

A KINETIC STUDY OF THE REACTION OF
SULPHURYL CHLORIDE WITH SOME PHENOLS

THESIS

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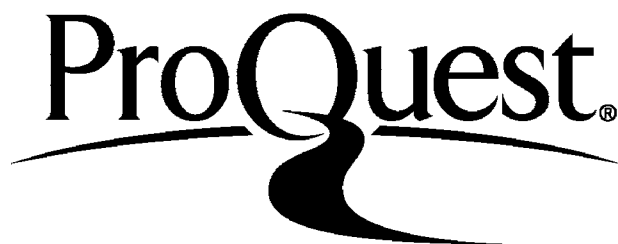
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ABSTRACT

The kinetic studies of some substituted phenols in their reactions with sulphuryl chloride in chlorobenzene and at 25°C. showed that the electrophile involved is molecular sulphuryl chloride ($\overset{+}{\text{Cl}}-\overset{-}{\text{SO}}_2-\text{Cl}$). In the poly methyl phenol studied, the magnitude of the effect of $-\text{CH}_3$ groups on the reactivity of the phenol molecule in this reaction suggested that the mechanism involves heterolytic attack of molecular sulphuryl chloride on the benzenoid nucleus. The kinetic study of 3,5-dimethyl anisole was done in benzene and showed similar effects. The reaction in all the phenols and anisole was found to be bimolecular and of second order.

The ether and the phenols were activated towards electrophilic attack particularly in the para position. This was supported by the analysis of the products formed in the reaction which also helped to trace the mechanism via which the electrophile substitutes a hydrogen of the benzenoid nucleus.

The compounds studied were:

2,4-xyleneol.

2,6-xyleneol.

3,5-xyleneol.

2,3,5-trimethyl phenol.

2,3,6-trimethyl phenol.

3,5-ditertiary butyl phenol.

3,5-dimethyl anisole.

The kinetic study of 3,5-xyleneol was studied in great detail and was extended to three solvents: benzene, chloro-

benzene and *o*-dichlorobenzene. In all the three cases a considerable change in second order rate constant was observed and indicated that the reaction was heterolytic in nature. The increase in the rate constant was also observed with the increase in the concentration of 3,5-xylenol in the reaction mixture and was explained due to the formation of a π -complex between xylenol or its chlorinated products (4-chloro, 3,5-xylenol and 2,4-dichloro, 3,5-xylenol) and sulphuryl chloride and its high reactivity. With the increase in xylenol concentration more π -complex was suggested to be formed thereby affecting the rate of reaction. Kinetics of 3,5-xylenol was also compared with 2,4,6-D₃-3,5-xylenol and *O*-deutero-3,5-xylenol to understand the other factors affecting the mechanism and to establish the rate determining step. Different quantities of 3,5-xylenol was also reacted with sulphuryl chloride in different mixture of solvents (benzene and chlorobenzene) to illustrate the effect of polarity of the solvent and the concentration of xylenol content on the rate of reaction.

The explained behaviour of the π -complex formed between 4-chloro, 3,5-xylenol and sulphuryl chloride was justified by the increase in second order rate constant of 3,5-dimethyl anisole, when reacted in presence of 4-chloro xylenol, with sulphuryl chloride. This study was extended to π -complexes of 2,4-dichloro, 3,5-xylenol, 4-chloro, 3,5-dimethyl anisole and 3,5-ditertiary butyl phenol formed with sulphuryl chloride. The nature and structure of π -complexes was also studied by u.v. and n.m.r. spectroscopy.

The reactivity of the phenols can be described in the order:

2,3,5-Me₃-phenol > 3,5-xyleneol > 2,3,6-Me₃-phenol and
3,5-dimethyl anisole > 2,4-xyleneol > 2,6-xyleneol >
3,5-ditertiary butyl phenol.

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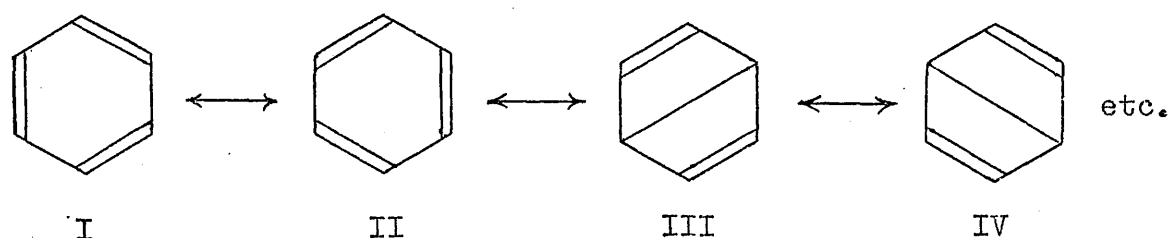
CHAPTER I

INTRODUCTION

1,2,3,4
AROMATIC SUBSTITUTION:

The aromatic hydrocarbons constitute a very important class of compounds.

The reactions of benzene and its derivatives demonstrate that all the six carbon atoms in the benzene molecule are equivalent. This further led to the brilliant idea of a cyclic structure possessing six fold symmetry. Kekule (1865) suggested that the real state of the benzene molecule is an intermediate of canonical structures, which are in dynamic equilibrium, and which do not have physical reality separately. Benzene is considered to be a hybrid of a number of canonical structures.



I,II Kekule structures

III,IV Dewar structures

These contributing forms satisfy the conditions for resonance, a hybrid of a set of structures, as resonance can only be among structures:

- (a) that correspond to the same, or nearly the same, relative positions of all the atomic nuclei.
- (b) that correspond to similar relative positions of the electrons.

- (c) that have the same numbers of unpaired electrons.
- (d) that are of the same, or nearly the same stability (energy).

The molecular orbital description of benzene gives an immediate idea of the source of its stability. The six carbon atoms are arranged in a planer hexagonal ring and each of the carbon atom is bonded with the two adjacent carbon atom and a hydrogen atom via its sp^2 orbitals. Each carbon atom is thus left with one electron in a pi-orbital situated at right angles to the plane of the nucleus. By overlapping laterally the pi-orbitals form a continuous pi-molecular orbital, consisting of annular clouds of negative charge above and below the plane of the ring.

This highly symmetrical delocalisation of pi-electrons corresponds to lowering of the internal energy of the symmetrical system and brings thermodynamic stability to benzene and related compounds. The resonance energy of aromatic compounds is found to be higher than that of the corresponding hypothetical structures. This further predicts its stability.

The stability of a ring with sp^2 atoms as in the case of benzene is predicted by Hückel's rule which states that to gain a closed shell stability through delocalization, the number of electrons present in the various pi-orbitals of all the atoms of the ring is $4n+2$, where n is an integer.

