (a) Methyl 2-nitro-4-t-butylbenzoate and (b) Methyl 2-nitro-5-t-butylbenzoate.

of (XI) shows a downfield shift of 5.8 cps relative to that of (X). The corresponding difference for the

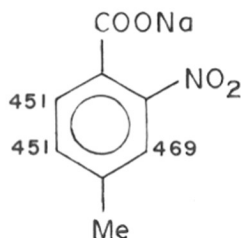
$$\begin{array}{r}
 \delta_{\text{H}_3}^{\text{Cor.}} \\
 \hline
 \text{X} \quad 471 - 4.8 = 466.2 \text{ cps} \\
 \text{XI} \quad 469 + 3 = 472.0 \text{ cps} \\
 \\
 \delta_{\text{H}_3}^{\text{Cor X}} - \delta_{\text{H}_3}^{\text{Cor XI}} = 466.2 - 472.0 = -5.8 \text{ cps.}
 \end{array}
 \qquad
 \begin{array}{r}
 \delta_{\text{H}_6}^{\text{Cor.}} \\
 \hline
 461 + 3 = 464 \text{ cps} \\
 460 - 4.8 = 455.2 \text{ cps}
 \end{array}$$

methyl derivatives is 12.2 cps, as shown earlier. This indicates that the angle which the nitro group makes with the aromatic ring is larger in the *t*-butyl derivative (XI) than in the methyl derivative (VI). The interaction of the nitro group appears to be stronger than that with the *t*-butyl group. The difference in the behaviours of the two sets of compounds is therefore strongly indicative of hyperconjugation in (VI). If the interaction were of the "inducto-mesomeric" type, the paramagnetic shift of the C₃-proton induced by the *t*-butyl group should have been larger than that induced by methyl substitution. What is found is, the reverse of this. Carbon-carbon hyperconjugation is apparently weaker than C-H hyperconjugation.

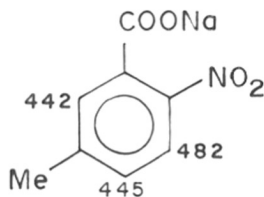
As in the case of the methyl derivatives a

diamagnetic shift is observed for the C_6 -proton of (XI) as compared with the corresponding proton of (X). We are not in a position to consider the C_6 -proton chemical shifts in detail, because the principal susceptibilities of the COOMe are not known. Moreover, crowding effects may have to be considered in (XI), since the conformation of the COOMe group may be only slightly different from that of the COOH group of *o*-nitrobenzoic acid.

A close look at the ring proton spectra of the sodium salts of the methyl- and *t*-butyl acids, supports these conclusions. These salts were prepared by neutralising the acids with just the required amount of pure sodium hydroxide solution and evaporating away the water. The aromatic regions of the spectra of the four salts are shown in Fig.VII and the chemical shift data in Table III. The spectra were taken in deuterium oxide with TMS as external reference. These data cannot be compared with those of the corresponding methyl esters, but a comparison among themselves support the earlier conclusions.



XII



XIII

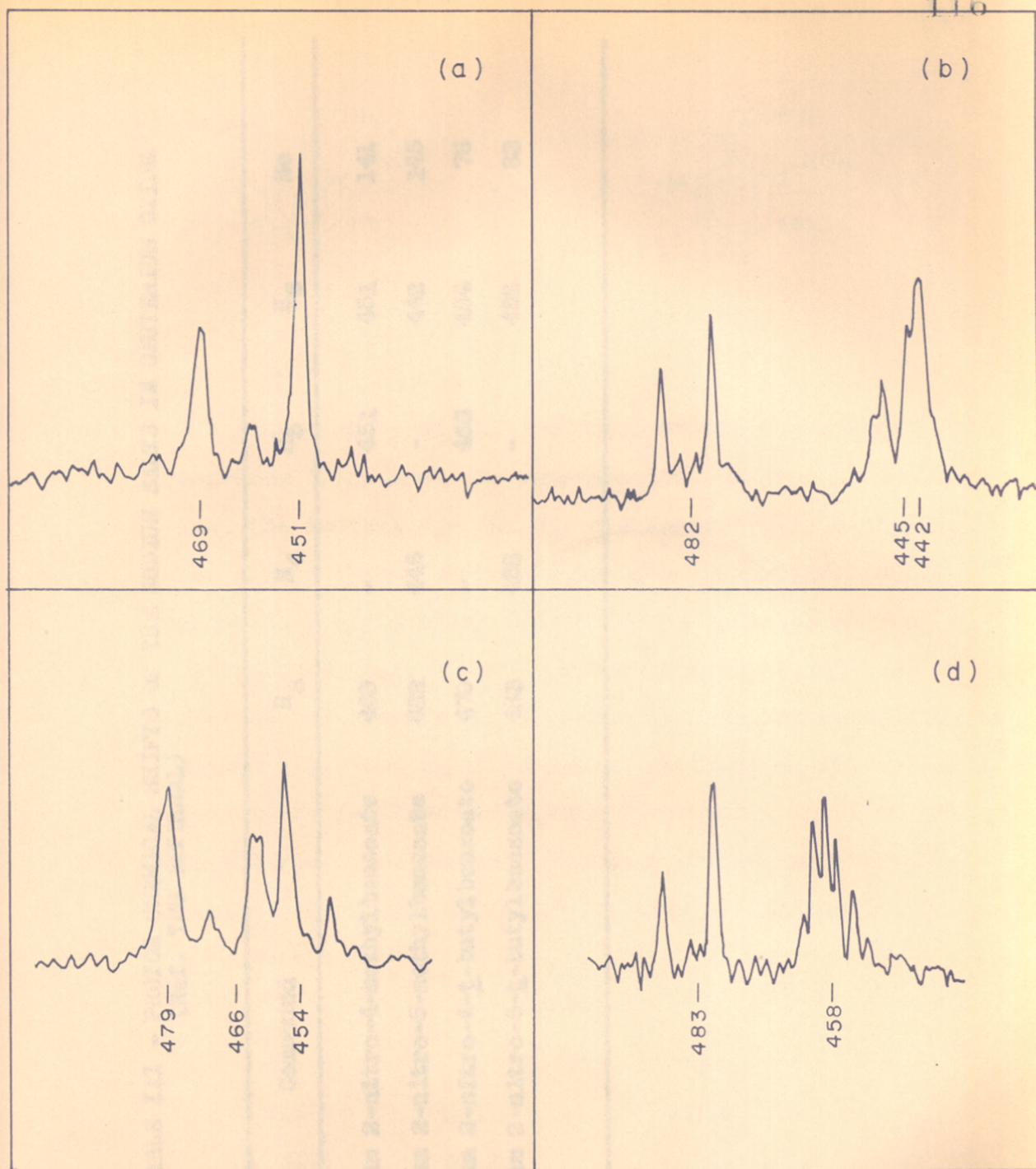
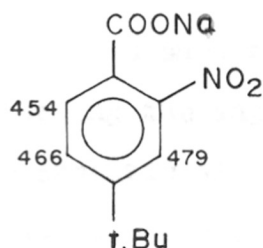
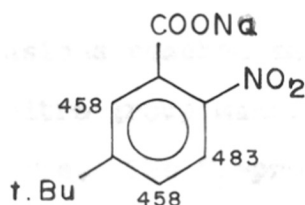


FIG. VII AROMATIC REGIONS OF THE NMR SPECTRA OF: (a) Sodium 2-nitro-4-methylbenzoate (b) Sodium 2-nitro-5-methylbenzoate (c) Sodium 2-nitro-4-*t*-butylbenzoate and sodium 2-nitro-5-*t*-butylbenzoate.

TABLE III - PROTON CHEMICAL SHIFTS OF THE SODIUM SALTS IN DEUTERIUM OXIDE
(Ref. TMS EXTERNAL)

No.	Compound	H ₃	H ₄	H ₅	H ₆	Me
1	Sodium 2-nitro-4-methylbenzoate	469	-	451	451	141
2	Sodium 2-nitro-5-methylbenzoate	482	445	-	442	145
3	Sodium 2-nitro-4- <u>t</u> -butylbenzoate	479	-	466	454	76
4	Sodium 2-nitro-5- <u>t</u> -butylbenzoate	483	458	-	458	83



XIVXV

The ring protons of (XII) shows, a simple two signal spectrum (Fig. VII a), one representing two protons showing that the protons C_5^- and C_6^- are magnetically equivalent. The change from a carbomethoxy to a carboxylate (COO^-), group has only a minor effect (4 cps upfield) on the C_6^- -proton signal. The C_3^- -proton absorbs at 469 cps, whereas the corresponding proton of m-nitrotoluene absorbs at 480 cps. But in the 5-methyl derivative, the molecule behaves as p-nitrotoluene, the C_3^- -proton absorption being at 482 cps. The observed chemical shifts and their values, after correction for the alkyl substituent effects are shown below:

	δ Corrected	
	<u>H_3</u>	<u>H_6</u>
XII	479.2	459.4
XIII	490.4	452.2
XIV	474.2	457.0
XV	486	453.2

The values show that the conclusions reached earlier regarding the angle which the nitro group makes with the aromatic plane are indeed true. The C₃-proton of (XIII) absorbs at lower field than its counterpart in (XII) and the same behaviour is seen in the pair XIV and XV. However, in these carboxylate salts there is practically no difference between the methyl and t-butyl derivatives, in so far as their effects on the conformation of the nitro group is concerned. The carboxylate (COO⁻) groups of these derivatives would be strongly solvated in water and its electrical interaction with the nitro group would be greatly reduced. This apparently reduces the height of barrier seen by the nitro group to such an extent that discrimination between the effects of substitution of the methyl and t-butyl groups in the para position is no longer possible. Even the interaction with the t-butyl group which is weaker of the two seems to be enough to bring the NO₂ group into the plane of the aromatic ring.

In conclusion it may be said that the evidence presented here for hyperconjugation seems to be truly unambiguous and is the first of its kind obtained so far. The technique of using sterically hindered systems has paid handsome dividends.

EXPERIMENTAL

All spectra were recorded on a Varian A-60 NMR Spectrometer (i.e. at 60 Mc). Details regarding scanning of the spectrum, calibration of the chart and other experimental details are as described in Chapter II of this Part. For all measurements in deuterium oxide, TMS was used as external reference and the chemical shifts (δ) are expressed in cps downfield from TMS. For all other solvents, TMS was used as internal reference.

Preparation and/or purification of the materials are as described below. All melting points and boiling points are uncorrected.

1. Methyl 2-nitro-4-methylbenzoate

p-Toluidine was converted to 4-acetaminotoluene by digesting with a mixture of acetic anhydride and glacial acetic acid (equal amounts). The product was isolated by the usual procedure¹². This was used without any further purification in the next stage.

4-Acetaminotoluene (170 g) was dissolved in glacial acetic acid (200 ml) in a 3-necked round bottomed flask, fitted with a mechanical stirrer, a thermometer and a dropping funnel. The mixture was stirred and

concentrated sulfuric acid (300 ml) was added slowly. The solution became hot and clear. After the addition was over, the mixture was cooled externally with a mixture of ice and salt. Fuming nitric acid (92 g, d, 1.5) was also cooled and added to the mixture at such a rate that the temperature did not rise above 20°. After the addition was over, the mixture was stirred for another hour and then poured on to crushed ice (1 kg) and water (1 litre) with stirring. Fine yellow crystals began to separate immediately, which were allowed to stand for an hour. It was then filtered, washed with cold water and dried. The crude 3-nitro-4-acetaminotoluene was recrystallised from alcohol as fine yellow needles. The yield of the product, which melted at 95-96° (lit. 96°), was 214 g (96-7%) and there was no indication of the formation of any polynitro compounds.

The 3-nitro-4-acetaminotoluene thus prepared was hydrolysed to the amine with conc. HCl, 38 g being used for every 15 g of the amide. The mixture was refluxed till it gave a clear solution with water. It was then cooled and poured on to crushed ice. The free amine was liberated from the hydrochloride with excess sodium hydroxide. The solution was kept overnight

in a frigidaire. The shining orange red crystals of 3-nitro-4-aminotoluene were separated by filtration. It was washed with a little cold water and dried. The filtrate was extracted with ether, as the amine is soluble in water to a certain extent. The material thus isolated was added to the main bulk. This was found to be pure enough for all practical purposes. A small amount was recrystallised from hot water, which came out as red leaflets melting at 116-17° (lit. 117°).

The amine was then converted to its nitrile. 3-Nitro-4-aminotoluene (51 g) was diazotised with hydrochloric acid (5N, 250 ml) and sodium nitrate (24 g). Cuprous cyanide solution¹³, prepared from copper sulfate (125 g) and potassium cyanide (35 g), was heated to 60° on a waterbath and the cold diazonium salt solution was added to it with good stirring, maintaining the temperature between 60-70°. The stirrer was replaced by a reflux condenser and the mixture heated on the boiling waterbath for 20-25 minutes in order to complete the reaction. The mixture was cooled and the solid nitrile was separated by filtration, washed with water and dried in air. It was then recrystallised from absolute alcohol. The

pure nitrile was obtained, as pale yellow needles melting at 100-101°, in a yield of 33 g (60%).

The above nitrile (25 g) was then hydrolysed¹⁴ with 70% sulfuric acid (200 g). The mixture was heated in an oil bath at 160-180° for four hours. It was then cooled and the acid crystallised was filtered. The filtrate was extracted with ether and the ether layer separated. The residue obtained on removal of the solvent was added to the main bulk. This crude acid was purified further by treating with sodium bicarbonate and the non-acidic impurities were removed by ether extraction. The acid was regenerated with dilute hydrochloric acid. The mixture was kept overnight in a frigidaire, and the acid was separated by filtration, washed with a little cold water and dried in a current of air. The yellow crystals of 2-nitro-4-methylbenzoic acid obtained were further purified by recrystallising from alcohol after treatment with a little animal charcoal. Fine pale yellow needle shaped crystals of the acid obtained was found to be quite pure from its NMR spectrum. The acid melted at 163° (lit. 164°). The yield (14.2 g, 50-55%) was low due to the formation of a large amount of tarry material during hydrolysis, probably because of the

high temperature employed (180°).

2-Nitro-4-methylbenzoic acid thus obtained was converted to its methyl ester in the usual way by refluxing with methanol and a little sulfuric acid as catalyst. The ester was obtained in almost quantitative yield as a yellow liquid, which distilled over at $146^{\circ}/3.5$ mm.

2. Methyl 2-nitro-5-methylbenzoate

m-Toluidine (53.5 g) was diazotised with sodium nitrite and hydrochloric acid and converted to the corresponding nitrile with cuprous cyanide by the same method employed for preparing 2-nitro-4-methyl benzonitrile described already. The nitrile was isolated by steam distillation as a colorless liquid. The yield of the pure nitrile, boiling at $63^{\circ}/2$ mm, was 40.2 g (70%).

m-Tolunitrile was then nitrated to get 2-nitro-5-methylbenzonitrile¹⁵. In a 3-necked round bottomed flask fitted with a mechanical stirrer, a dropping funnel and a thermometer, conc. H_2SO_4 (60 g) was taken. It was then cooled externally by an ice-salt mixture and m-tolunitrile (10 g), was added slowly with stirring and keeping the temperature at -5° . AR nitric acid (25 ml, d 1.42) was added to the nitrile solution at

such a rate that the temperature did not rise above 3° . The solution became viscous and dark red. After an hour a crystalline material began to separate. The mixture was then allowed to stand for an hour and poured on to crushed ice (500 g). The dark solid material formed was separated by filtering with suction and washed with water to remove any acid. A fair amount of tarry material was obtained, which was separated by treating with carbontetrachloride, in which it (the tarry material) was insoluble. The carbontetrachloride was distilled off and the residue obtained was further purified by recrystallising from alcohol, after treatment with a little animal charcoal. The nitrile, obtained as a fine yellow solid melting at 93° (lit. 93°), was quite pure, as shown by its NMR spectrum. The reported¹⁵ yield is only 29%, but by keeping the temperature strictly within the limits, during nitration, 5.6 g (40%) of the nitrile was obtained.

The above nitrile was hydrolysed to the acid with conc. HCl¹⁶. The nitrile (10 g) was taken with conc. HCl (50 g, d 1.16) in a sealed tube (Pyrex) and heated in an oil-bath for two hours at 150° . It was then cooled and the reaction mixture poured on to crushed ice. The solid separated was filtered and a

second crop was collected by keeping the filtrate overnight in a frigedaire. The pale yellow crystals of 2-nitro-5-methylbenzoic acid were separated by filtration, washed with a little cold water and dried in air. The acid obtained was found to be quite pure, melting at $132-33^{\circ}$ (lit. 134°).

A small amount of m-toluic acid (200 mg) was formed in this hydrolysis, which was separated easily, as it is insoluble in water, while the 2-nitro-5-methylbenzoic acid is fairly soluble in hot water. Alkaline as well as sulphuric acid hydrolysis gave mixtures, with m-toluic acid as the major component.

The above acid was converted to its methyl ester by refluxing with methanol and a little sulfuric acid. The ester was isolated as pale yellow needle shaped crystals, which melted at 78° (lit. $78-79^{\circ}$).