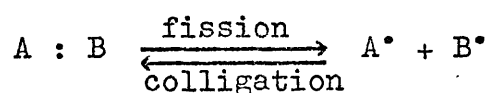
Coulson and Rushbrooke's idea of classifying pi-electron systems into "alternants" and "non alternants" led to a wider and modern concept of aromaticity. Benzenoid

systems taken as a special case and described as "alternant", whose carbon atoms can be divided into two sets in such a way that no two members of the same set are joined by a bond. Here delocalization of the pi-electrons will not be associated with the formation of the terminal charges, as in the case of non-alternants, and the stability will be greater than in ordinary conjugation.

HOMOLYSIS AND HETEROLYSIS:

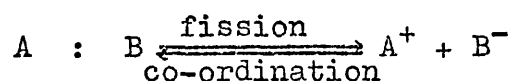
The description of a chemical bond in physical terms as the sharing of two electrons implies that bond breaking and bond making will consist of a redistribution of electrons between atoms.

Bonds can be formed from electrons supplied one by each of the combining species (colligation) and broken by the reverse process (homolysis) forming highly reactive but electrically neutral free radicals.



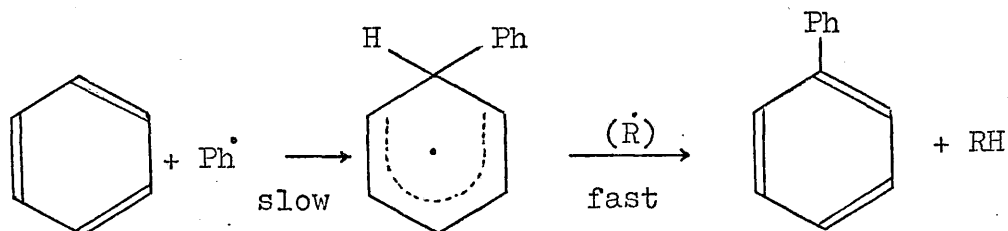
Few of these unpaired electron systems are stable in ordinary conditions and can be transiently produced by thermal, photolytic or radiative dissociation of a covalent bond. Such reactions are called homolytic reactions.

Alternatively the formation of a single covalent bond can be by co-ordination; on cleavage both electrons are transferred to one of the atoms (heterolytic or polar process)



(electrophiles and nucleophiles).

Homolytic substitution of benzenoid systems comes under the banner of unsaturated homolytic substitutions. Here the substrate contains a shell of pi-electrons, the classic example being benzene, and the attacking radical colligates with the aid of one electron of the pi-shell. The resulting radical then loses an atom of hydrogen. Phenylation of benzene illustrates the mechanism involved. The phenyl radical may be obtained by the thermal decomposition of the dibenzoyl peroxide. An unpaired electron is accommodated in the pi-shell of the intermediate formed.



The chief characteristics of radical reactions are their rapidity and initiation by radicals themselves (initiators) with inhibition by substances which react readily with radicals (inhibitors). Radicals of both long life and short life are known.

The presence of polar groups in a structure will facilitate attack at a particular site by reagents of

different electronic type. According to its nature a reagent can be labelled as an electrophile or nucleophile.

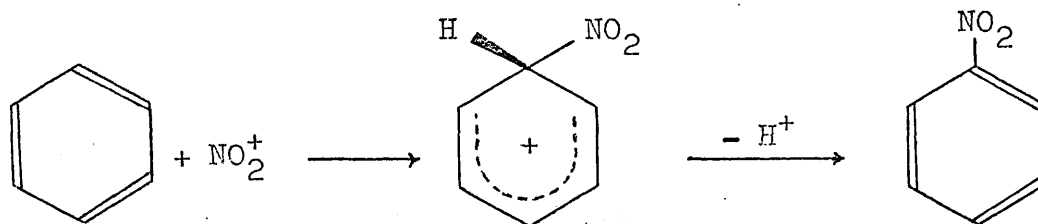
An electrophile can accept electrons to complete its outer valency shell, through bond formation with substrates having available electron pairs, while a nucleophile donates electrons to form a bond with an electron deficient nucleus.

The concentration of negative charge above and below the plane of the benzene ring shields the carbon atoms from the attack of nucleophilic reagents x^- but promotes the attack by electrophilic reagents x^+ or electron deficient species.

Electrophiles are described as:

1. Positive ions Y^+ (e.g. H^+ , Cl^+ , R^+ , $Ar-N_2^+$)
2. Dipolar molecules which give cations $Y^{\delta+}-X^{\delta-}$ (e.g. $Cl-OH$, $>C=O$, Brønstead acids $H-Y$) and non polar molecules which polarise under the influence of the substrate (e.g. $Br-Br$, $Cl-Cl$)
3. Electron deficient compounds. (e.g. SO_3 , $ZnCl_2$, $AlCl_3$, BF_3)
4. Oxidising agents (e.g. O_3 , $R-O-O-R$, Fe^{3+})

In electrophilic substitution (S_E) both the electrons, which form the covalent bond between the reagent and the benzene molecule are provided by the latter. This way a temporary electron deficiency is caused in the pi-orbital of the aromatic ring and a proton is removed from the ring to bring the molecule to the normal state.



The electrophilic substitution (S_E) is discussed in detail in this chapter as it is in the context of the work carried out.

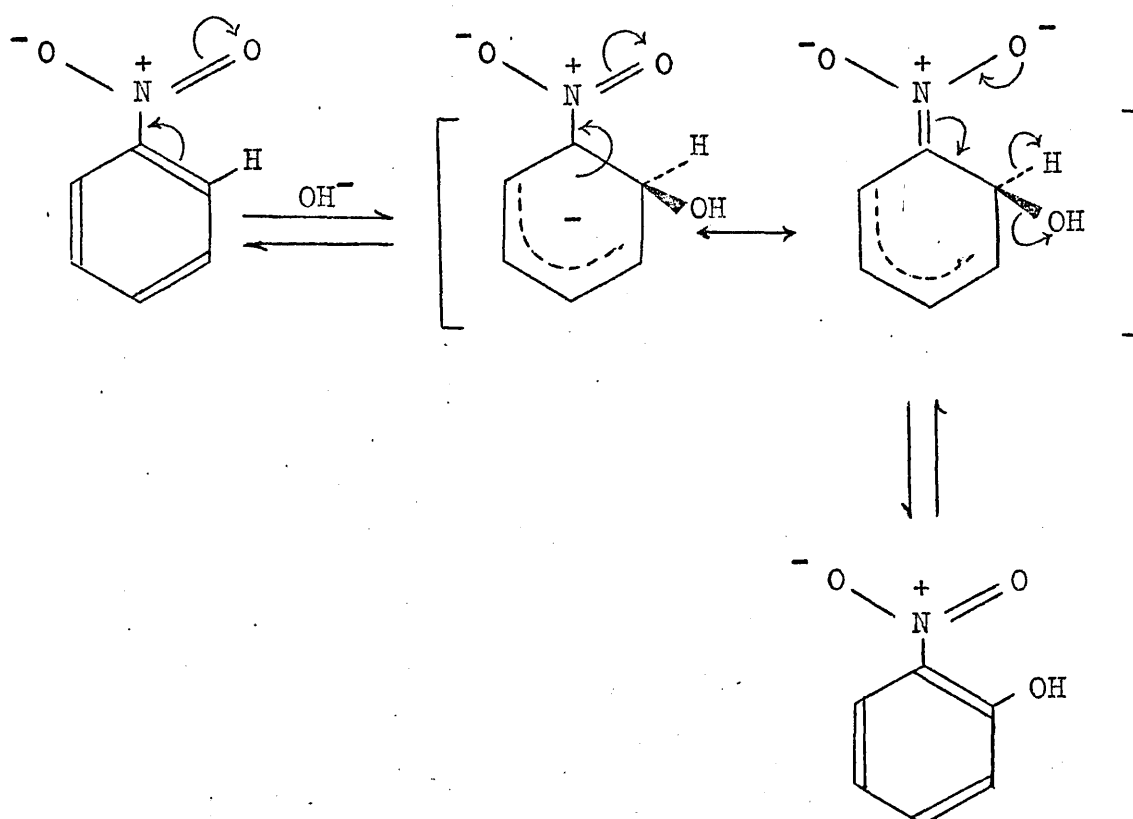
The nucleophilic reagents can be described as:

1. A negative ion Y⁻ (e.g. HO⁻, Cl⁻, RO⁻, N₃⁻, carbanion)
2. A dipolar molecule acting as anion - donor $\overset{\delta-}{Y}-\overset{\delta+}{X}$
(e.g. R⁻Li, R⁻MgBr, $\text{>C}=\text{C}<$)
3. A neutral species with sufficiently mobile free pairs of p electrons.
(e.g. R-O-R, R₃N:, R-O $\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{O}}}$ -H, Lewis bases in general)
4. A reducing agent (e.g. Na, Fe²⁺)

Ammonolysis, hydrolysis and alcoholysis are among the typical nucleophilic substitution reactions (S_N).

Nucleophilic substitution can proceed either by unimolecular mechanism (S_{N1}) or bimolecular mechanism (S_{N2}). The former mechanism is limited to the replacement of only those substituents which are sufficiently loosely bound to undergo spontaneous heterolysis in solution. For any nucleophilic substitution to take place a strongly

electron withdrawing substituent is expected to render attack by a nucleophile possible. In contrast to electrophilic substitution a negative charge is accommodated in the nucleus of the intermediate formed and again after releasing a group the molecule retains its normal state. e.g. nitrobenzene fuses with potash in the presence of air to yield o-nitrophenol.



Despite the size of the adjacent NO_2 , the inductive effect will make o-position more electron deficient than p-. As expected a substituent promoting attack in the m-position by an electrophile will promote o-p- attack by a nucleophile.

2,4,5,6,8,9

ELECTROPHILIC AROMATIC SUBSTITUTION:

In the middle of the 1870's attempts were made to develop a theory which could separate the groups contributing to the two contrasting types of orientation, one leading to o- and p- substitutions and another to m- substitutions.

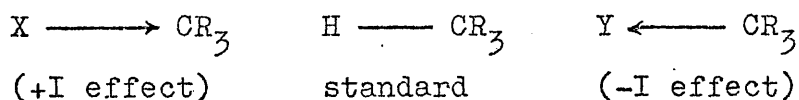
Koerner¹⁰ and Hubner¹¹ supported Berzelius' idea and associated the basic and acidic character of the groups with their directing abilities. Crum Brown and Gibson differentiated the two classes of groups on the basis of their ability to undergo direct oxidation (m-directing) or not (o- and p-directing). Other theories to explain the role of a group already present in benzene, were put forward by Flürscheim and Fry but were not found satisfactory in all the cases.

Ingold and Shaw¹² were first to point out the reasons for the preferential formation of o- and p- or m- products only and linked it with the influence of a substituent upon the reactivity of nuclear carbon atom through one of several combinations ie. it may be activating o- and p- positions but deactivating to m- position; or it may be activating o- and p- positions and not affecting the m- positions; or it may be activating all the positions but to the greatest at o- and p- position. The activation or deactivation by a substituent already present in a ring was studied with comparison to a carbon atom of unsubstituted benzene ie. the probability of substitution at each carbon atom of benzene being set at unity. To explain the electron displacements Lucas and his collaborators in 1924 used the Inductive,

Mesomeric and Electromeric effects interpreting the substitution in aromatic systems.

INDUCTIVE EFFECT:

Lewis¹³ observed that in a molecule where the constituents were unlike atoms, sharing of electrons gave rise to an 'electrical disymmetry' which could be electropositive or electronegative depending on electron repelling or electron attracting nature of the group or atom compared to hydrogen (standard) in the same molecular situation.

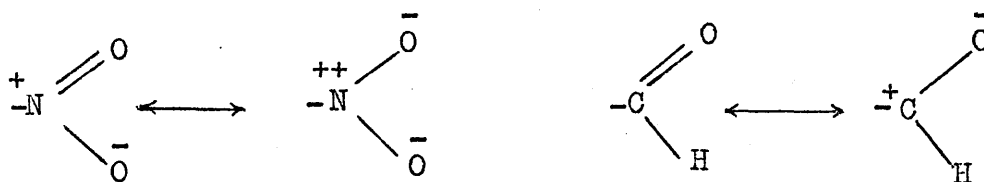


This electrical disymmetry can be propagated along a chain of bonded atoms via σ bonds towards the direction of electronegative atom or group, and dies out with the increasing distance away from the group or atom. Lewis accepted the inductive effect as a permanent molecular condition which could affect chemical equilibria and other physical properties of the molecule e.g. dipole moment.

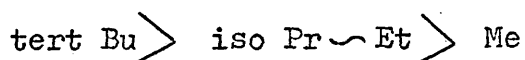
The free energy of ionization and thereby the strength of an organic acid varies with the change of the structure of the acid. Certain positive groups like $(\text{CH}_3)_3\text{N}^+$ or NH_3^+ , if introduced, facilitate the departure of H^+ ion from the $-\text{COOH}$ group, and lower its free energy of ionization (increase the ionization constant). An electro-negative group, if introduced, pulls away the electron density from other atoms and makes the acid much more strong.