3. Sodium 2-nitro-4-methylbenzoate

2-Nitro-4-methylbenzoic acid (1 g) was neutralised with AR sodium hydroxide (0.221 g, N/10 solution was used) and the water removed by slow evaporation. The sodium salt was obtained as an yellowish brown micro-crystalline solid in quantitative yield.

4. Sodium-2-nitro-5-methylbenzoate

It was prepared exactly in the same manner as described above. The pure salt was obtained as an yellow micro-crystalline solid.

5. Methyl *o*-nitrobenzoate

o-Nitrotoluene was oxidised with alkaline potassium permanganate and the resulting acid isolated. This acid was converted to its methyl ester by refluxing with methanol and a little sulfuric acid as catalyst. The ester, an yellow liquid boiling at $157^{\circ}/3$ mm, was found to be quite pure.

6. Dimethylphthalate

Pure *o*-phthalic acid was esterified with methanol in the traditional way and the ester isolated. The pale yellow liquid obtained was further purified by distillation to get a colorless liquid. b.p. $161^{\circ}/3$ mm.

7. Methylsalicylate

Commercial methyl salicylate was purified by distillation and the fraction boiling between $81-82^{\circ}/2$ mm was used. It was found to be quite pure from its NMR spectrum.

8. Dimethyl 4-aminophthalate^{17,18}

Commercial phthalic acid was nitrated to get a

mixture of 3- and 4-nitrophthalic acids almost in equal amounts. The 3-nitro acid being very less soluble in water, was separated as far as possible by recrystallisation from water. Even after four recrystallisations, the product obtained was not pure, but the mixture contained mainly the 4-nitro acid. This was then esterified with methanol, which was saturated with hydrogen chloride. The 3-nitro acid present in the mixture forms the monomethyl ester, while the 4-nitro acid forms the dimethyl ester¹⁷. The monomethyl ester of 3-nitrophthalic acid was separated by treating with a strong solution of sodium carbonate. The dimethyl ester of 4-nitrophthalic acid was obtained as a heavy liquid, which was allowed to crystallise. The ester, obtained as pale yellow crystals, melted at 111-12°.

Dimethyl 4-nitrophthalate (30 g) was taken in a 3-necked round bottomed flask equipped with a mechanical stirrer and a dropping funnel. Zinc dust (20 g) and water (100 ml) were added to it and 50% acetic acid (150 g) was added slowly, while the mixture was kept stirred. The temperature was not allowed to rise above 25°. After the addition was over, the mixture was stirred for another hour. The amino ester was precipitated

by adding excess ammonia and the precipitate formed was separated by filtration. It was dissolved in ethylacetate and the zinc salts removed. The ethylacetate extract was treated with dil. H_2SO_4 (15%), whereby all the amino compound passed into the acid, leaving any unreacted nitro compound in the ethylacetate layer. The free amino ester was liberated with excess ammonia. On cooling the solution with crushed ice, dimethyl-4-amino-phthalate crystallised out and was separated by filtration. The colorless crystals were further purified by recrystallising from alcohol. The amino ester obtained, melted at 83° (lit. 84°). Yield: 19.2 g (73%).

9. Dimethyl 4-methylphthalate¹⁹⁻²¹

In a one litre round bottomed flask fitted with a reflux condenser was placed maleic anhydride (37.5 g), freshly distilled isoprene (25 g), picric acid (100 mg) and benzene (130 ml). The mixture was heated to start the reaction, which then proceeded with evolution of heat. When the initial reaction subsided, the mixture was heated under gentle reflux for 20 hours. The benzene and isoprene were then removed by distillation under reduced pressure. The residue was treated with pet. ether ($80-120^\circ$) and

enough benzene to dissolve the material. The solution was treated with a little charcoal and allowed to crystallise. The 4-methyl-1,2,3,6-tetrahydrophthalic anhydride (40 g), which separated as colorless needle shaped crystals, was quite pure and melted at 64° .

The above anhydride (19 g) was dissolved in glacial acetic acid (40 ml) and a solution of bromine (50 g) in glacial acetic acid (44 ml) was added to it slowly keeping the temperature of the mixture at 60° . The addition of bromine was completed in an hour. The first third of the bromine solution was decolorized immediately and some hydrogen bromide evolved. The mixture was then refluxed for 16 hours and the solution concentrated under reduced pressure. The residue was then heated at $210-220^{\circ}$ for 9 hours, during which time considerable amount of hydrogen bromide evolved and the material became dark. This residue was distilled under reduced pressure (20 mm). A colorless liquid was obtained, which crystallised immediately. The crude 4-methylphthalic anhydride was further purified by recrystallising from benzene-pet. ether mixture. The yield of the pure material melting at 93° was 12 g (68%).

was collected

The pure 4-methylphthalic anhydride (5 g) was refluxed with absolute methanol (50 ml) and a little sulfuric acid as catalyst, for one hour. The mixture was poured into cold water from where the dimethyl ester was separated by extraction with ether and the unreacted 4-methylphthalic acid was removed (0.27 g). The solvent was distilled off and the resulting oil distilled under reduced pressure. The dimethyl-4-methylphthalate came off at 121-22°/3.5 mm.

10. Methyl 2-nitro-4-t.butylbenzoate.

Thiophene free benzene was converted to t-butylbenzene²² in 65-70% yield by the Friedel-Crafts' alkylation method using anhydrous aluminium chloride and t-butyl alcohol. A small amount of p-diter.butylbenzene was formed, which was separated by fractional distillation. The pure t-butylbenzene, which distilled over at 163-64° was collected.

t-Butylbenzene was then converted to the 4-nitro-t-butylbenzene²³. Fuming nitric acid (216 g, d 1.5) was added drop by drop to mechanically stirred t-butylbenzene (217 g) at ordinary temperature. The mixture was stirred for one hour more after the addition was over and then poured in to an ice-water mixture. The yellow oil, which separated was collected

and washed with water several times to remove the excess nitric acid. Again it was washed with sodium carbonate solution followed by water. It was found that extraction with benzene is better, while working on a small scale. The yellow oil obtained was dried over anhydrous sodium sulfate and fractionated. Pure 4-nitro-t-butylbenzene distilled over at $88^{\circ}/2$ mm. Yield: 198 g (66-70%). There was a small amount of unreacted t-butylbenzene (43 g) which was separated during fractionation.

4-Nitro-t-butylbenzene was reduced to the corresponding amine with iron and hydrochloric acid²⁴. Iron powder (175 g), 4-nitro-t-butylbenzene (180 g) and water (200 ml) were taken in a three-necked round bottomed flask fitted with a mechanical stirrer, a reflux condenser and a dropping funnel. The mixture was heated on a water-bath at 100° , while conc. hydrochloric acid (120 ml) was added slowly and the mixture stirred vigorously. After the addition was over, the mixture was stirred for another two hours, while the temperature was maintained at 100° . The free amine was liberated from the hydrochloride with excess sodium hydroxide solution and separated by steam distillation. The unreacted nitro compound, being not steam-volatile,

remained in the flask. The free amine, which is slightly soluble in water was separated by extracting with ether. The ether solution was dried with potassium hydroxide and the solvent removed. The residue was distilled under reduced pressure and pure 4-amino-t-butylbenzene, which distilled over at $78-9^{\circ}/2$ mm as a colorless liquid was collected. Yield: 127 g (84%).

This amine was converted to its acetyl derivative by digesting with an acetic anhydride-acetic acid mixture. The product was isolated by pouring into crushed ice and separating the solid material. The 4-acetamino-t-butylbenzene was obtained in 95-96% yield, as a white crystalline solid, which melted at 168° (lit. $169-70^{\circ}$). It was used without further purification in the next stage.

4-Acetamino-t-butylbenzene (191 g, 1 mole) was dissolved in glacial acetic acid (200 ml) and conc. sulfuric acid (280 ml) added to it slowly with stirring. The solution became hot and clear. The mixture was then cooled externally by an ice-salt mixture to 5° and fuming nitric acid (54 ml, d 1.5) added slowly at such a rate that the temperature of the mixture did not rise above 15° . The addition took about 2 hours and

the mixture was stirred for another hour. It was then poured onto crushed ice and the mixture stirred. Fine yellow crystals of 3-nitro-4-acetamino-t-butylbenzene separated at once. The mixture was allowed to stand for an hour and the solid product separated by filtration. The solid was washed with cold water and dried in air. The yield of the product melting at 86° was 222 g (94%).

The 3-nitro-4-acetamino-t-butylbenzene (100 g) was hydrolysed with 70% sulfuric acid (750 ml) by refluxing for 2 hours. The solution was cooled and the free amine was isolated by treating with excess ammonia. The solution was kept overnight in a frigidaire and the solid material was separated by filtration. The amine was found to be slightly soluble in water and hence the filtrate was extracted with ether, and the dissolved amine recovered and added to the main bulk. It was found to be pure enough and used as such in the next stage. The yield of the product which melted at 79° was 65 g (82%).

This 3-nitro-4-amino-t-butylbenzene was used as the starting material for preparing both the required final products.

The 3-nitro-4-amino-t-butylbenzene was converted

to the corresponding nitrile by the same method used for preparing 2-nitro-4-methylbenzonitrile, described under methyl-2-nitro-4-methylbenzoate. The reaction went smoothly and the product was isolated by extracting with ether. The pure nitrile was obtained on distillation after removal of the ether, as a yellow liquid boiling at $127^{\circ}/2$ mm. Yield: 31.6 g (63%).

The above nitrile (5 g) was then hydrolysed to the carboxylic acid using sulfuric acid containing an equal volume of water (50 ml of the mixture). The mixture was heated at $160-180^{\circ}$ for four hours. The reaction mixture was cooled and the solid material formed was separated. Unlike in the hydrolysis of 2-nitro-4-methyl-benzonitrile, no tarry material was noticed in this hydrolysis. The acid obtained was further purified by treating with sodium bicarbonate and the non-acidic impurities were removed by extracting with ether. The free acid was regenerated with dilute hydrochloric acid and separated by filtration. The crude acid was further purified by decolourisation with charcoal and recrystallisation from alcohol. The acid was obtained as white crystals (m.p. $132-33^{\circ}$) in a yield of 4.7 g (83%). It was found to be quite pure from its

AMR spectrum.

The above acid was then converted to its methyl ester, in the usual way. The ester obtained was distilled under reduced pressure. The pure material distilled over at $127-28^{\circ}/2$ mm, as a yellow liquid.

11. Methyl 2-nitro-5-t-butylbenzoate

3-Nitro-4-amino-t-butylbenzene (100 g) was dissolved in 95% ethanol (250 ml). Conc. H_2SO_4 (100 g) was added to the solution, slowly with stirring. The amine was converted to its acid salt, which precipitated as orange red crystals, on cooling. The mixture was cooled externally by means of an ice-salt mixture to 0° , and a solution of sodium nitrite (36 g) in the minimum quantity of water was added drop by drop, so that the temperature did not rise above 5° , while the mixture was kept stirred mechanically. The mixture was stirred for another half an hour after the addition was completed and the reaction mixture heated over a water-bath, replacing the stirrer with a reflux condenser. The temperature was raised very cautiously, so that the reaction is under control. When the initial vigour of the reaction subsided, the temperature was raised to 100° and the mixture heated till there was no evolution of gas. The 3-nitro-t-butylbenzene

was converted to perchloric acid. The nitrile which

formed remained at the top as a separate layer. The alcohol was distilled off as far as possible. The residue was cooled and extracted with benzene. The benzene layer was washed several times with water, to remove the dark color and finally the product was obtained as a yellowish brown liquid, after removal of the solvent. It was further purified by fractionation. The pure 3-nitro-*t*-butylbenzene was obtained as a yellow oil, which distilled over at $112^{\circ}/2$ mm in a yield of 72 g (78-80%).

This nitro compound was reduced to the corresponding amine²⁴, with iron and hydrochloric acid by the same method employed for preparing 4-amino-*t*-butylbenzene described under methyl-2-nitro-4-*t*-butylbenzoate. The 3-amino-*t*-butylbenzene which is slightly soluble in water was separated by steam distillation. The distillate was extracted with ether and the free amine isolated. The amine obtained was quite pure, and it distilled over at $76-7^{\circ}/2$ mm as a colorless liquid. Yield: 65 g (85%).

The amino compound was converted to its nitrile, with cuprous cyanide by the same method described earlier. The product was isolated by steam distillation. Some amount of isocyanide also was formed, which was destroyed with hydrochloric acid. The nitrile which was

separated was further purified by distillation. The pure nitrile was obtained as a colorless liquid, which distilled over at 111-12^o/2 mm in a yield of 48 g (60%).

The 3-t-butylbenzonitrile was nitrated according to the following procedure²⁵.

Potassium nitrate (10 g, AR grade) was dissolved in conc. sulfuric acid (60 g) with vigorous stirring and efficient cooling. The nitrile (10 g) was dissolved in conc. sulfuric acid (60 g) at -5^o and the mixture was cooled further to -10^o. The cold potassium nitrate solution was added to the nitrile solution, at such a rate, that the temperature did not rise above 5^o, while the mixture was stirred mechanically. The reaction mixture which became dark red was stirred for another hour after the addition was over. It was then poured onto crushed ice (500 g), with stirring. After a few minutes a dark colored highly viscous mass was obtained. It was extracted with ether and the ether layer was washed first with sodium carbonate solution and then with water. The ether extract was dried with anhydrous sodium sulfate. The solvent was distilled off to get a dark semisolid mass, which was found to be a mixture both by NMR and thin-layer chromatography. This dark material was

chromatographed on a silica gel column with chloroform whereby the dark polymeric materials were removed. It was rechromatographed on a silica gel column and eluted with carbon tetrachloride. The impurities came out. The pure nitrile was obtained on eluting with chloroform. The pale yellow crystalline material obtained was found to be cent percent pure from TLC as well as NMR spectrum. The yield of the material which melted at 47° was 3.8 g (32% only).

As in the case of *m*-tolunitrile, the nitration was tried with conc. nitric acid. But the major product obtained was *m*-nitrobenzonitrile along with small amounts of other materials, which were not identified.

The 2-nitro-5-*t*-butylbenzonitrile (2 g) was then hydrolysed with 70% sulfuric acid (20 ml). The mixture was heated at $160-180^{\circ}$ for 3 to 4 hours. After cooling, the solid product was separated and the filtrate extracted with ether to recover the dissolved organic acid. The ether was distilled off and the residue (230 mg) was added to the main bulk. The acid was further purified by treating with sodium bicarbonate solution and the non-acidic impurities removed by ether extraction. The acid was regenerated by adding dilute hydrochloric acid, and isolated by ether extraction.

The ether solution was dried over anhydrous sodium sulfate and the solvent removed. The dark yellow acid obtained was further purified by recrystallising from alcohol, after treatment with a little charcoal. The pure acid was obtained as colorless needle shaped crystals, which melted at 128° . Yield: 1.85 g (81%).

Unlike in the case of the corresponding methyl derivative, the hydrolysis went smoothly and it was found that there is no need to use conc. HCl in sealed tube reaction, in which the likelihood of an explosion was quite appreciable.

The pure 2-nitro-5-t-butylbenzoic acid obtained was converted to its methyl ester. The ester was obtained as a pale yellow liquid which distilled over at $142^{\circ}/2$ mm in almost quantitative yield.

12. Sodium Salts

Sodium salts of the two t-butyl acids were prepared by neutralisation of the pure acid with sodium hydroxide solution and removal of the water by slow evaporation. Both the salts were obtained as snow white microcrystalline solids.

J. Org. Chem., 32, 3553 (1967).

J. Org. Chem., 32, 3553 (1967).

J. Org. Chem., 32, 3553 (1967).

REFERENCES

- 1 R.A. Hoffman and S. Gronowitz, Arkiv. Kemi **16**, 471 (1961) and references therein.
- 2 M.J.S. Dewar "Hyperconjugation" Ronald Press, 1962.
- 3 P.L. Corio and I. Weinberg, J. Chem. Phys. **31**, 569 (1959).
- 4 G.S. Reddy and J.H. Goldstein, J. Am. Chem. Soc. **83**, 2045 (1961).
- 5 C.A. Coulson "Molecular Orbitals in Physics, Chemistry and Biology" Ed. by P.O.Lewdin and B. Pullman, Acad. Press, 1964, p.12.
- 6 I. Yamaguchi, Mol. Phys. **6**, 105 (1963).
- 7 G.W. Smith, J. Mol. Spec. **12**, 146 (1964).
- 8 L.A. Bigelow, J. Am. Chem. Soc. **41**, 1559 (1919).
- 9 S.R. Swift and A. McGrookin, J. Soc. Chem. Ind.(Jap) **58**, 152 (1934).
- 10 T.D. Sakore, S.S. Tavale and L.M. Pant, Acta Crysta. (in Press).
- 11 G.A. Sim et al. Acta. Crysta. **8**, 157 (1955).
- 12 A.I. Vogel, "Practical Organic Chemistry" Longmans Green and Co. p.577.
- 13 A.I. Vogel, ibid. p.582.
- 14 St.Niementowsky and Br.Rozanski, Ber. **21**, 1993(1888).
- 15 P. Pfeiffer et al. Ber. **51**, 559 (1918).
- 16 W. Findelke, Ber. **38**, 3553 (1905).
- 17 M.T. Bogert and L. Boroschek, J. Am. Chem. Soc. **23**, 752 (1901).
- 18 M. Hayashi et al. J. Soc. Chem. Ind.(Jap) **44**, 436 (1941)

- 19 N. Rabjohn et al. J. Am. Chem. Soc. 78, 1633 (1956).
- 20 R.L. Frank et al. ibid. 69, 2313 (1947).
- 21 M.S. Newman et al. ibid. 63, 1542 (1941).
- 22 R.C. Huston et al. J. Org. Chem. 3, 251 (1938).
- 23 J.B. Shoesmith and A. Mackie, J. Chem. Soc. 2336 (1928).
- 24 D. Craig, J. Am. Chem. Soc. 57, 196 (1935).
- 25 W. Findelee, Ber. 3544 (1905).
- 26 R.W. Taft, "Steric Effects in Organic Chemistry"
Ed. M.S. Newman, p.594-97, John Wiley and Sons, 1956.

PART II

STABLE ACETOXY PHENYL
CARBONIUM SALTS

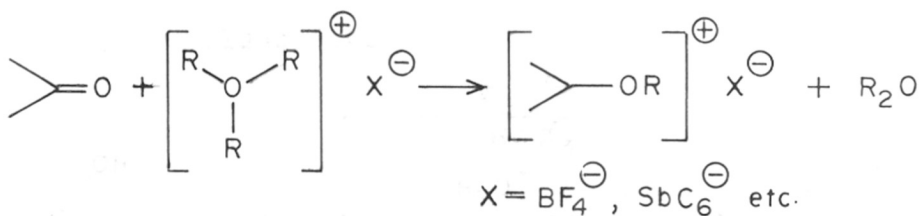
STABLE ACETOXY PHENYL CARBONIUM SALTS

Introduction:

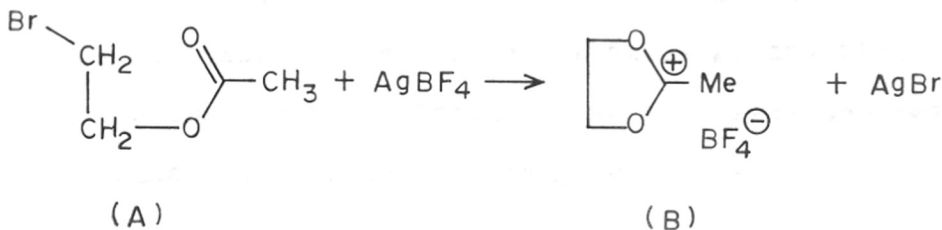
In connection with the separation of the inductive and mesomeric effects of substituent groups in benzene ring, it was considered that measurements of barriers to internal rotation would give valuable information. It appeared that oxy-carbonium salts that can conceivably be obtained from a series of para-substituted benzaldehydes, would furnish a suitable system, for which the temperature range for experimental measurements would be more convenient and accessible, than in the case of aldehydes¹ themselves. By dissolution of these aldehydes in reagents like conc. H_2SO_4 we can, of course, obtain the corresponding hydroxy carbonium ions. But these could not be expected to permit the observation of molecular properties unhampered by interactions with the solvent. The information available now on oxy-carbonium ions^{2,3} is not as much as might be desired. The available literature on the subject is briefly surveyed below.

Hydroxy carbonium ions resulting from the protonation of ketones, have been known for a long time⁴. A few years ago Meerwein and his coworkers⁵⁻⁷ prepared

a large number of dialkoxy and trialkoxy carbonium salts by several methods. Carbonyl compounds, like esters, were alkylated with trialkyl oxonium salts or with alkyl bromides and silverfluoborate. The reactions are represented below:



In the second reaction the halide grouping can be internal. For example, with (A), the dioxolenium system (B) was obtained.

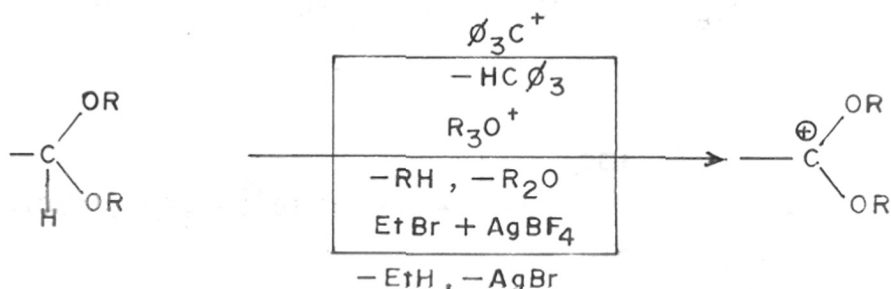


In (A), if bromine is replaced by F, treatment with BF_3 gives the carbonium salt. If the chloride was taken instead, treatment with SbCl_5 gave the carbonium

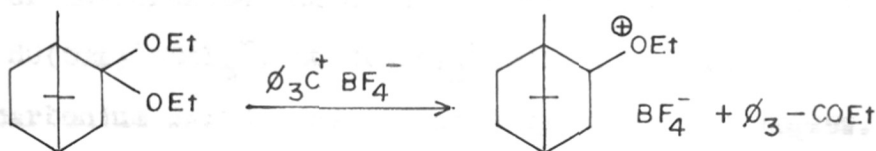
salt, as the hexachloro antimonate.

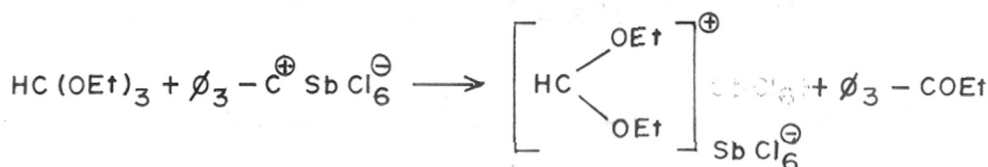
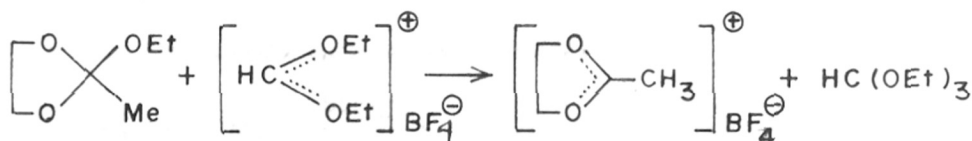
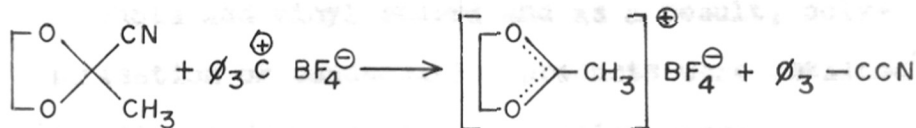
Another technique employed was abstraction of hydride from acetals to give dioxycarbonium salts⁷.

The hydride abstracting agents were triphenyl carbonium ion, triethyloxonium ion or a mixture of ethyl bromide and silverfluoborate.



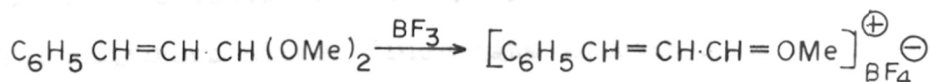
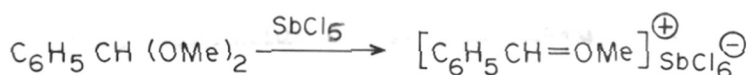
Alkoxide abstraction and cyanide abstraction were two other reactions that gave useful results. The reagents used for the purpose were triphenyl carbonium fluoborate and 1,3-dioxolenium fluoborate. The substrates tried included acetals, ortho-esters, ortho-carbonates and amide acetals, in the case of alkoxide abstraction. Cyanide abstraction experiments were on 2-cyano-2-methyl dioxolane. Some examples are given below:



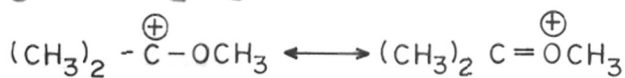


Alkoxide transfer is reversible and usually more rapid than hydroxide transfer. Reagents like $\text{BF}_3 \cdot \text{Et}_2\text{O}$, SbCl_5 have also been used to cleave off OR groups. Thus on addition of $\text{BF}_3 \cdot \text{Et}_2\text{O}$ to ortho-formates and ortho-carbonates in methylene chloride at low temperatures, salts like $\text{HC}(\text{OEt})_2^+ \text{BF}_4^-$, $\text{MeC}(\text{OEt})_2^+ \text{BF}_4^-$ were produced. Similarly antimony pentachloride reacts with ortho-formates and ortho-carbonates to give salts like $\text{HC}(\text{OEt})^+ \text{SbCl}_6^-$, $\text{EtC}(\text{OEt})_2^+ \text{SbCl}_6^-$. A number of oxy-carbonium salts were prepared by these techniques. The formation of carbonium salts from acetals by treatment with BF_3 or SbCl_5 was found to proceed through

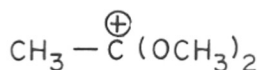
side reactions, resulting in the formation of alcohols and vinyl ethers and as a result, polymerisation or condensation products were obtained⁸. But it was found that the reaction proceeds through the formation of tertiary oxonium salts in some cases, a few of which are shown below:



Taft and Ramsey⁹ found that alkoxy carbonium ions, in general, can be produced by addition of ketals to 25% SO_3 - 75% H_2SO_4 .

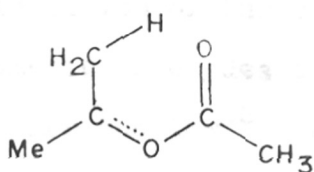


Dialkoxycarbonium ions were found to be formed when ortho-esters were added to 96% sulfuric acid and the carbonium ions were characterised by their NMR spectra.

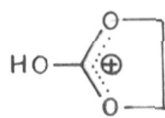
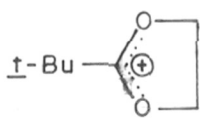
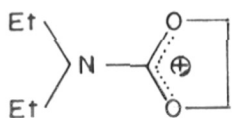


On the other hand, ortho-carbonates in 96% sulfuric acid produced trialkoxy carbonium ions like $(\text{MeO})_3\text{C}^+$.

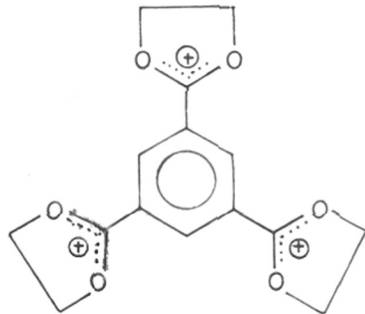
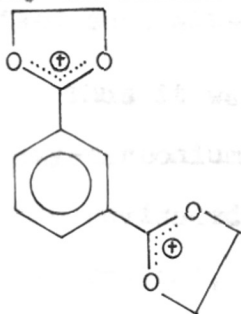
α -Acetoxy isopropyl cation has been observed as one of the species present in the solution of isopropenyl acetate in sulfuric acid¹⁰.



Recently Hart and Tomalia^{11,12} reported a series of alkoxy carbonium ions, generated by treating equimolecular amounts of the appropriate 2-bromo ethyl esters with anhydrous silver fluoborate in methylene chloride, in yields ranging from 50 - 80%, along with three cyclic



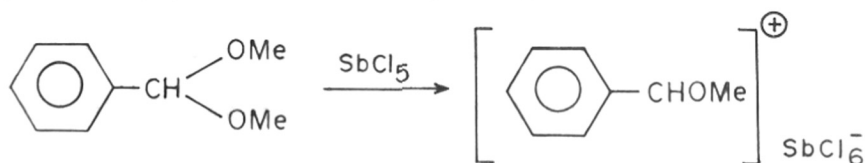
alkoxy carbonium ions.



The NMR spectra of a number of these carbonium ions were recorded and their spectral characteristics studied¹¹⁻¹³.

Salts of only the more highly conjugated members of the aromatic aldehyde series appear to be stable

enough to allow isolation of the salts, because the basicities of aromatic aldehydes that are not extensively conjugated are too low¹³. Although Meerwein has mentioned⁸ the formation of mono-oxyphenyl carbonium salts, experimental details have not been described. Benzaldehyde dimethyl acetal on treatment with SbCl_5 seems to have formed the mono methoxy salt to the extent of 73% but, unlike the other salts reported, this one, doesn't appear to have been isolated.



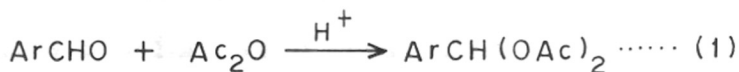
As indicated by Meerwein⁸, the salt might have polymerised soon after its formation.

Thus it was seen that very little is known about the oxy-carbonium systems which were regarded as suitable for the envisaged barrier measurements by the NMR method. In this context, it was proposed to investigate the behaviour of para-substituted benzaldehydes in the well known acetylating medium, acetic anhydride-perchloric acid. It was thought that it might be possible to find conditions which would permit the isolation of α -acetoxybenzyl perchlorates.

RESULTS AND DISCUSSION

On addition of a small drop of anhydrous (72%) perchloric acid to *p*-iodobenzaldehyde in pure acetic anhydride, a violent reaction is noticed and the solution turns dark red. ~~The violence of the reaction may be due to the hydrolysis of acetic anhydride with the water from the perchloric acid.~~ Even though the deep color of the solution suggests the formation of some carbonium ions, the NMR spectrum showed only the presence of the diacetate of the aldehyde, which is colorless. The vigour of the reaction and the color of the solution were traced to the acid catalysed self condensation of acetic anhydride and perchloric acid, which were warmed together. The reaction was very vigorous and the resulting solution had the same red color as before.

The conversion of the aromatic aldehyde into the corresponding benzylidene diacetate was found to require only catalytic amounts of perchloric acid. The stability of the diacetate itself in presence of acid was not



expected to be high. It was therefore considered that a useful experiment to try, would be to mix equimolecular proportions of the aldehyde and perchloric acid in acetic

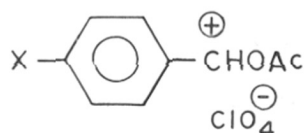
anhydride and remove the solvent from the mixture by suction. It was thought that the equilibrium (2) might be existing in the solution and that if the volatile products are removed, the carbonium salt might be left behind. A practically colorless solution of



the diacetate was obtained when pre-cooled solutions of equimolecular amounts of the aldehyde (or diacetate) and perchloric acid in acetic anhydride were mixed. When the solvent was removed from this solution by suction at room temperature, the solution turned pale yellow, then pink and finally dark red. After 2-3 hrs pumping most of the solvent got out, leaving behind a dark red solid. In order to remove any residual solvent it was pumped for 12-14 hours, at the end of which time, a fine dark crystalline solid was obtained. Similar results were obtained for a number of substituted benzaldehydes. In all cases except with benzaldehyde, anisaldehyde (p-) and p-dimethylaminobenzaldehyde, the solids obtained were crystalline. With benzaldehyde, the product obtained was a dark viscous semisolid mass, part of which could eventually be shown to be the carbonium salt, while p-dimethylaminobenzaldehyde gave a hard amorphous mass, with a greenish tinge. On the other hand,

anisaldehyde (*p*-) polymerised immediately, on addition of perchloric acid.

The elemental analysis and acetyl values* for the solid materials obtained, indicated that they are α -acetoxybenzyl perchlorates. The analysis data are



I

(X=H, Cl, Br etc.)

given in Table I along with the expected values for the carbonium salts, while the calculated values for the pure aldehydes and the diacetates are given in Table II for comparison.

It is clear that the observed values do not come anywhere near those expected for the aldehydes or the diacetates. The acetyl values show that there is only one acetyl group per phenyl group, in these products. The carbon, hydrogen and halogen values are in agreement with the formula $(X-C_6H_4-CHOAc)ClO_4^-$ for these salts (X representing the para-halogen). The hydrogen values are invariably higher than expected, while carbon values

*The author wishes to record his gratitude to Dr. V. S. Pansare and his colleagues for the micro-analysis work.

TABLE I - OBSERVED AND CALCULATED VALUES FOR THE CARBONIUM SALTS.

No.	p-Substituent	Observed value	Calculated value
1	Chloro-	C = 38.86%	38.1%
		H = 3.67%	2.82%
		COCH ₃ = 15.54%	15.1%
2	Bromo-	C = 29.47%	32.6%
		H = 3.54%	2.43%
		COCH ₃ = 12.2%	13.1%
3	Iodo-	C = 27.46%	28.8%
		H = 3.46%	2.134%
		COCH ₃ = 12.8%	11.46%
		(Cl + I) = 40.42	43.5%

TABLE II - CALCULATED VALUES FOR THE ALDEHYDES
AND DIACETATES.