Acid	pK
CH_3COOH	4.80
$(\text{CH}_3)_3\text{N}^+\text{CH}_2\text{COOH}$	1.83
FCH_2COOH	2.66
ClCH_2COOH	2.86
Cl_2CHCOOH	1.3
Cl_3CCOOH	0.65

An electronegative atom or group bonded to a more positive atom by either a double or triple bond can allow the following polar forms.



This oxygen atom therefore attracts electron density more than a single bonded oxygen atom in an ether or alcohol having a positive charge in the neighbouring atom. On the other hand alkyl groups are electron releasing (+I effect) therefore relative to hydrogen they decrease the strength of saturated acids. The +I effect is greater, the more branched the structure of the group is and is in order:-

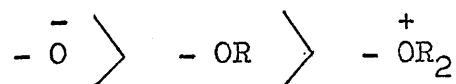


Unsaturated groups like vinyl and phenyl groups are found to increase the acidity of an acid and suggest that unsaturated carbon atoms are more electronegative (attractor) than saturated carbon atoms.

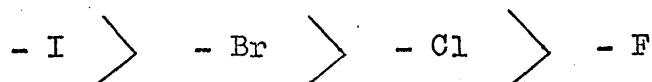
The inductive effect transmitted through space instead of the bonds of a molecule has also been noticed and is referred as the direct effect. Although it has been difficult to distinguish between the two effects in an aromatic system, both effects are found to be affecting the isomer ratios.

INDUCTOMERIC EFFECTS:

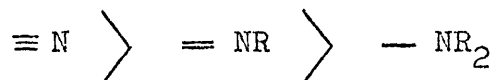
Some workers¹⁴ prefer to differentiate the inductive effect, which is a property of the molecule of the reactants from these effects which take place only at the time of need and demand by one reagent on another and call it inductomeric effects. These effects play a dominant part in a transition state of a reaction. The electrical forces give rise to polarisability effects which depends on the electronic requirements of the reaction and thus facilitates the reaction. The inductomeric polarisability decreases with positive ionic charge and increases with a negative charge.



Also it diminishes with decreasing atomic number in the same Mandele'jeff's group.



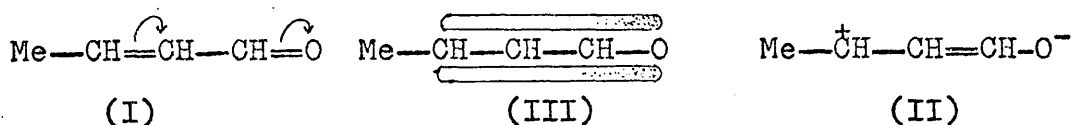
The bond length (C-D bond is shorter than C-H and is less polarisable) and additional electrons taking part in the bond also make a difference in the polarisability factor:



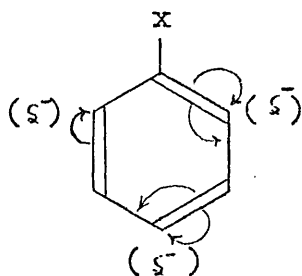
The inductomeric influence thus depends in particular on polar excited states which have their orbitals overlapped with that of the ground state to facilitate electron shifts.

MESOMERIC EFFECT:

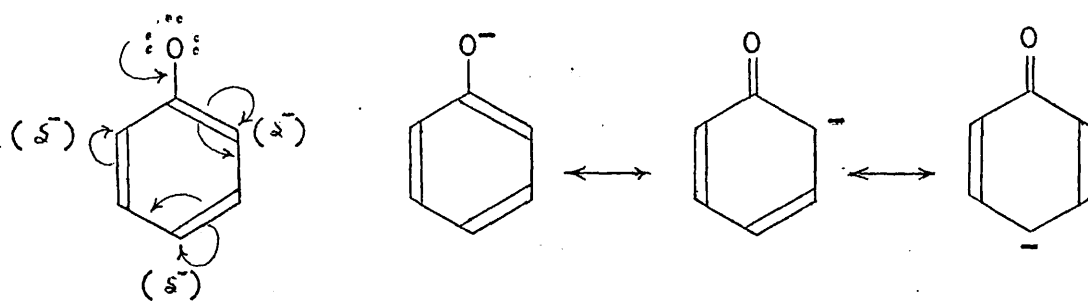
This effect is caused by the disturbance in π electron density at one atom and is distributed over the " π -electron streamer " present in a conjugated and aromatic system. Irrespective of the distance, the polarisation is relayed with the same intensity to various positions of the molecule. In contrast to electron displacement in inductive polarisation, the forces promoting mesomeric effect, displaces the electrons to the maximum extent possible in a conjugated system providing much more stability and creating new dipoles. The true electronic structure (III) of a molecule capable of exhibiting mesomeric effect is in between the original non-dipolar structure (I) and the dipolar structure (II).



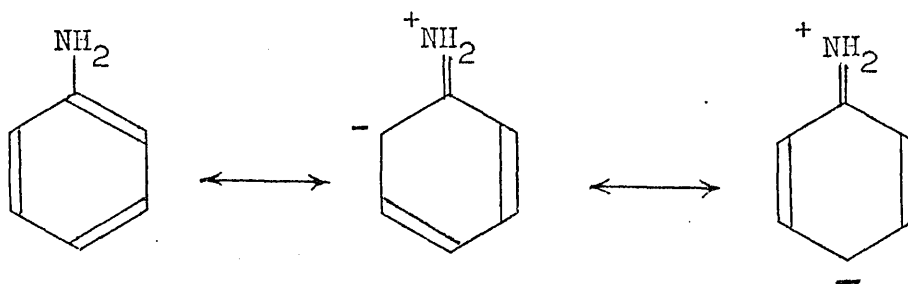
Where a positive mesomeric effect (+ M) exists; groups or atoms exhibiting the effect, when attached to a conjugated system, decrease their own electron density and increase that of the conjugated residue and thus shows a tendency to increase its covalency.



For example in phenol, the acidity is boosted by means of a mesomeric effect and this can not be accounted for by the inductive effect.

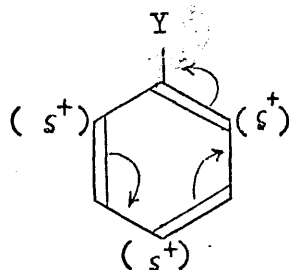


While the diminishing basicity of aniline can be accounted again for the mesomeric effect where the electron density is distributed above and below the plane of the benzene ring, and is not localized on nitrogen atom as in the aliphatic amines.