No.	p-Substituent	Aldehyde	Diacetate
1	Chloro-	C = 58.9% H = 3.8% COCH ₃ = -	54.3% 4.5% 35.4%
2	Bromo-	C = 45.4% H = 2.7% COCH ₃ = -	46.0% 3.8% 30.0%
3	Iodo-	C = 36.2% H = 2.15% COCH ₃ = - I = 54.7%	39.52% 3.29% 25.74% 38.02%

are low. This can be partly due to the fact that the salts might have absorbed a little moisture during the weighing and transferring operations for analysis, and partly due to the presence of a small amount of the condensation product of acetic anhydride with perchloric acid. But the results for the *p*-chloro-case seem to be fairly good, the deviations of the observed values from the theoretical values being minimum. There is only 2% error in the carbon value, while that for the acetyl is only 2.9%. The possibility of a large error due to the presence of the condensation product is ruled out by the fact that there was no development of color during the mixing of the solutions and that the chances of the condensation reactions taking place at the low temperature employed are not serious. The absence of these products was later established, with the help of NMR spectrum. The elemental analysis results, although, they are not satisfactory from the point of view of purity, are more than adequate as far as the identities of the products are concerned.

When mixing of the solutions was done without cooling, the reaction that set in was often very vigorous. Removal of the solvent from such solutions usually gave impure products. Apart from the condensation reaction

of acetic anhydride, the aldehyde itself appeared to be involved in a polymerisation reaction. When more than 10% of the required amount of perchloric acid was used, the trouble on account of polymerisation reaction was serious and it was difficult to get a pure salt. In such cases it was, moreover, very difficult to get the excess solvent removed, even with prolonged pumping. The diacetates formed in acetic anhydride solutions could be recovered after treating these solutions with water.

The solid products obtained, which appeared to be carbonium perchlorates, were highly hygroscopic and, on decomposing with water, gave the corresponding aldehydes. Even exposure to air for a short while, decomposes the salt to the aldehyde, perchloric acid and acetic acid. But the pure salts could be stored in a dry atmosphere, for periods varying from a few to several days, the stability being dependent on the substituents present.

Reliable proof of the structure of these salts came from their NMR spectra. The presence of the lone acetyl group was shown by the sulfuric acid spectrum of the salt obtained. The spectra for two typical cases, namely, α -acetoxy-*p*-chlorobenzyl and α -acetoxy-*p*-xylyl perchlorates are shown in Figs. I and II respectively. From the relative signal intensities it can be seen, that

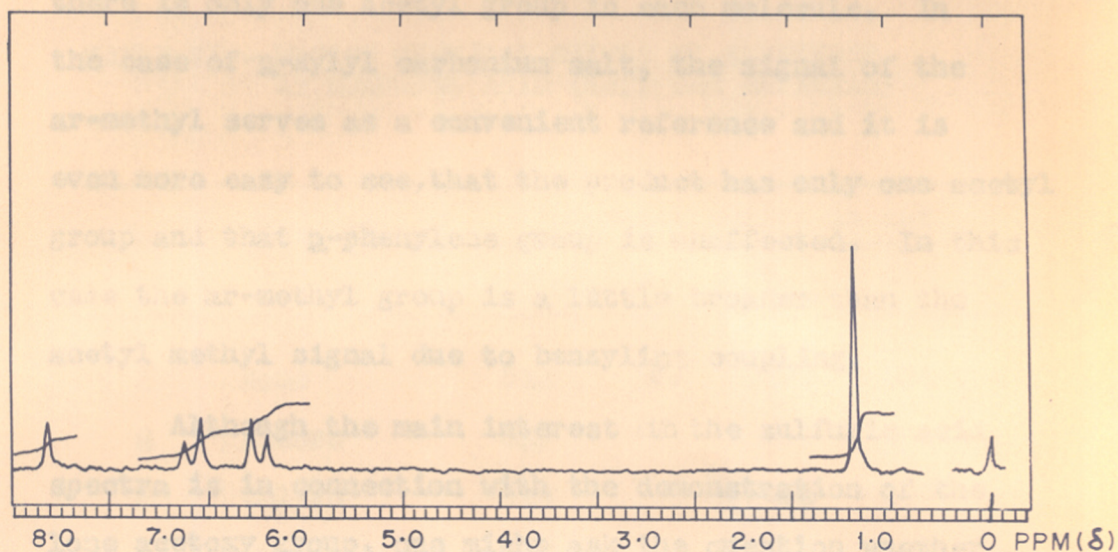


FIG. I. NMR SPECTRUM OF α -ACETOXY-*p*-CHLOROBENZYL PERCHLORATE
(IN H_2SO_4) (offset 100 cps)

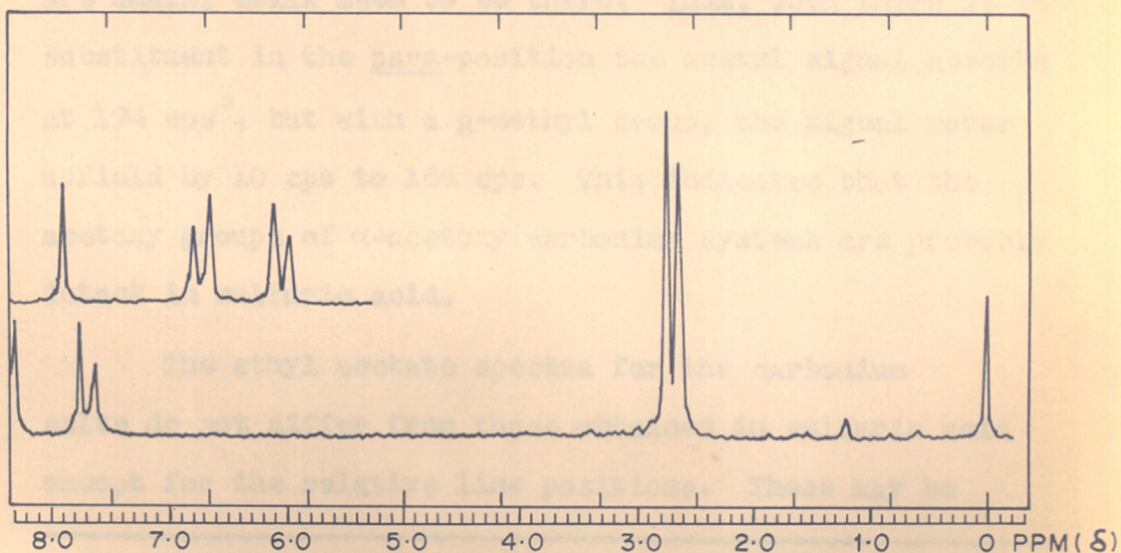


FIG. II. NMR SPECTRUM OF α -ACETOXY-*p*-XYLYL PERCHLORATE (IN H_2SO_4)

there is only one acetyl group in each molecule. In the case of *p*-xylyl carbonium salt, the signal of the *ar*-methyl serves as a convenient reference and it is even more easy to see, that the product has only one acetyl group and that *p*-phenylene group is unaffected. In this case the *ar*-methyl group is a little broader than the acetyl methyl signal due to benzylic coupling.

Although the main interest in the sulfuric acid spectra is in connection with the demonstration of the lone acetoxy group, one might ask the question whether the acetoxy group is not hydrolysed to acetic acid in the medium. The spectra of the aldehydes and the carbonium salts in sulfuric acid have been compared from this point of view (Tables VI and VII). Differences, eventhough they are small, still seem to be there. Thus, when there is no substituent in the *para*-position the acetyl signal absorbs at 174 cps*, but with a *p*-methyl group, the signal moves upfield by 10 cps to 164 cps. This indicates that the acetoxy groups of α -acetoxy carbonium systems are probably intact in sulfuric acid.

The ethyl acetate spectra for the carbonium salts do not differ from those obtained in sulfuric acid except for the relative line positions. These may be

*NMR spectra were taken on a Varian A-60 NMR spectrometer (60 Mc). Chemical shifts are expressed in cps downfield from TMS.

TABLE VI - PROTON CHEMICAL SHIFTS OF ALDEHYDES
IN SULFURIC ACID (Ref. TMS EXTERNAL)

No.	p-Substituent	Chemical shifts in cps			
		H _{2,6}	H ₄	H _{3,5}	CHO
1	None	512	502	476	586
2	Fluoro	519		459	582
3	Chloro	516		484	589
4	Bromo	507		492	589
5	Iodo	509		496	591
6	Methyl	500		461	572

TABLE VII - PROTON CHEMICAL SHIFTS OF CARBONIUM
SALTS IN SULFURIC ACID (Ref. TMS EXTERNAL)

No.	p-Substituent	Chemical shifts in cps				
		H _{2,6}	H ₄	H _{3,5}	H _α	OAc
1	None	516	509	482	588	174
2	Fluoro	521		461	582	172
3	Chloro	505		475	580	168
4	Bromo	500		487	582	170
5	Iodo	502		489	583	170
6	Methyl	499		461	572	164

(Me=157)

compared with the aldehyde spectra in the same solvent. The absorptions of the α -protons of these α -acetoxy carbonium systems appeared in the region 578-600 cps δ and those of the ring protons showed an A_2B_2 pattern typical of the phenylene group. The latter appeared at positions different from those of the corresponding aldehydes and diacetates. The spectral data for the ethylacetate solutions are given in Table IV. The corresponding data for the aldehydes and diacetates in ethylacetate and carbontetrachloride are given in Tables III and V respectively, for comparison. Two cases, on which we may make some observations, are those of α -acetoxybenzyl- and α -acetoxy-*p*-bromobenzyl perchlorates (Fig. IIIa and IVa). In the spectrum of the former, the para-proton absorption, which appears roughly as a triplet, is at lower field than the absorptions of the meta-protons. In the case of the aldehydes these come almost together in one group. The delocalization of some positive charge on the carbonium ion into the para-position is apparently the reason for the low field shift of the para-proton in the salt. Pure *p*-bromobenzaldehyde shows a single signal for the ring protons, while the diacetate shows an A_2B_2 pattern, with the separation between the A_2 and B_2 pairs being very small. But the ring proton of the carbonium salt shows, a clear

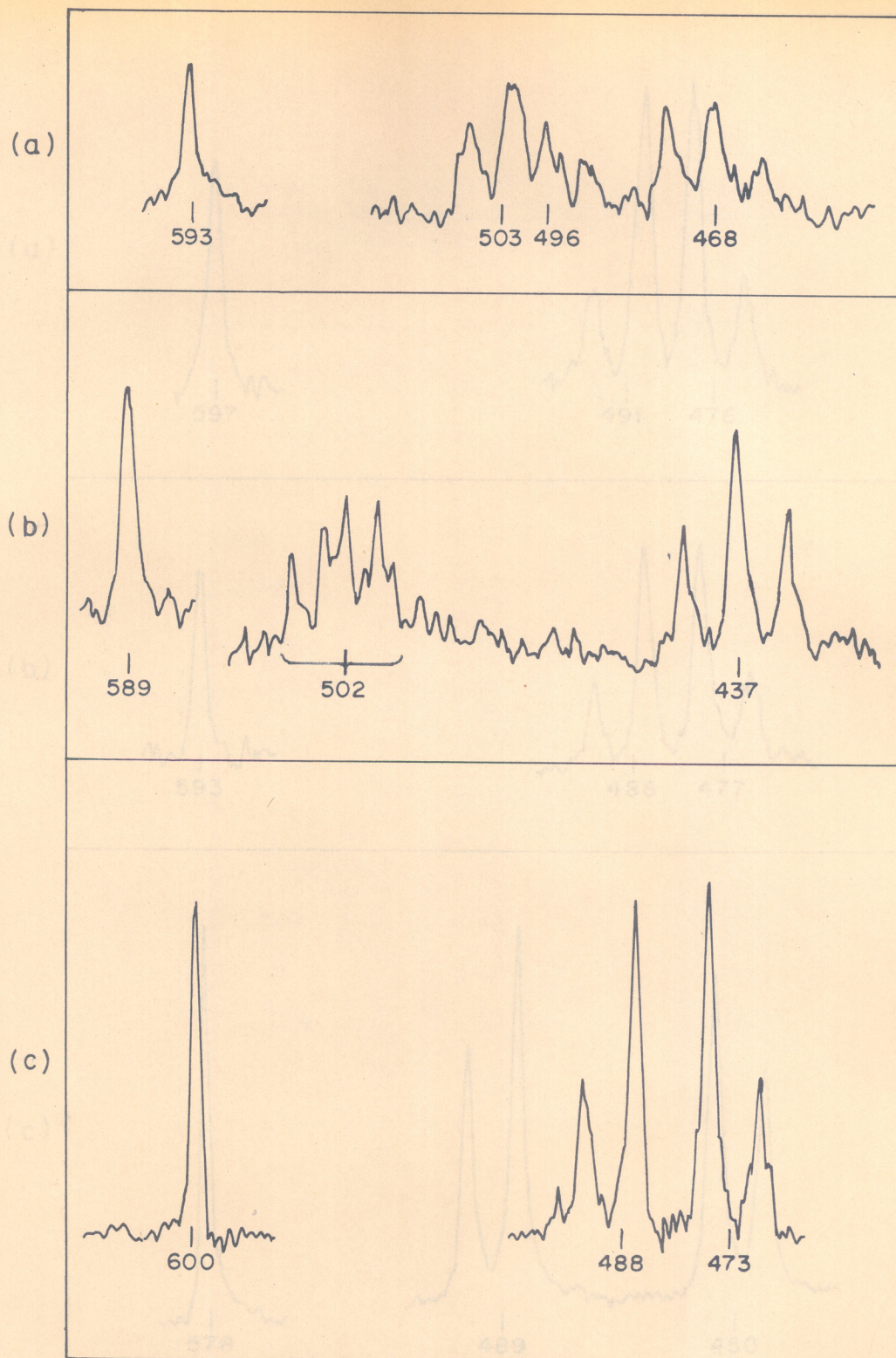


FIG. III. AROMATIC REGION OF THE NMR SPECTRA OF: (a) α -acetoxybenzyl perchlorate (b) α -acetoxy-p-fluorobenzyl perchlorate and (c) α -acetoxy-p-chlorobenzyl perchlorate.

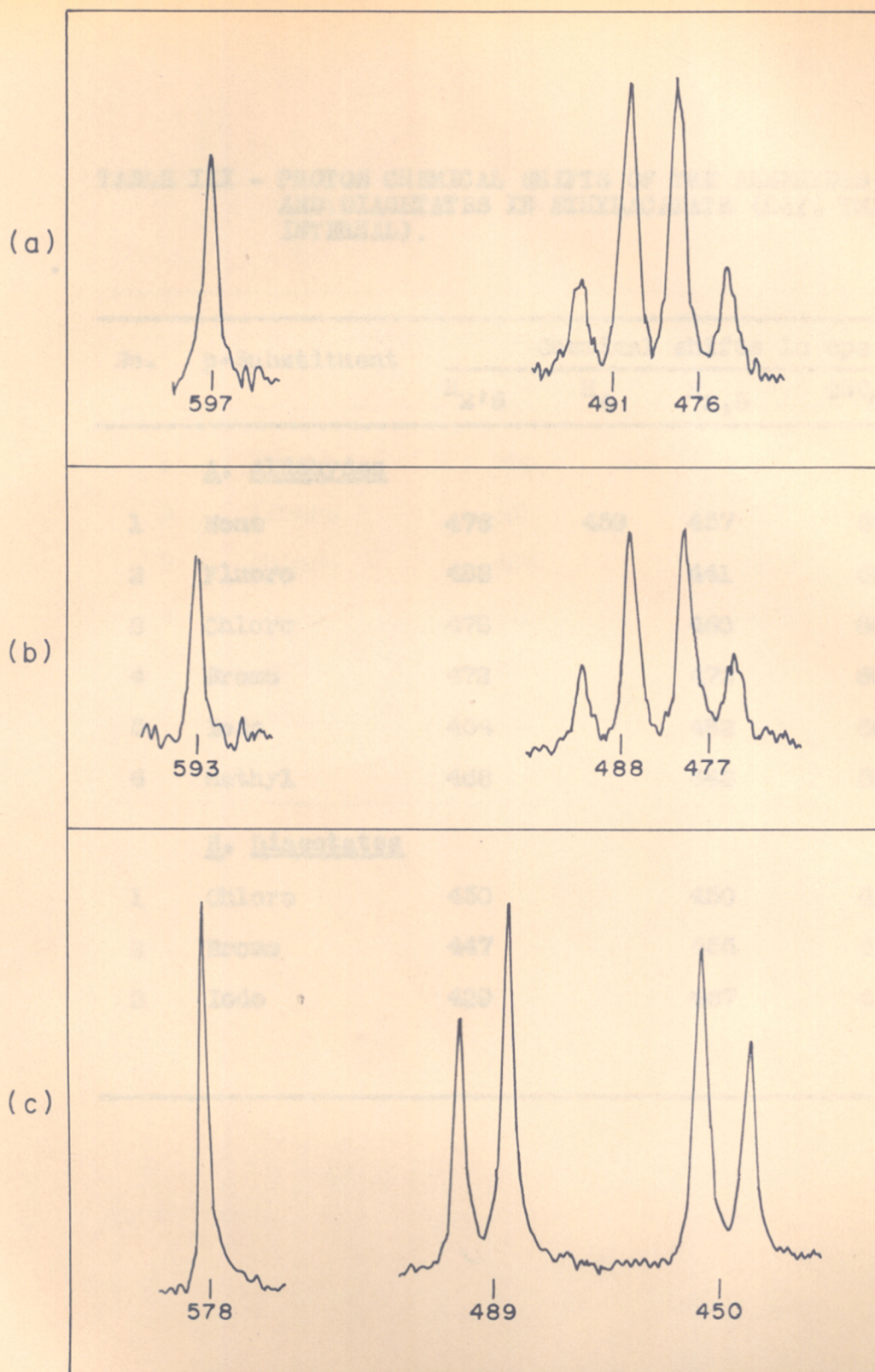


FIG. IV. AROMATIC REGION OF THE NMR SPECTRA OF: (a) α -acetoxy-*p*-bromobenzyl perchlorate (b) α -acetoxy-*p*-iodobenzyl perchlorate and (c) α -acetoxy-*p*-xylyl perchlorate.

TABLE III - PROTON CHEMICAL SHIFTS OF THE ALDEHYDES
AND DIACETATES IN ETHYLACETATE (Ref. TMS
INTERNAL).

No.	β -Substituent	Chemical shifts in cps			
		H _{2,6}	H ₄	H _{3,5}	CHO/H α
<u>A. Aldehydes</u>					
1	None	476	459	457	605
2	Fluoro	483		441	604
3	Chloro	478		460	605
4	Bromo	472		472	605
5	Iodo	464		482	603
6	Methyl	468		443	598
<u>B. Diacetates</u>					
1	Chloro	450		450	456
2	Bromo	447		455	455
3	Iodo	439		467	455

TABLE IV - PROTON CHEMICAL SHIFTS OF CARBONIUM
 SALTS IN EtOAc (Ref. TMS INTERNAL)

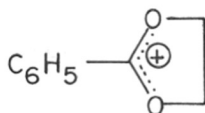
No.	p-Substituent	Chemical shifts in cps			
		H _{2,6}	H ₄	H _{3,5}	H _α
1	None	503	498	468	593
2	Fluoro	502		437	589
3	Chloro	488		473	600
4	Bromo	491		476	597
5	Iodo	488		477	593
6	Methyl	489		450	578

TABLE V - PROTON CHEMICAL SHIFTS OF THE ALDEHYDES AND DIACETATES
IN CCl_4 (Ref. TMS INTERNAL).

No.	p-Substituent	Chemical shifts in cps				
		H _{2,6}	H ₄	H _{3,5}	CHO/H _{α}	OAc Other groups
(a) Aldehydes						
1	None	471	454	452	602	-
2	Fluoro	474		434	597	-
3	Chloro	471		451	597	-
4	Bromo	462		462	598	-
5	Iodo	459		479	601	-
6	Methyl	461		435	595	142(Me)
7	Dimethylamino	459		400	582	185(NMe)
(b) Diacetates						
1	Chloro	444		444	451	124
2	Bromo	444		452	449	124
3	Iodo	432		460	446	124

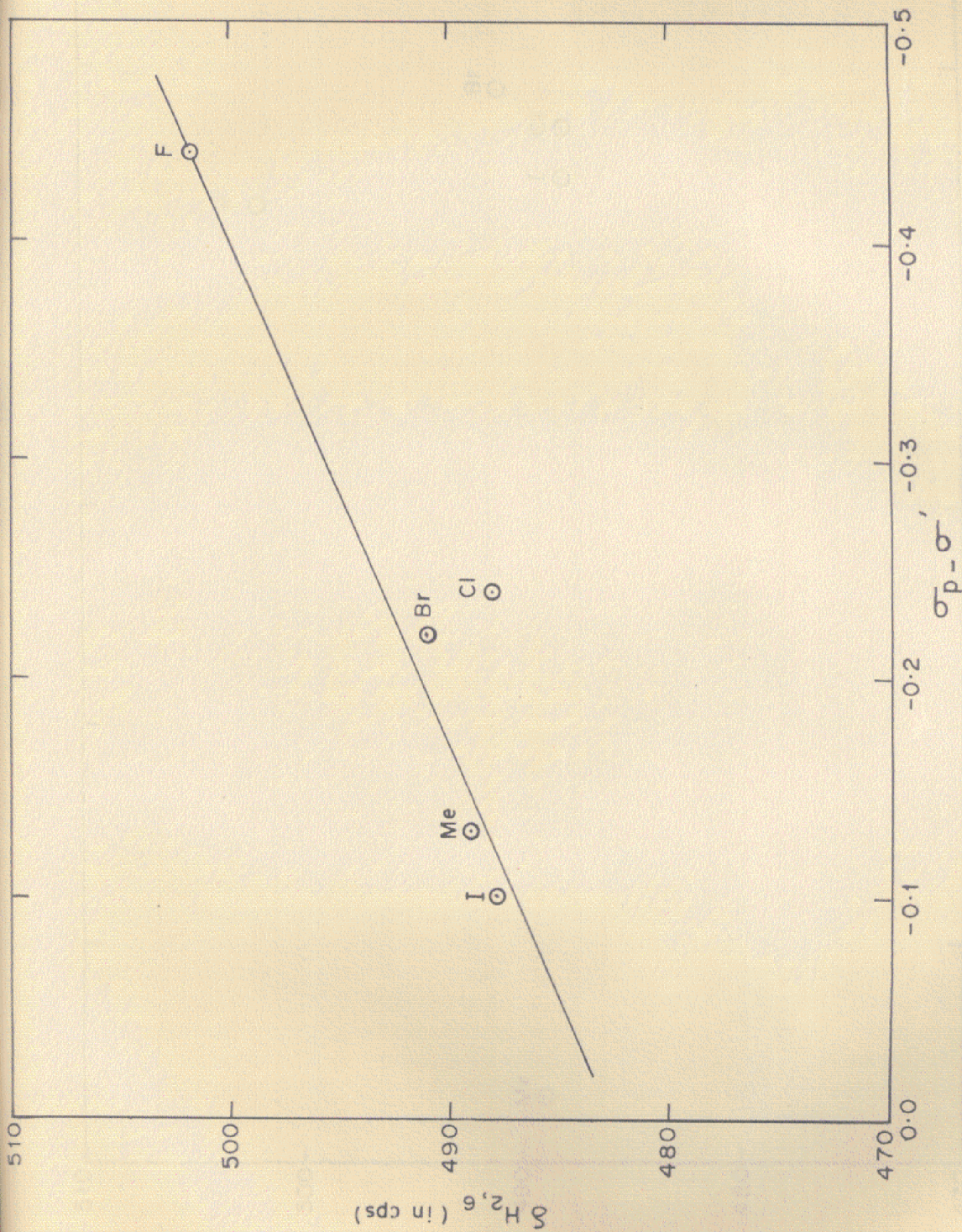
A_2B_2 absorption pattern with a 15 cps shift between the A_2 and B_2 pairs (Fig.IVa). The lower field part of the A_2B_2 pattern is apparently produced by the protons in the 2- and 6-positions which are electron deficient. In all the cases the lower half of the A_2B_2 pattern is assigned to the 2- and 6-protons and the correctness of this assignment is further substantiated by the spectra of the *p*-fluoro and *p*-methyl derivatives (Fig.IIIb and IVc).

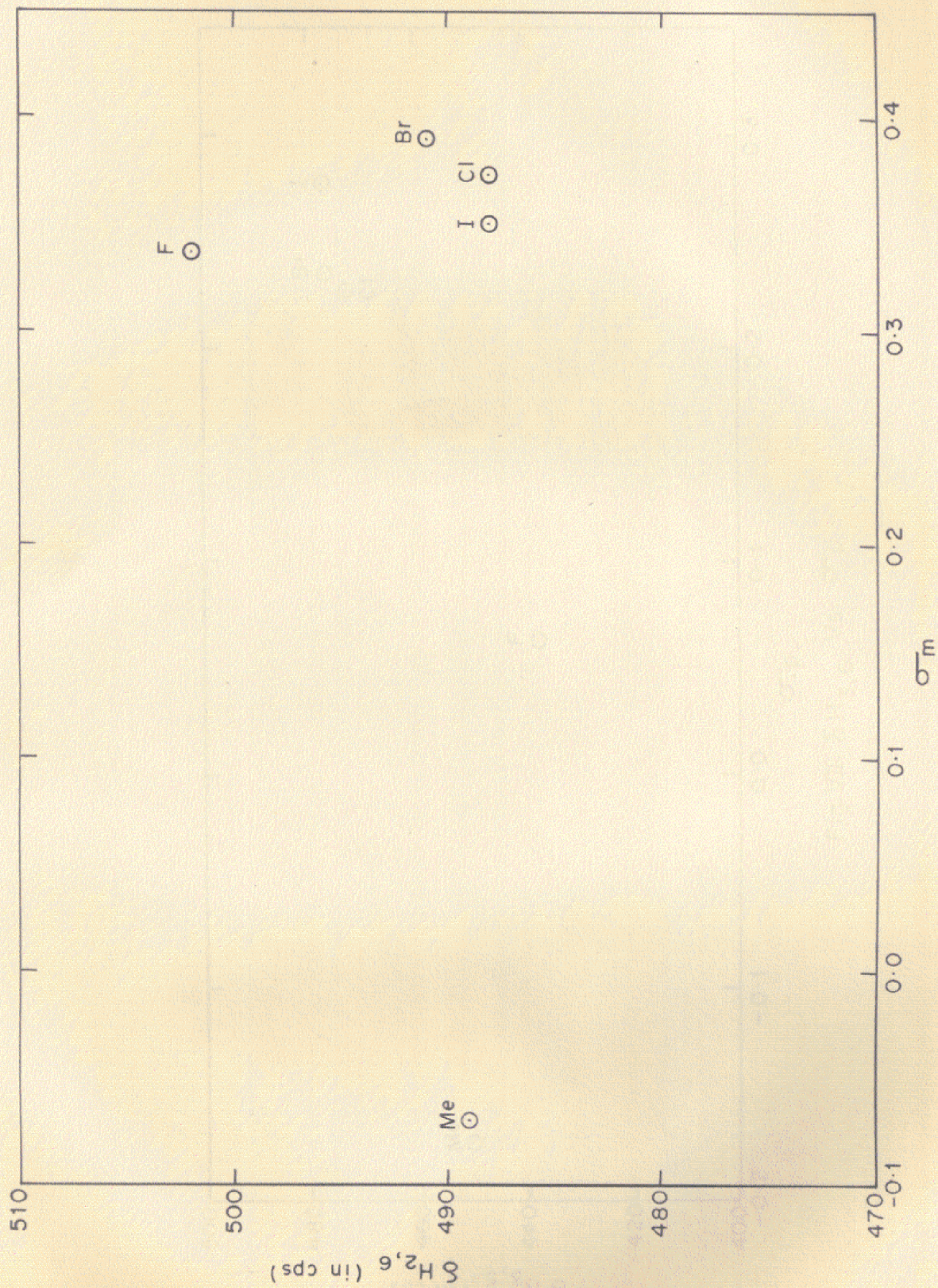
Unlike in the case of 2-phenyl-1,3-dioxolenium cations (II), we might expect significant phenyl group participation in the resonance of α -acetoxy benzyl cations.

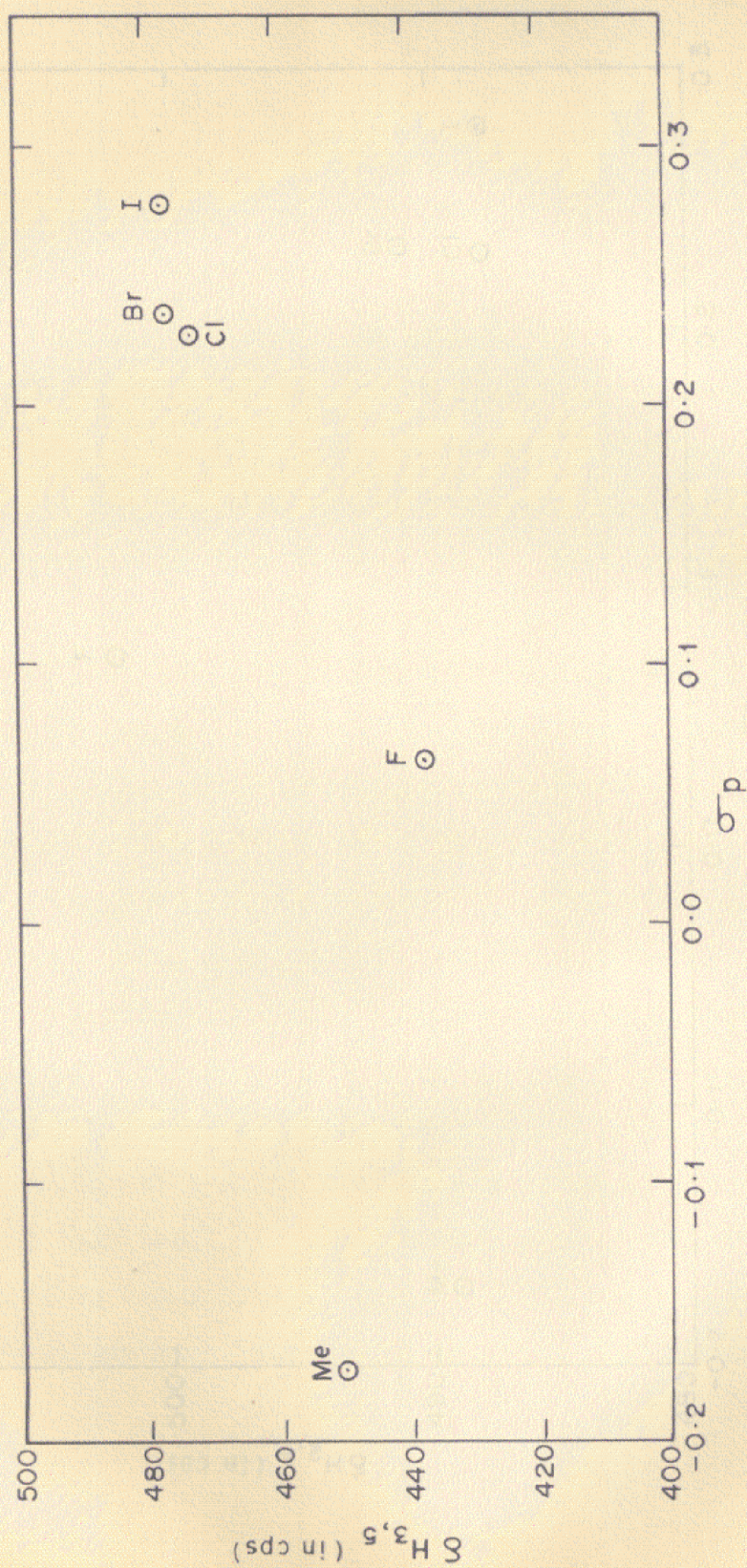


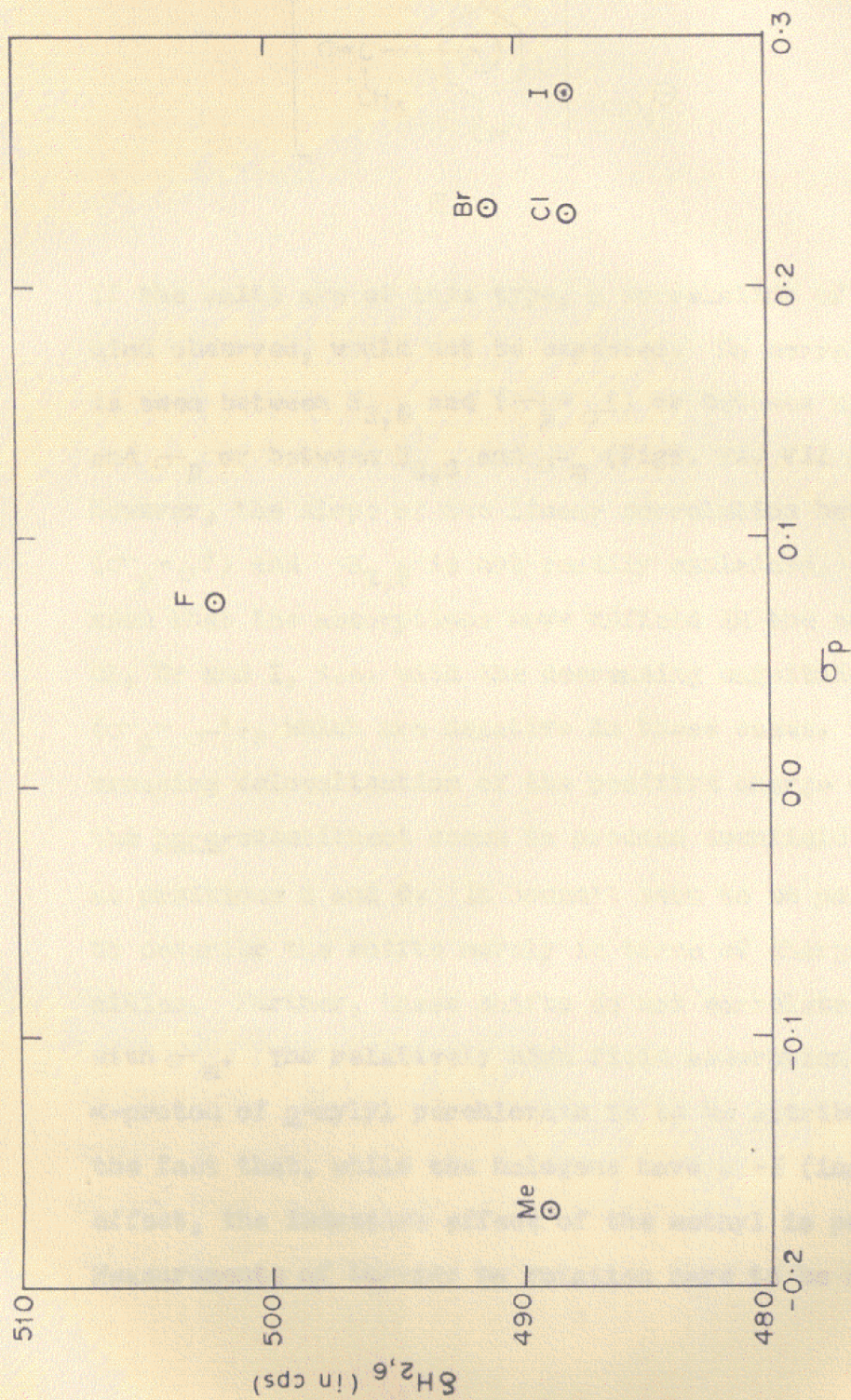
II

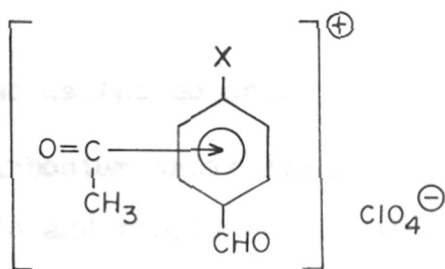
If this is so, the donor capacity of the substituents at the 4-positions should be reflected in the chemical shifts of the protons at positions 2 and 6. Although the total observed variation of these shifts is rather small, Fig.V shows that they seem to correlate fairly well with the Hammett type parameter ($\sigma_p - \sigma'$), which is a measure of resonance effects only¹⁴. This has some relevance to the structure of these salts for which one possibility we have ignored is of the π -complex type (III).