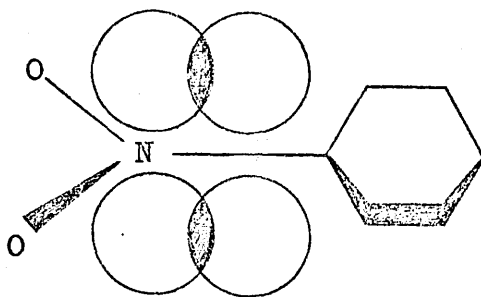
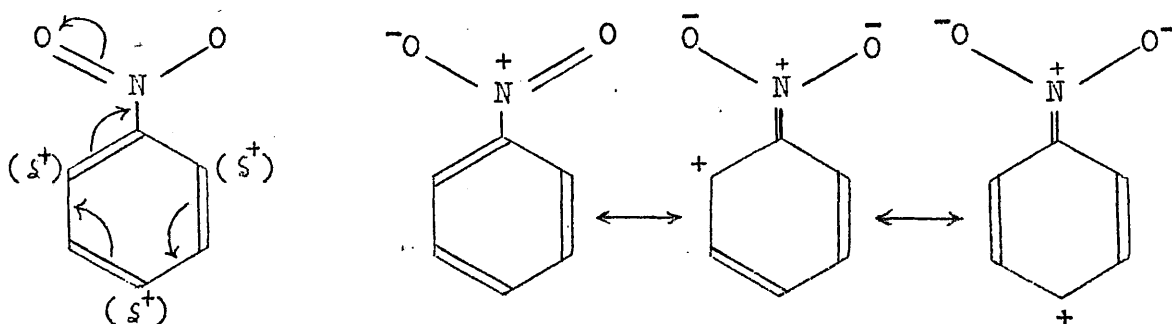
The groups like NH_2 , Cl , OR , $-\text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{R}$ are labelled as + M substituents. Although they also exhibit - I effect, the + M effect opposes it and is more important as it can travel to the p-position with the same intensity as to o-position. Some groups e.g. $-\text{CH}_3$ and $-\text{CR}_3$ are found to exhibit slight + M effect besides their + I effect due to hyper-conjugation (discussed later).

In negative mesomeric effects, the electron attraction depends on the tendency of the positive ionic charge (Y) bound to the conjugated systems and to decrease the covalency acting electronegatively.



The p-nitro benzoic acid is found to be stronger than the m-nitro benzoic acid showing the ability of $-\text{NO}_2$ group of exhibiting a $-M$ effect besides its $-I$ effect.

In maximum overlapping a steric requirement is demonstrated in the need for coplanarity between the $-\text{NO}_2$ group and the benzene ring.



Other groups exhibiting $-M$ effect are $-\text{CONR}_2$,
 $-\text{COOR}$, $-\text{COCl}$, $-\text{CHO}$, $-\text{COR}$, $-\text{CN}$, $-\text{NO}$, etc.

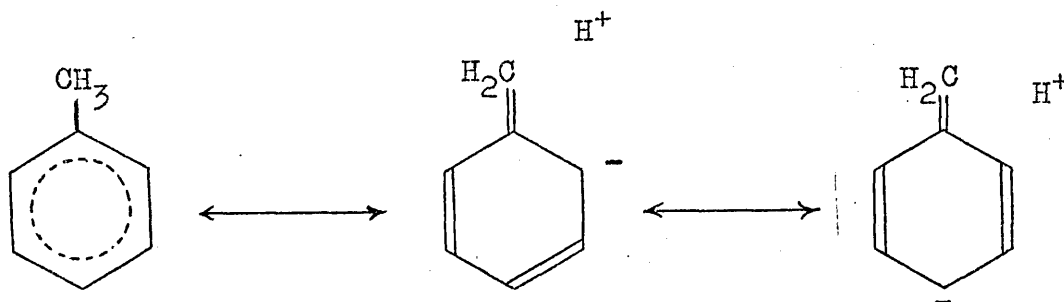
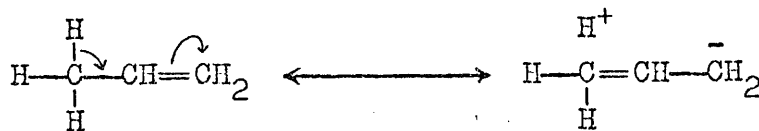
ELECTROMERIC EFFECT:

As in the case of inductomeric effect, some workers, distinguish the mesomeric effect in un-excited states from the effect appearing in the transition state of a reaction and have called it the Electromeric effect. Being a polarisability effect its sole aim is to facilitate the reaction. It is stated⁴ that the amount of conjugative electron displacement in a normal mesomeric state where mesomeric system is produced by conjugation of a single +M or -M group with an unsaturated hydrocarbon residue is nearly always under 10% of what would be involved in a complete conversion to the dipolar structure. (This is evident from the dipole moments). A +M group will exhibit strong +E effect in a reaction where electrical needs of the reaction centre are of right sign, but only weak -E effect, where electrical needs are of opposite sign.

The π -electrons are highly polarisable and cause electromeric polarisability to be of more importance than inductomeric polarisability which is transmitted via σ electrons.

HYPERCONJUGATION:

Baker and Nathan¹⁵ noticed an additional mechanism of electron release by alkyl groups in p-alkyl benzyl systems. The mechanism develops strongly in methyl groups but is found to diminish when alkyl hydrogens are replaced by carbon and it was concluded that the electron pairs of the C-H bonds of the methyl group are less localized than those of C-C bonds and are so able to conjugate, like unshared electron pairs with the unsaturated system.



Toluene is found to nitrate more readily than benzene and resembles anisole, although not apparently having electrons to supply to the ring.

Although theoretically electron release by alkyl groups is expected, it is hard to predict the extent of effect¹⁶ and so the possibility of accounting it for the experimental observation.

STERIC EFFECT:

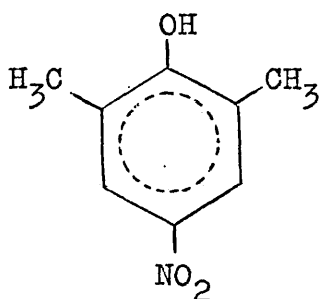
A compound's reactivity is very much affected by availability or non availability of electrons in bonds or at particular atoms. These factors are modified by steric factors which influence the delocalization of π electron by affecting the degree of overlapping between

orbitals.