Fig. V. $\delta_{H_{2,6}}$ Vs. ($\sigma_p - \sigma'$)

Fig. VI. $\delta_{H_{2,6}}$ Vs. σ_m

Fig. VII. $\delta H_{3,5}$ Vs. σ_p

Fig. VIII. $\delta_{H_{2,6}}$ Vs. σ_p

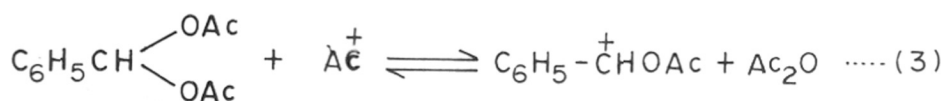


III

If the salts are of this type, a correlation of the kind observed, would not be expected. No correlation is seen between $H_{3,5}$ and $(\sigma_p - \sigma^!)$ or between $H_{2,6}$ and σ_p or between $H_{2,6}$ and σ_m (Figs. VI, VII and VIII). However, the slope of the linear correlation between $(\sigma_p - \sigma^!)$ and $H_{2,6}$ is not readily explained. It is seen that the absorptions move upfield in the order F, Cl, Br and I, i.e. with the decreasing magnitudes of $(\sigma_p - \sigma^!)$, which are negative in these cases. Increasing delocalization of the positive charge on to the para-substituent seems to produce downfield shifts at positions 2 and 6. It doesn't seem to be possible to describe the shifts merely in terms of charge densities. Further, these shifts do not correlate well with σ_m . The relatively high field absorption of the α -proton of p-xylyl perchlorate is to be attributed to the fact that, while the halogens have a -I (inductive) effect, the inductive effect of the methyl is positive. Measurements of barrier to rotation have to be made

before further useful comments can be made.

The carbonium salts obtained remained unaltered in acetic acid and ethylacetate solutions, but were converted to benzylidene diacetates in acetic anhydride. Even in the acetic acid solution, if sufficient amount of acetic anhydride is added, it is converted to the diacetate. With one drop of acetic anhydride, a complex spectrum showing the presence of two species was noticed. With increasing amounts of acetic anhydride, the signals which represented the carbonium ions disappeared and with four drops of the reagent only signals of the diacetate were obtained. The different stages are shown in Fig. IX.



It is clear that an equilibrium of the type shown in (3) exists. Once the acetic anhydride is removed from the system, the carbonium salt is formed, but when it is reintroduced the reverse reaction sets in and the diacetate is obtained. Since the base strengths of the carbonyl groups of acetic acid and ethylacetate are undoubtedly higher than that of any of the oxygen atoms of acetic anhydride¹⁵, speaking in a molecular sense, this behaviour

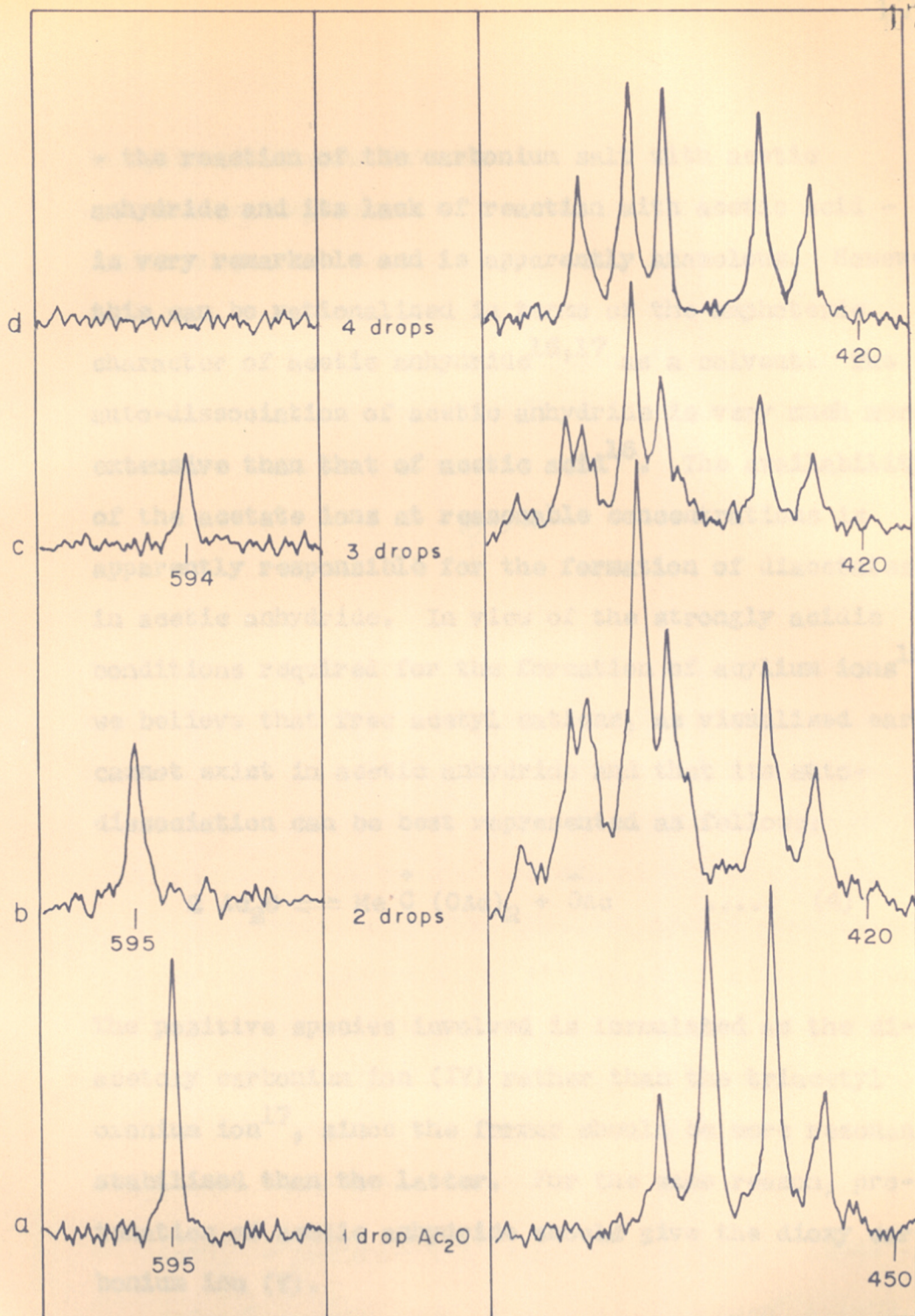
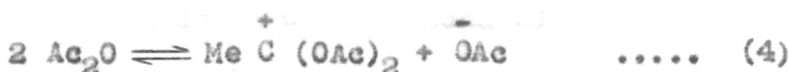


FIG. IX. AROMATIC REGION OF THE NMR SPECTRA OF α -ACETOXY-*p*-IODOBENZYL PERCHLORATE IN AcOH WITH INCREASING AMOUNTS OF Ac_2O .

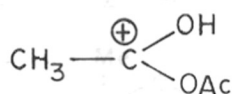
- the reaction of the carbonium salt with acetic anhydride and its lack of reaction with acetic acid - is very remarkable and is apparently anomalous. However, this can be rationalized in terms of the amphoteric character of acetic anhydride^{16,17} as a solvent. The auto-dissociation of acetic anhydride is very much more extensive than that of acetic acid¹⁶. The availability of the acetate ions at reasonable concentrations is apparently responsible for the formation of diacetates in acetic anhydride. In view of the strongly acidic conditions required for the formation of acylium ions^{18,19}, we believe that free acetyl cations, as visualised earlier cannot exist in acetic anhydride and that its auto-dissociation can be best represented as follows:



The positive species involved is formulated as the diacetoxy carbonium ion (IV) rather than the triacetyl oxonium ion¹⁷, since the former should be more resonance stabilized than the latter. For the same reason, protonation of acetic anhydride should give the dioxy carbonium ion (V).

Since we are dealing here with acetoxy carbonium

ions, it is of some interest and relevance to point out some consequences of the realization, that the positive species involved in the acetic anhydride dissociation is, diacetoxyethyl cation (IV). If Ac^+ can co-ordinate only at the keto oxygen of acetic anhydride, the same should be true for H^+ , so that protonated acetic anhydride would be represented by (V).

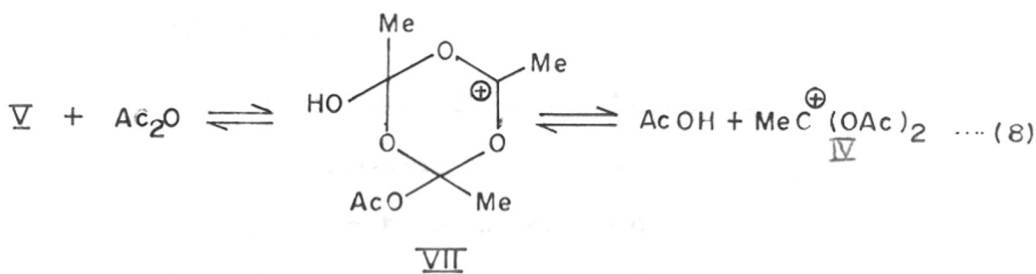
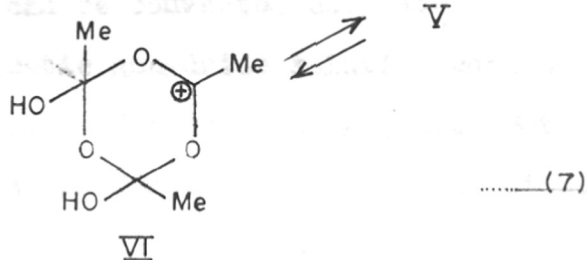
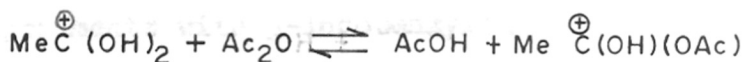


V

In a recent study on perchloric acid catalysed acetyl exchange in $\text{AcOH}-\text{Ac}_2\text{O}$ systems, Sheinblatt and Alexander¹⁵ have expressed the opinion that for solutions containing relatively small amounts of acetic anhydride, the exchange reaction is between protonated acetic acid and acetic anhydride, rather than, between acetic acid and protonated acetic anhydride, on the basis of a feeling that the latter reaction cannot be sufficiently fast. This is a difficult point to understand, since no clear mechanism is put forward. The representation given by the authors is reproduced below:



Such a representation can hardly sustain the opinion expressed. It is suggested here that the difficulty can be removed by the formulation of the positive species involved as dioxy carbonium ions. Thus the protonation equilibrium and exchange mechanism may be represented as follows:



The reaction sequence (7) shows that the mechanistically more probable situation is exactly the reverse of that proposed by Sheinblatt and Alexander. It is possible to write a neat mechanism for acetyl exchange between protonated acetic anhydride and acetic acid through the symmetric intermediate (IV), while no such thing is possible for the alternative case. The deviations of the

proportionality of the rate of acetyl exchange to $[\text{Ac}_2\text{O}]$ found by Sheinblatt and Alexander¹⁵, in solutions rich in acetic anhydride, seem to be in agreement with the expectation that in media containing relatively large amounts of acetic anhydride the reaction sequence (8) should contribute significantly to the exchange.

Experiments with *p*-iodobenzylidene diacetate have shown that it can be converted completely into the carbonium salt in acetic anhydride solution when suitable amounts of perchloric acid are added (Fig.X). But this behaviour is not general for the diacetates studied. The *p*-bromoderivative was found to polymerise before the carbonium ion could be produced by addition of increasing amounts of perchloric acid.

In this context, it was interesting to see whether similar alkoxy carbonium salts could be prepared from the acetals by the same technique. The spectrum of the only salt that could be prepared in a pure state is that of α -ethoxy-*p*-dimethylaminobenzylperchlorate, which is shown in Fig.XI. The *p*-dimethylaminobenzaldehyde diethyl acetal spectrum in sulfuric acid is also shown for comparison (Fig.XII). This carbonium salt was prepared exactly in the same way as the acetoxy salts, with maximum care to prevent any evolution of heat, which may decompose the

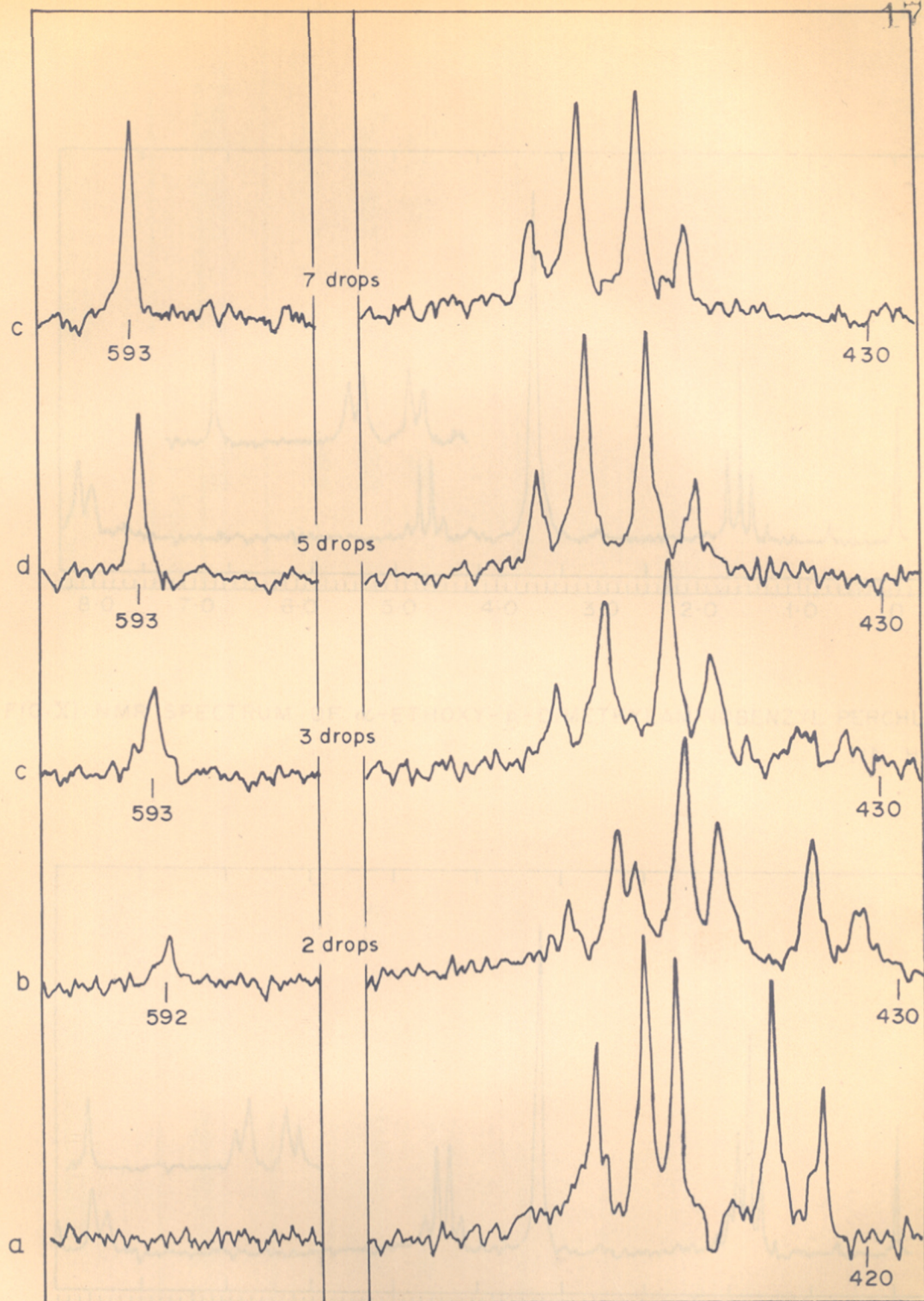


FIG. X. AROMATIC REGION OF THE NMR SPECTRA OF *p*-IODOBENZYLIDENE DIACETATE IN Ac_2O WITH INCREASING AMOUNTS OF PERCHLORIC ACID.