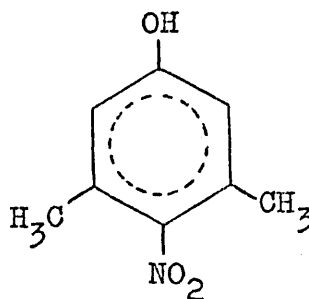
Claus¹⁷ observed that aryl cyanides and benzamides when substituted at o-position were resistant to hydrolysis by usual methods and reagents. Victor Meyer¹⁸ proved the presence of steric hinderance in detail by showing that o-disubstituted benzoic acids are harder to esterify and the esters are harder to hydrolyse than the o-disubstituted phenyl acetic acids in which the site of reaction is removed one atom further out from the branched structure.

The extent of the mesomeric effects is subject to the planarity of the molecule which can be disturbed by the steric inhibition as it effects the dipole moment, reaction speed, rate and equilibria also.

The nitro group increases the acidity of phenolic -OH group present in p-position by means of a -M effect but o-substitution forces the nitro group to lie out of plane and denies the implementing of the -M effect to its full extent. Therefore 4-nitro 3,5-xylenol is found to be a weaker acid than 4-nitro 2,6-xylenol.



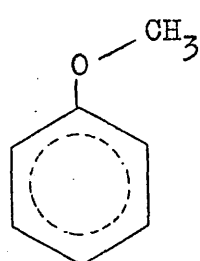
($pK_a = 7.16$)



($pK_a = 8.24$)

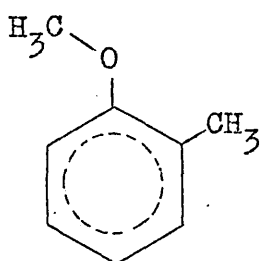
Steric interaction alters the influence of the substituents that enhances the reactivity by resonance. This is illustrated by the relative rates of bromination of anisole (I), 2-methyl anisole (II) and 2:6-dimethyl anisole (III).

The first methyl group increases the velocity by a factor of six. The second methyl group reduces the rate below that of anisole as the $-OCH_3$ group loses its co-planarity with the rest of the molecule and thus overlapping between orbitals containing the charge



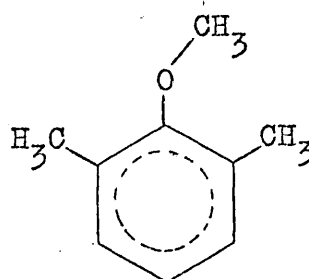
1.0

I



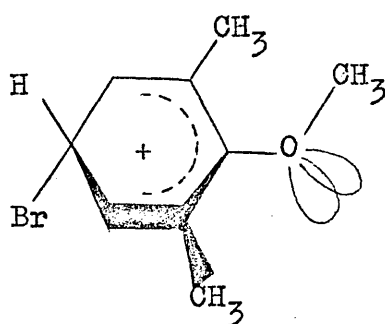
6.3

II



0.39

III



deficiency and the orbitals of the oxygen containing the non bonding electron, affecting and diminishing charge delocalization.

EFFECTS OF SUBSTITUENTS ON REACTIVITY AND ORIENTATION:

Following conclusions can be drawn from the electropolarity of the substituents and the various polarization effects:

- (a) Availability of electrons at o- and p-positions by the substituent already present in the ring, leads to electrophilic substitution in these reaction sites.
- (b) The m-substitution is caused by withdrawal of electrons from these centres by the substituent present in the ring.
- (c) The negative charges are transferred to o- and p-positions.

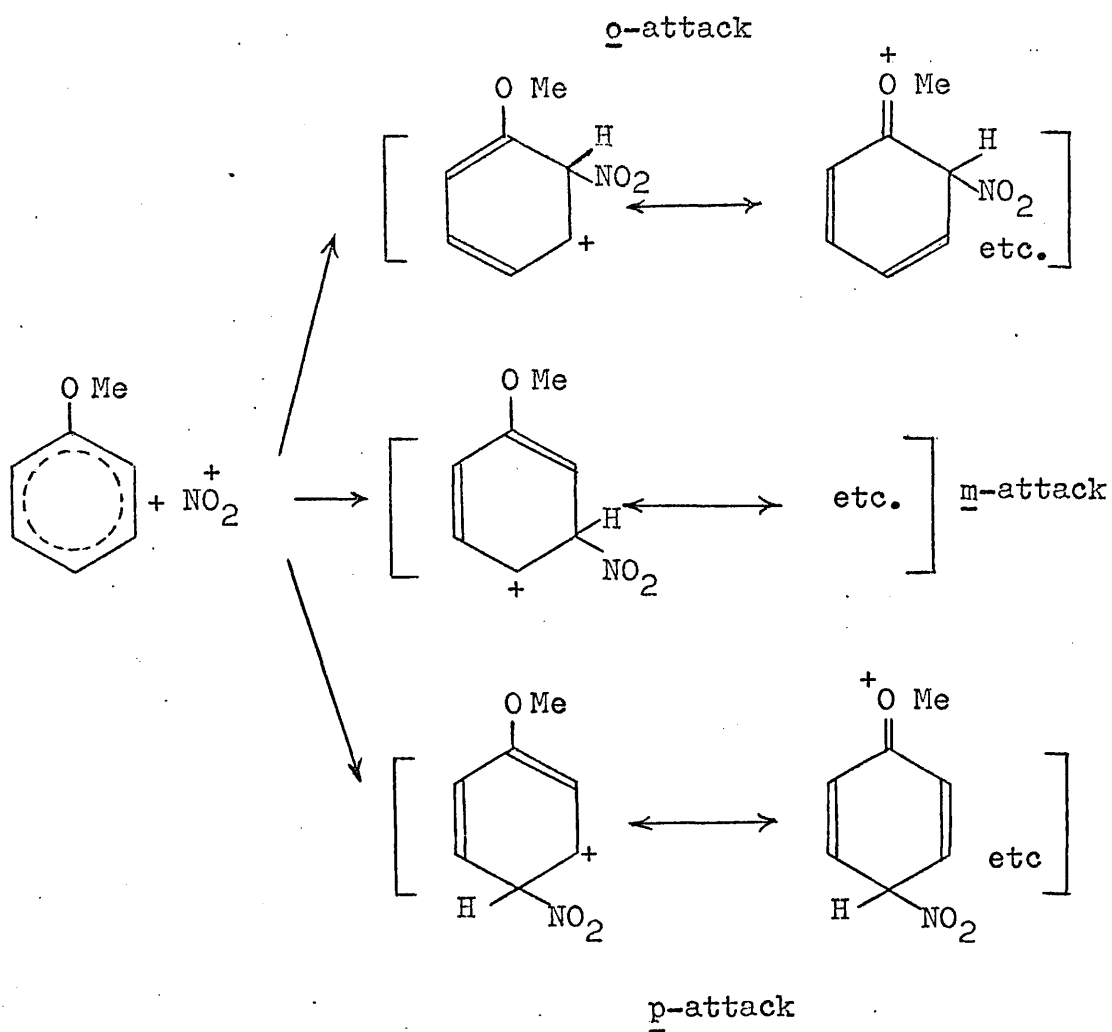
It is also assumed that positive charges selectively deactivate o- and p- positions explaining that m- attack takes place not because of being a more reactive centre but because o- and p- centres are even less reactive.

The influence of the substituent on a rate of reaction has been measured by a competitive method. The specific rate of attack by the nitronium ion on two or more substrates in a single solution is calculated and then the values are compared to explain the influence of the substituent.

The nitronium (NO_2^+) ion enters to an electron rich site and therefore the process is facilitated by electron releasing substituents (e.g. Cl, CH_3 , OH etc) and retarded by electron attracting substituents (e.g. NO_2 , COOEt etc). A few comparisons are given below.

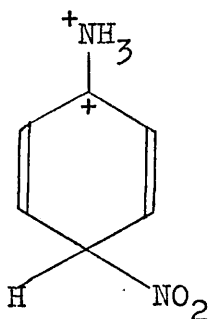
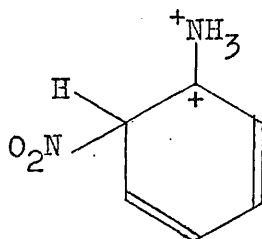
Ph- NO_2	6×10^{-8}	Ph-H	1.00
Ph-Br	0.03	Ph- CH_3	25
Ph-F	0.15	Ph-OH	1000

For nitration of anisole structures can be drawn showing the dispersion of positive charge in the ring by the π electron density drifting from electron rich oxygen atom and thus lowering the energy of the intermediate and the transition state leading to it, in all facilitating an o- and p- orientation. While for nitration at the m-position, the alternating character of the aromatic system does not allow such a structure and therefore charge from the NO_2^+ ion must remain on the benzene ring until the proton departs.



In alkyl groups (substituents), hyperconjugation helps to disperse the positive charge carried in by the attacking electrophile at the o- or p- position.

Substituents like -NH_2 and -NR_2 are strongly o- and p-directing, but in acidic media for nitration, they are converted to the -NH_3^+ and NR_2H^+ groups, which are just as strongly m-directing. Any substituent attached to the benzene ring and bearing a +ive charge is m-directing. The following structures are unstable because of positive charges on adjacent atoms and therefore their contribution to the respective intermediates must be relatively small.



The orienting of some groups is given in the following table:

Groups	Substituent type	Activating influence	Orienting influence
alkyl groups	+I	+	<u>o</u> -, <u>p</u> -
aryl groups	+I , ± M	+	" "
-O ⁻	+I , + M	+	" "
-NR ₂ , -NH-CO-CH ₃ , -OR	-I , + M	+	" "
-Cl, -Br, -CH=CH-NO ₂	" "	-	" "
-NMe ₃ ⁺	-I	-	<u>m</u> -
-NO ₂ , -CN, -CCl ₃ , -COOH,	-I , - M	-	<u>m</u> -
-SO ₂ OH, -COR, -CHO			

ORTHO TO PARA - RATIO

The statistically expected ortho to para ratio is 2:1, but this is rarely observed. A general analysis of data regarding the ratio between o- and p- substitution was done by Ingold¹⁹ in 1926 and showed that

(a) the primary steric effect decreases the o- reactivity.

(b) -I effect decreases and +I effect increases

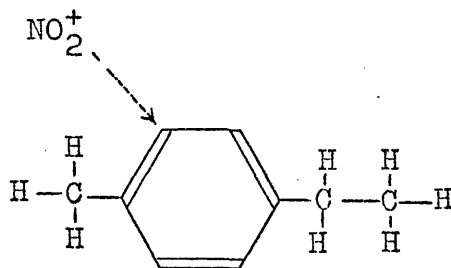
o- > p- reactivity

(c) -M effect decreases and +M effect increases

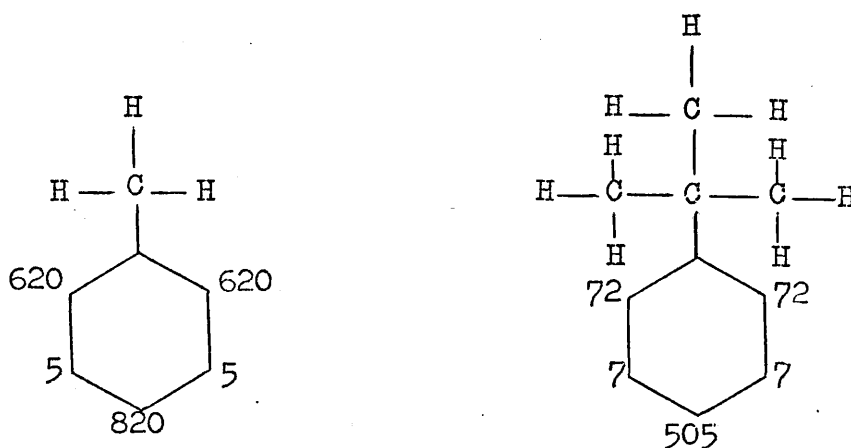
p- > o- reactivity

The steric effect on the o- and p- ratio is seen in the nitration of alkyl benzenes. Polar effects of two alkyl groups are not very much different and thus decreases in the extent of o- substitution in case of large alkyl

groups as the directing substituents can be assigned due to steric effect. Le Fevre²⁰ showed that favoured substitution was adjacent to the methyl groups of the p- alkyl toluenes, and this was further established by Brady and Day²¹ for the nitration of ethyl toluene:



Chlorination, nitration and sulphonation of chlorobenzene suggests that as the attacking reagent increases in size the ratio of o- to p- falls. Halogenation of toluene and t-butyl benzene also establishes the role of steric effect on o- and p- ratio; e.g. in the case of chlorination by chlorine:

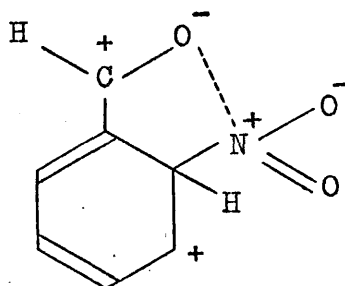


The proof of the statement that +I substituents increase o-reactivity more than the p-positions while -I substituents decrease o-reactivity more than the p-reactivity, is found in the series of PhF, PhCl, PhBr, and PhI. Nitration of these compounds gives a clear idea, as shown in the table below:

	PhF	PhCl	PhBr	PhI
<u>o</u> -	12	30	37	38
<u>m</u> -	—	0.9	12	1.8
<u>p</u> -	87	69	62	60

The deactivating intensity overrides the steric hinderance which provides a contradictory situation in this case. The electron density at the o-position is less than at the p-position in the case of more electronegative Fluorine and thus the p-position is favoured by the electrophile.