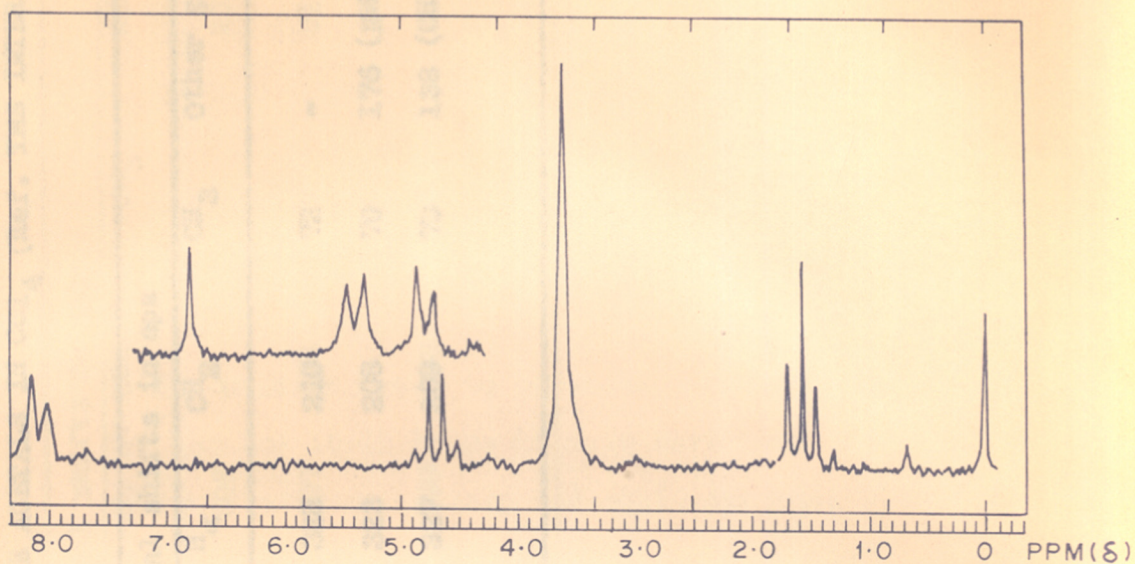


FIG. XI. NMR SPECTRUM OF α -ETHOXY-*p*-DIMETHYLAMINO BENZYL PERCHLORATE
(IN H_2SO_4)

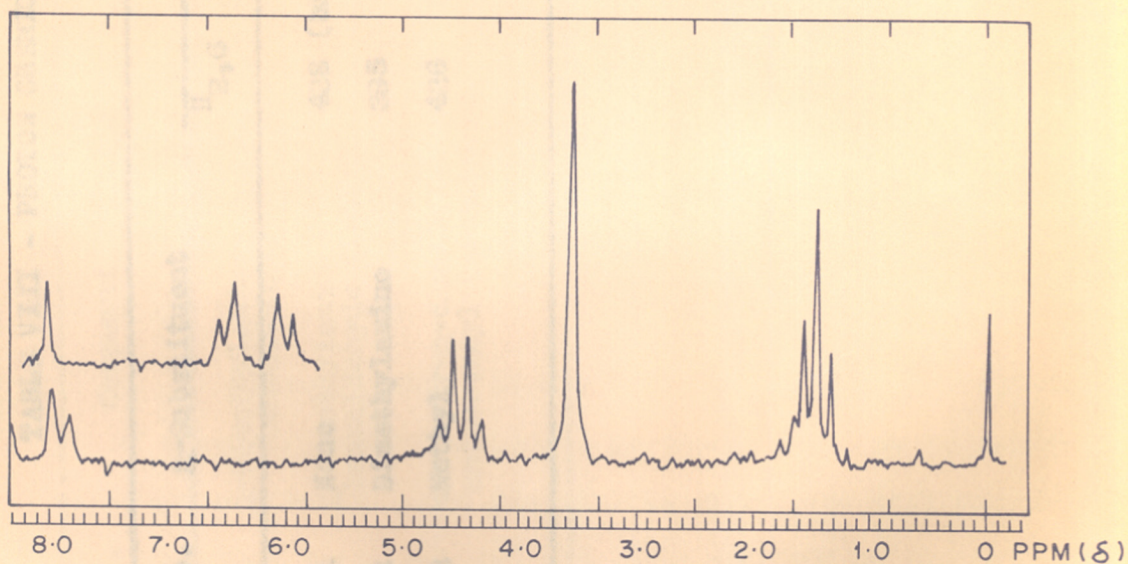


FIG. XII. NMR SPECTRUM OF *p*-DIMETHYLAMINO BENZALDEHYDE DIETHYL ACETAL
(IN H_2SO_4)

TABLE VII - PROTON CHEMICAL SHIFTS OF THE ACETALS IN CCl₄ (Ref. TMS INTERNAL)

No.	p-Substituent	Chemical shifts in cps					
		H _{2,6}	H ₄	H _{3,5}	H _α	CH ₂	CH ₃ Other groups
1	None	438	(broad multiplet)	328	210	72	-
2	Dimethylamino	395	-	435	323	70	176 (NMe ₂)
3	Methyl	426	-	438	327	70	138 (CH ₃)

TABLE IX - SOLVENT: SULFURIC ACID (Ref. TMS EXTERNAL)

No.	Compound	Chemical shifts in cps					
		H _{2,6}	H _{3,5}	H ₄	OCH ₂	-CH ₃	NMe ₂
1	2-Dimethylamino-benzaldehyde	506	478	598	-	-	214
2	2-Dimethylamino-benzaldehyde diethyl acetal.	505	477	597	268	87	213
3	4-Ethoxy-2-dimethyl-aminobenzyl perchlorate.	505	477	599	268	87	212

acetal to the aldehyde in presence of mineral acids. Equivalent amounts of pre-cooled solutions of the acetal and perchloric acid in acetic anhydride, were mixed together under efficient cooling. A colorless solution was obtained. The solvent was then pumped out. After 3-4 hours of pumping, most of the solvent was removed and a dark red solid material began to separate. Pumping was continued for another 10-12 hours to make sure that there was no solvent left, and a deep red solid material obtained. This solid dissolved in sulfuric acid to give a deep red solution, the spectrum of which showed it to be α -ethoxy-*p*-dimethylaminobenzyl perchlorate (Fig. XI). A comparison of this spectrum with that of the pure diethyl acetal in sulfuric acid suggests that the alkoxy group of the carbonium ion is cleaved i.e. the spectrum obtained is that of the protonated aldehyde. However, it is clear that only one alkoxy group had been removed during the preparation of the salt. With benzaldehyde diethyl acetal and *p*-tolualdehyde diethyl acetal, only polymeric materials could be obtained.

In conclusion, it may be said that the possibility of preparing α -acetoxybenzyl perchlorates from benzaldehydes and benzylidene diacetates, which has been visualised, has been realized and these can now be employed for

the intended barrier measurements. The difference noticed between the behaviour of these salts in acetic acid and acetic anhydride has lead, to an amplification of the chemical nature of acetic anhydride and the suggestion of a mechanism for acid catalyzed acetyl exchange in acetic acid-acetic anhydride systems.

acetic acid, tetraacetylilane was used as an internal reference, while for all other solvents, the same was used as internal reference.

The results of the barrier measurements of the salts in acetic acid and acetic anhydride are given in Table I and Table II respectively.

The results of the barrier measurements of the salts in acetic acid and acetic anhydride are given in Table I and Table II respectively. The results of the barrier measurements of the salts in acetic acid and acetic anhydride are given in Table I and Table II respectively.

The results of the barrier measurements of the salts in acetic acid and acetic anhydride are given in Table I and Table II respectively. The results of the barrier measurements of the salts in acetic acid and acetic anhydride are given in Table I and Table II respectively.

Acetylacetate was first washed with sulfuric acid and then several times with water. It was then dried over calcium chloride sulfate and distilled. It was again distilled with calcium chloride and distilled. The fraction between 100 and 110°C. only was used.

EXPERIMENTAL

All the spectra were recorded on a Varian A-60 NMR spectrometer (60 Mc). General experimental conditions and details regarding scanning of the spectrum are described in Chapter II of Part I. For measurements in sulfuric acid, tetramethylsilane was used as external reference, while for all other solvents TMS was used as internal reference.

Preparation and/or purification of the materials are as described below. All melting points and boiling points are uncorrected.

Acetic anhydride (AR) was repeatedly distilled and the fraction boiling at 136° (710 mm) was collected. This was tested by NMR for any acetic acid and only cent percent pure acetic anhydride was used.

Perchloric acid (72%) was distilled under reduced pressure and the low boiling fractions were removed. Only the highest boiling fraction (d 1.72) was used.

Ethylacetate was first washed with sulfuric acid and then several times with water. It was then dried over anhydrous magnesium sulfate and distilled. It was again dried with phosphorus pentoxide and distilled. The fraction boiling at 76° (710 mm) only was used.

Acetic acid (AR grade) was repeatedly distilled and the fraction boiling at 117° (710 mm) was collected.

All solvents were tested for purity by NMR and only cent percent pure materials were used for the studies described here.

Preparation of the materials

1. Benzaldehyde

Commercial benzaldehyde was distilled under reduced pressure, after removing the acid present by treating with a solution of sodium bicarbonate, and the fraction boiling at $49^{\circ}/1.5$ mm was collected. For all experiments described here, only freshly distilled samples were used.

2. p-Halobenzaldehydes

All the p-halobenzaldehydes were prepared from the corresponding halotoluenes by chromic anhydride oxidation, in acetic anhydride-acetic acid solution and hydrolysing the benzylidene diacetate to the aldehyde²⁰. The halotoluenes were prepared from p-toluidine as described below.

a) p-Fluorotoluene²¹

p-Toluidine (54 g) was dissolved in conc. HCl (126 ml) and water (126 ml) in a one litre beaker. It

was necessary to warm the solution. The mixture was cooled to 0° in an ice-salt mixture and stirred mechanically. Some *p*-toluidine hydrochloride separated as fine crystalline salt. A solution of sodium nitrite (36.5 g) in water (75 ml) was added drop by drop from a separating funnel, so that the temperature did not rise above 5° . The temperature was kept below 5° by adding crushed ice, whenever necessary. After all the nitrite solution was added, the mixture was stirred for another fifteen minutes and a chilled solution of sodium fluoborate (76 g) in water (150 ml) was added slowly with good stirring. Stirring was continued for another half an hour and the precipitate formed was separated by filtration. The precipitate obtained was then washed with water (30 ml), methyl alcohol (15 ml) and finally with ether (30 ml). It was then dried in a desiccator. The yield of the borofluoride, which melted with decomposition at 113° , was 76 g.

The diazonium fluoborate was then taken in a distilling flask. The solid was heated gently at one point near its surface, until decomposition begins. The flame was removed and the reaction was allowed to proceed till it subsides. Then it was heated again till the decomposition appeared to be over. Finally the flask

was heated strongly in order to drive out any p-fluorotoluene remaining inside. Most of the material was collected in the first receiver, which in turn was connected to a second one and the second one to an inverted funnel which was kept just dipped under the surface of water, in a beaker. The distillate was washed with 10% sodium hydroxide solution, until the washings are colorless, to remove any cresol formed. It was then washed with water and dried over anhydrous sodium sulfate. The pure material was obtained on distillation in a yield of 28 g (26%), as a colorless liquid boiling at 114-15°/710 mm.

(a₂) p-Chlorotoluene²²

Copper sulfate (250 g) and sodium chloride (65 g) were dissolved in water (800 ml) in a two litre round bottomed flask, which was fitted with a mechanical stirrer. An alkaline solution of sodium sulfite (53 g NaHSO₃ and 35 g NaOH in 400 ml water) was added during a period of 5-10 minutes and the mixture was refluxed for 3-4 hours. It was then cooled to room temperature and the cuprous chloride formed was washed with water by decantation. The cuprous chloride was obtained as a white powder, which was dissolved in conc. HCl (400 ml 28%, d 1.14) and this solution was used for the preparation

of p-chlorotoluene.

p-Toluidine (95 g) was diazotised just as described under p-fluorotoluene. The cuprous chloride solution was cooled to 0° and the cold diazonium salt solution was poured into it with good stirring. The solution became thick owing to the separation of an addition product between the diazonium salt and cuprous chloride. The cold solution was allowed to warm up to room temperature. The solid addition product decomposed with the formation of p-chlorotoluene. The mixture was placed over a waterbath and heated to 60° to complete the reaction. The p-chlorotoluene was then isolated by steam distillation. The product was separated from the distillate, washed with cold conc. H_2SO_4 and then with water. It was finally dried over anhydrous magnesium sulfate. The yield of the material which distilled over at 52°/2 mm, was 84 g (76%).

(a₃) p-Bromotoluene

It was prepared exactly in the same way as described in the case of p-chlorotoluene using cuprous bromide. Instead of hydrochloric acid, sulfuric acid was used for diazotisation. The product was isolated by steam distillation. The yield of the material which distilled over at 58°/2 mm was 79%.

(a₄) p-Iodotoluene

p-Iodotoluene was prepared just as in the above cases. Instead of the cuprous salt potassium iodide was used. Pure p-iodotoluene was obtained as colorless crystals which melted at 35°, in a yield of 81%.

(b) Preparation of the aldehydes

All the aldehydes were prepared in the same way by oxidising the halotoluene with chromic anhydride. This method was preferred over the classical method of bromination followed by hydrolysis²³, due to the relative simplicity, even though the yields were poor. As a typical example the preparation of p-chlorobenzaldehyde is described below.

In a three necked round bottomed flask, fitted with a mechanical stirrer and a thermometer glacial acetic acid (570 ml) and acetic anhydride (565 ml) were taken along with p-chlorotoluene (45 g). The mixture was cooled using an ice-salt mixture. Conc. H₂SO₄ (85 ml) was added slowly while the mixture was kept stirred. It was then cooled to 0° and chromic anhydride (CrO₃, 100 g) was added in small amounts, at such a rate that the temperature of the mixture did not rise above 5°. Stirring was continued for one hour more after the addition

was over. During this time a solid material crystallised on the sides of the flask. The reaction mixture was then poured onto crushed ice (2 kg) and water (1 litre). The solid product obtained was separated by filtration, washed with cold water until the washings are colorless. A second crop was obtained on diluting the filtrate further. The solid product obtained was then suspended in 20% sodium carbonate solution (150 ml) and stirred mechanically. After stirring for about 20 minutes, the solid product was separated, washed with cold water and finally with a little alcohol (20 ml). The product, p-chlorobenzylidene diacetate, weighed 33 g (40%), after drying in a desiccator.

This crude diacetate was then hydrolysed to the aldehyde by refluxing for 30 minutes with water (100 ml) in ethyl alcohol (150 ml) containing a little conc. H_2SO_4 (10 ml). The solution was then poured onto crushed ice and the aldehyde precipitated was separated by filtration. It was washed with water and dried. The crude p-chlorobenzaldehyde obtained was then converted to its bisulfite addition compound. The aldehyde was then regenerated with dil. sulfuric acid. The pure aldehyde was obtained as colorless

crystals after recrystallising from alcohol. It melted at 45-46°. Yield: 22 g (86%).

p-Fluorobenzaldehyde was obtained, as a colorless liquid boiling at 57°/2 mm, in a yield of 28-29%.

p-Bromobenzaldehyde was obtained in a yield of 36% as a fine crystalline solid which melted at 55°, while p-iodobenzaldehyde was obtained as needle shaped crystals melting at 75-6° in a yield of 32%.

3. p-Anisaldehyde

Commercial p-anisaldehyde was used after distillation without any further purification.

4. p-Tolualdehyde²⁴

A solution of p-bromotoluene (20.8 g, 0.122 mole) in ether (100 ml) was added drop by drop to a mechanically stirred mixture of Grignard magnesium (3.3 g 0.136 mole) in ether (20 ml), in an atmosphere of nitrogen. The reaction was initiated by adding ethylbromide (0.5 ml) and a small crystal of iodine. When all the bromotoluene was added, the mixture was refluxed for 2 hours. Ethyl orthoformate (22 g, 0.142 mole) in ether (30 ml) was added rapidly in 5 minutes and the mixture was refluxed for another 5 hours. The ether was then distilled off and when all the ether

was removed, there was a sudden violent reaction. The flask was then immersed quickly in ice and cooled till the reaction subsided. It was then allowed to stand overnight. To this reaction mixture, crushed ice (50 g) and hydrochloric acid (125 ml, 5N) were added and the mixture refluxed for 30 minutes, in an atmosphere of carbon dioxide. The aldehyde was then steam-distilled and the distillate was ether extracted. The solvent was then removed and the residue heated on a waterbath to remove any propionic aldehyde formed from ethylbromide. The crude aldehyde was taken up in ether and vigorously shaken up with saturated sodium bisulfite solution and the solid formed was filtered off. The filtrate was again shaken with bisulfite solution and the solid obtained was mixed with the main bulk. This bisulfite addition product was washed with ether and dried. The dry solid weighed 20.2 g (74%). It was decomposed with dil. H_2SO_4 and the free aldehyde isolated. This aldehyde was further purified by distillation. Just like benzaldehyde it gets oxidised to the acid very easily on exposure to air.

5. p-Dimethylaminobenzaldehyde²⁵

In a 3-necked two litre flask equipped with a mercury seal stirrer, a dropping funnel and a reflux

condenser topped by calcium chloride guard tube, is placed dimethylformamide (DMF, 44.2 ml, 0.6 mole). The flask was cooled in an ice-salt mixture and phosphorus oxychloride (25.3 g, 0.165 mole) was added drop by drop, with stirring. A vigorous reaction occurred with the formation of a $\text{DMF} \cdot \text{POCl}_3$ complex. After all the oxychloride was added, dimethylaniline (20 g, 0.165 mole) was added slowly, with stirring. At the end of the addition, a greenish yellow precipitate began to form. The reaction mixture was heated on a waterbath and stirring continued for another two hours. The precipitate redissolved and the mixture was then cooled and poured onto crushed ice (500 g). The solution was made nearly neutral by adding a solution of sodium hydroxide, while the temperature was kept below 20° by adding crushed ice. The solution was finally neutralised to pH 6-8 by adding aqueous sodium acetate solution (150 ml) with vigorous stirring. *p*-Dimethylaminobenzaldehyde began to separate and the mixture was kept overnight in a frigdeaire. The precipitate was separated by filtration and the greenish color was removed by washing with water. A pale yellow solid was obtained, which weighed 20 g after drying in air. The pure aldehyde obtained, after recrystallisation through a cold trap and the air was pumped

from alcohol melted at 72° (lit. 73°).

6. Preparation of the Carbonium salts

All the carbonium salts were prepared by the same technique from the aldehydes. Except benzaldehyde, anisaldehyde and *p*-dimethylaminobenzaldehyde, all aldehydes studied gave crystalline salts. Benzaldehyde gave a black semisolid mass, which was found to be mostly polymeric, while *p*-dimethylaminobenzaldehyde gave a black solid polymeric material. Anisaldehyde gave a dark blue solution on adding perchloric acid. The NMR spectrum showed it to be a polymeric material. As a typical example, the preparation of α -acetoxy-*p*-iodobenzyl perchlorate is described below.

p-Iodobenzaldehyde (70.2 mg) was dissolved in pure acetic anhydride (0.5 ml). Perchloric acid (72%, 23.5 mg, 2% excess) was mixed with acetic anhydride (0.2 ml) under efficient cooling. Both the solutions were cooled to 0° and mixed together. Care was taken to prevent any evolution of heat. The test tube used for taking perchloric acid was rinsed with a little acetic anhydride and transferred to the aldehyde solution. There was practically no evolution of heat and no development of color. It was then connected to a high vacuum pump through a cold trap and the solvent was pumped out

slowly. Care was taken to prevent bumping. The solution turned pale yellow, pink, red and finally deep red. After 2-3 hours pumping most of the solvent was removed and a dark red crystalline solid began to separate. The vacuum was raised slowly and the pumping continued for 12-14 hours. When all the solvent was removed a dark red solid material was obtained, which was transferred to a P_2O_5 desiccator, with as little contact with atmospheric air as possible.

The salts obtained were found to be quite pure from their NMR spectra except for the two cases mentioned earlier. In no experiments, benzaldehyde gave more than 30% of the carbonium salts. These carbonium salts could be stored in a P_2O_5 desiccator for several days.

7. Preparation of the Diethyl Acetals

(a) Benzaldehyde Diethyl Acetal²⁶

Freshly distilled benzaldehyde (10.6 g) was dissolved in technical grade anhydrous ethanol (75.0 ml). Conc. HCl (0.5 ml) was added to it and the mixture allowed to stand at ordinary temperature for five days with occasional shaking. A solution of sodium ethoxide in ethanol was added to it until the solution just turned

alkaline to moistened litmus paper. The alcohol was then distilled off on a waterbath and the residue cooled to room temperature. It was then treated with cold water to remove the inorganic salts. The acetal was then separated by ether extraction. The ether solution was dried with anhydrous magnesium sulfate. It was again dried over anhydrous sodium carbonate. The ether was then removed and the residue distilled under reduced pressure. The yield of the product, which distilled over at $68-9^{\circ}/2$ mm, was found to be 136 g (70-72%).

(b) p-Dimethylaminobenzaldehyde diethylacetal²⁷

A mixture of p-dimethylaminobenzaldehyde (30 g), 5% alcoholic hydrogen chloride (175 ml) and ethylorthoformate (75 g) were kept in a stoppered flask overnight at room temperature. A solution of sodium ethoxide (prepared by dissolving 8 g sodium in 175 ml alcohol) was added to the well stirred mixture to remove excess hydrogenchloride. Stirring was continued for another 15 minutes and the mixture poured onto ice-water mixture (500 g). It was then extracted with ether thrice and the ether solution dried with anhydrous magnesium sulfate. The solvent was removed and the residue distilled under reduced pressure. The pale yellow oil

which distilled over at $76-77^{\circ}/2$ mm was collected in a yield of 36.6 g (80%).

(c) p-Tolualdehyde diethylacetal²⁸

p-Tolualdehyde (12 g), ethylorthoformate (16.5 g, 0.11 mole) and anhydrous ethanol (50 g) were taken in a flask and a few drops of a saturated solution of hydrogenchloride in ethanol added. The mixture was shaken for a while and kept overnight. The reaction mixture was stirred with an excess of sodium carbonate for 15 minutes to neutralise the hydrogen chloride. The mixture was then extracted with ether, filtered and distilled. The fraction, boiling at $48^{\circ}/1$ mm, of pure acetal was collected in a yield of 15.8 g (83%).

8. Preparation of carbonium salts from acetals

Only one carbonium salt of this series could be prepared in a pure state, i.e. from p-dimethylaminobenzaldehyde diethyl acetal. The other two acetals gave polymeric materials. p-Tolualdehyde diethylacetal gave a semisolid viscous mass, while benzaldehyde diethylacetal gave a hard dark solid which did not even dissolve in sulfuric acid. The preparation of α -ethoxy-p-dimethylaminobenzyl perchlorate

is described below.

The acetal (0.2246 g) was dissolved in pure acetic anhydride (0.5 ml) and the solution was cooled in a freezing mixture. Pure perchloric acid (0.1372 g, 72%, 2% excess) was mixed with acetic anhydride (0.2 ml) under cooling. The two solutions were cooled efficiently and mixed together, so that there was no evolution of heat at all. The excess solvents were pumped out at ordinary temperature as described under the α -acetoxy salts. The solution slowly turned pale yellow, yellow, pink and finally dark red. After 4-5 hours pumping a dark red crystalline material began to separate. Pumping was continued for another 10-12 hours, so that the entire solvent was removed. At the end of this time a dark red crystalline solid was obtained which dissolved in sulfuric acid to give a deep red solution. This salt also was found to be stable in absence of moisture.

16. H. A. E. Mackenzie and D. R. H. Jones, *J. Chem. Soc.*, 159 (1958).
17. H. Usanovitch and K. Yatsunobu, *J. Chem. Soc.*, 954, 959 (1941).
18. S. C. Jens et al. *J. Am. Chem. Soc.*, 56, 1070 (1934).

REFERENCES

- 1 F.A.L. Anet, J. Am. Chem. Soc. 86, 119 (1964).
- 2 N.C. Deno in Progress in Physical Organic Chemistry Vol.2, Ed. S.G. Cohen, A. Streitweiser Jr. and R.W. Taft, Interscience Publishers, 1964, pp.182-83.
- 3 N.C. Deno, Chem. and Eng. News Vol.42, No.40, p.94(1964).
- 4 G. Culbertson and R. Petit, J. Am. Chem. Soc. 85, 741 (1963) and references therein.
- 5 H. Meerwein et al. Arch. der Pharm. 291, 541 (1958).
- 6 H. Meerwein et al. Ann. 632, 38 (1960).
- 7 H. Meerwein et al. Ann. 635, 1 (1960).
- 8 H. Meerwein, Angew. Chem. 67, 374 (1955).
- 9 See Ref.3.
- 10 J.A. Langraebe, J. Org. Chem. 30, 2105 (1965).
- 11 H. Hart and J.A. Tomalia, Tetrahedron Letters 3383(1966)
- 12 J.A. Tomalia and H. Hart, ibid. 3389 (1966).
- 13 C.B. Anderson et al. ibid. 2037 (1963).
- 14 R.W. Taft in Steric Effects in Organic Chemistry, Ed. M.S. Newman, John Wiley and Sons, 1956, pp.594-597.
- 15 M. Sheinblatt and S. Alexander, J. Am. Chem. Soc. 87, 3905 (1965).
- 16 H.A.E. Mackenzie and E.R.S. Winter, Trans. Fara. Soc. 44, 159 (1958).
- 17 M. Usanovitch and K. Yatsimirski, J. Gen. Chem. Russ. 11 954, 959 (1941).
- 18 N.C. Deno et al. J. Am. Chem. Soc. 86, 4370 (1964).

- 19 G.A. Olah et al. J. Am. Chem. Soc. 84, 2733 (1962).
- 20 Organic Synthesis, Coll. Vol.II, Ed. Henry Gilman
John Wiley and Sons, 1932, p.441.
- 21 A.I. Vogel, "Practical Organic Chemistry" Longmans
Green and Co. p.586.
- 22 Organic Synthesis, Coll. Vol.I, Ed. Henry Gilman,
John Wiley and Sons, 1932, p.163.
- 23 Organic Synthesis, Coll. Vol.II, p.133.
- 24 L.I.Smith and J. Nichols, J. Org. Chem. 6, 500 (1941).
- 25 Organic Synthesis, Coll. Vol.IV, p.331.
- 26 Organic Synthesis, Coll. Vol.III, p.644.
- 27 A.C. Bottomley et al. J. Chem. Soc. 1891 (1937).
- 28 J. Klien and E.D. Bergman, J. Am. Chem. Soc. 79,
3452 (1957).

SUMMARY

SUMMARY

PART I - CONJUGATION AND HYPERCONJUGATION

The development of the concepts of conjugation and hyperconjugation and the evidence in favour of the latter have been briefly reviewed. The explanations that have been offered as alternatives to hyperconjugation have also been considered. It has been concluded that the evidence so far obtained for conjugation and hyperconjugation in unsaturated systems, for which only one classical (unexcited) resonance structure can be written is indeed ambiguous, as has been claimed by Dewar.

Since doubts have been raised regarding the conjugation of nitro and carboxyl groups of aromatic compounds, on the basis of X-ray crystallographic data, it was considered that measurements of long range spin-spin coupling in suitable derivatives would clarify the position. The technique of using the methyl group as a sensing element has been extended to study the changes in π -electron distribution that accompany nitro and carboxyl substitution in the benzene ring. By the technique employed, these changes can be followed only to the extent they are reflected in the mobile bond orders. The PMR methyl bandwidths for the isomeric toluic esters,

sodium toluates and nitrotoluenes are reported. The results obtained have been extremely useful. They have confirmed the fact that nitro or carboxyl substitution in a benzene ring tends to lengthen the bond between the ortho and meta carbon atoms and to shorten the other bonds of the ring. The behaviour of the carboxylate salts suggest that this effect arises from the distribution of π -electrons, rather than from changes in hybridisation, as suggested by Trotter. The difference between the COOMe and COO⁻ systems, is that mesomeric electron withdrawal from the benzene ring is important in the former; while it is absent in the latter. It is suggested that the apparently anomalous bond length changes are to be attributed to the effects of electron correlation, and not to the absence of conjugation. X-ray data in support of this suggestion are cited.

Although the band width data for the nitrotoluenes are qualitatively similar to those for the toluic esters, some quantitative difference is indicated. The possibility that this difference might arise from an interaction involving the methyl group with the acceptor groups, is considered and the question of the nature of such an interaction is raised.

The rule of additivity of chemical shifts in benzene

derivatives has been re-examined, with the help of additional chemical shift data for disubstituted derivatives, in the context of their possible use in the study of mutual interaction between groups across the aromatic ring. The additivity rule has been found to hold to a very good approximation. Even in para-disubstituted benzenes, where strong resonance interaction between the substituent groups is well established, as in p-aminobenzoic acid and p-nitroaniline, the interaction is not reflected in the chemical shifts.

The difficulty regarding the use of chemical shifts for studying resonance interaction between substituent groups has been solved, with the help of sterically hindered systems. The paramagnetic shifts that are usually associated with the ortho-protons of nitro and carboxyl derivatives are not seen in the PMR spectra of methyl o-nitrobenzoate or dimethylphthalate, in which the substituent groups are rotated from the plane of the aromatic ring. Large parts of these downfield shifts are due to the magnetic anisotropy of the groups. It is suggested that placement, at the 4-position of such a 1,2-disubstituted system, of a group capable of resonance interaction with the group at C₁, may be expected to tend to rotate it and bring it closer to the plane of the

aromatic ring. This conformational change should be reflected in a downfield shift of the absorption of the ortho-proton concerned (at C_3). This expectation is shown to be correct with the example of dimethyl 4-amino-phthalate. In order to answer the question regarding the interactions of the methyl group, methyl 2-nitro-4-methylbenzoate, methyl 2-nitro-5-methylbenzoate, methyl 2-nitro-4-t-butylbenzoate and methyl 2-nitro-5-t-butylbenzoate have been prepared, the last two being new compounds. The NMR spectra of the compounds demonstrate (a) that the methyl group does interact with the nitro group tending to bring it into the plane of the aromatic ring and (b) that the similar effect of the t-butyl group is weaker. It is concluded that the interaction between the nitro and methyl group is predominantly of the 'hyperconjugative' type and not of the 'inducto-mesomeric' type. If it were of the latter type, the paramagnetic shift for the C_3 -proton caused by the t-butyl group in methyl 2-nitro-5-t-butylbenzoate would have been much larger than the corresponding shift seen in the methyl analogue. We believe that this is the most unambiguous proof, so far advanced in favour of the concept of hyperconjugation.

Similar interaction between the methyl and carboxyl

groups is illustrated with the help of the spectrum of dimethyl 4-methylphthalate. The difficulty of observing this interaction in the *o*-nitro-carbomethoxy system is rationalized in terms of the small angle of rotation of the COOMe group.

PART II - STABLE ACETOXY PHENYL CARBONIUM SALTS

A series of six oxy-carbonium salts of the type $[\text{X-C}_6\text{H}_4\text{-CHOAc}]^+ \text{ClO}_4^-$ have been prepared for the first time, by employing a new and simple technique. These salts have been obtained as crystalline solids, by mixing equimolecular proportions of the aldehyde and perchloric acid (72%) in acetic anhydride, with cooling and removing the solvent and other volatile material by suction at room temperature. Elemental analysis, acetyl values and NMR spectra showed them to be α -acetoxybenzyl-perchlorates. These salts are all highly hygroscopic and decompose to the aldehydes in presence of moisture, but can be preserved in a dry atmosphere for periods ranging from a few to several days, depending on the substituent in the para-position.

A similar attempt has been made to prepare alkoxy carbonium salts from acetals, but only one could be prepared in a pure state, while others polymerised.

While the α -acetoxybenzyl perchlorates are stable

in acetic acid, they are converted into the diacetates in acetic anhydride. This behaviour is anomalous from the point of view of the basicities of molecular acetic acid and acetic anhydride. The anomaly has been rationalized in terms of the amphoteric character of acetic anhydride as a solvent. A dioxycarbonium structure has been proposed for the positive species involved in the auto-dissociation of acetic anhydride and this has further led to the suggestion of an acceptable mechanism for perchloric acid catalysed acetyl exchange in acetic anhydride acetic acid systems.