Groups like -CHO, -COCl, and -NO₂ are known to have -I effect besides having steric requirements, but the o- to p- ratio in these compounds are found to be large. This has been explained by dipole - dipole interaction with the incoming substituent for e.g. nitronium ion.



Looking at the ortho and para - quinonoid structures where the cationic intermediates are stabilized due to the drift of the negative charge from the orienting group x, we find that if the p-quinonoid structure is considered to be more stabilized than the o-quinonoid structure then it can be said that the -M groups deactivate the para position more than the ortho position, increasing the o-/p- ratio. While +M groups activate para position more than the ortho decreasing o-/p- ratio.

There has been evidence for a polarisability effect influencing ortho and para ratio. Orientation by oxy and amino substituents has been found to be dominated entirely by +E effect and was first pointed out by Lapworth and Robinson.²² They noted that nitro substituted diazonium ions preferred to attack para position of the substrate like 1-naphthyl amine 3 and 5 sulphonic acids. While unsubstituted diazonium ions attacked mostly at ortho position.

ENERGETICS OF REACTION AND CHEMICAL KINETICS:^{6,23}

In the course of a chemical reaction bonds are broken and formed. The reacting molecules are subjected to all kinds of distortion and strain to give, finally the products. This involves the formation of intermediates which implies a change in the energetic content of the system, the difference being the free energy of reaction. The transition state (or Activated complex) has the least stable arrangement of atoms with the highest possible free energy allowing the most favourable route from the initial to the final state. A free energy of activation is

required for its formation, and the time of its existence is comparable to that of molecular vibrations.

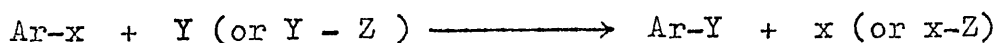
The reaction rates are proportional to the product of concentration of species that react to produce the postulated transition state and are determined by the free energy difference between the reacting species and the transition state just as the extent of a reaction at equilibrium depends on the free energy difference between reactants and products.

2,4,5,24,25,26

MECHANISM OF ELECTROPHILIC AROMATIC SUBSTITUTION:

The negative charge above and below the plane of the ring carbon atoms promotes attack by electron deficient species (electrophilic reagents) and this kind of interaction may give products of addition, substitution or a competition between the two.

The first consequence of the considerable stabilization energy is that substitution reactions are more likely to occur when the formation of an intermediate involves a large symmetry and energy reduction, whilst addition will be favoured if the corresponding loss is comparatively small. The course of the reaction will be guided by the surroundings, solvent, temperature and substituent effects present on the ring carbon atom. The state of hybridisation of the neighbouring carbon controls the possibilities for delocalization of the electrons and therefore the energy barrier to a change of configuration of the unsaturated centre.



where Y may or may not carry a formal positive charge.

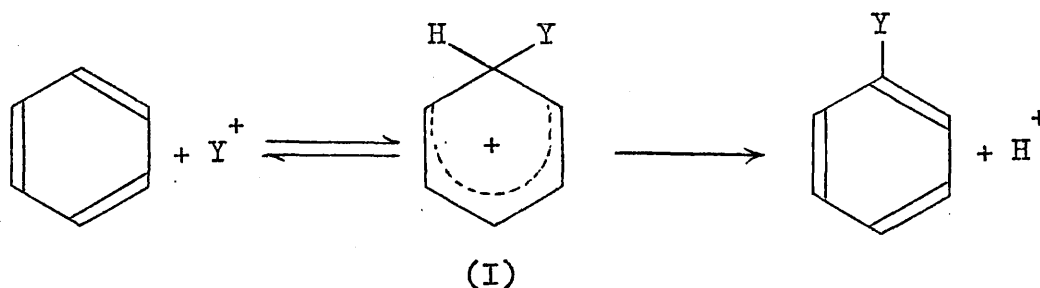
Among the different possible reaction paths, the most studied one is S_{E2} mechanism and the situation in which $x=H$ and $Y \neq H$ constitutes the kind of substitution of widest applicability including nitration, sulphonation, halogenation and Friedel and Craft's reactions. The two electrons forming the covalent bond between the aromatic compound and the reagent are both supplied by the former.



Chlorine behaving as an electrophile because of the ability of one of its atoms to be displaced as chloride ion.

A benzenoid compound might react with an electrophile in the following way:

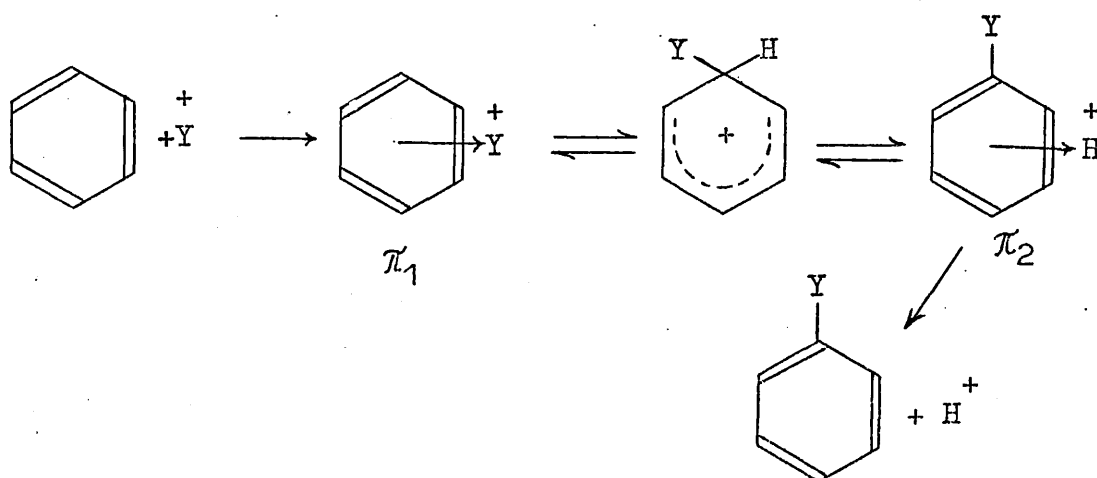
- (a) By a synchronous formation of C-Y bond and cleavage of C-H bond. In the transition state carbon is partially bonded both to Y and H.
- (b) By the addition of the electrophile to the nucleus followed by loss of proton from the adduct, an intermediate (I) being formed [S_{E2} mechanism].



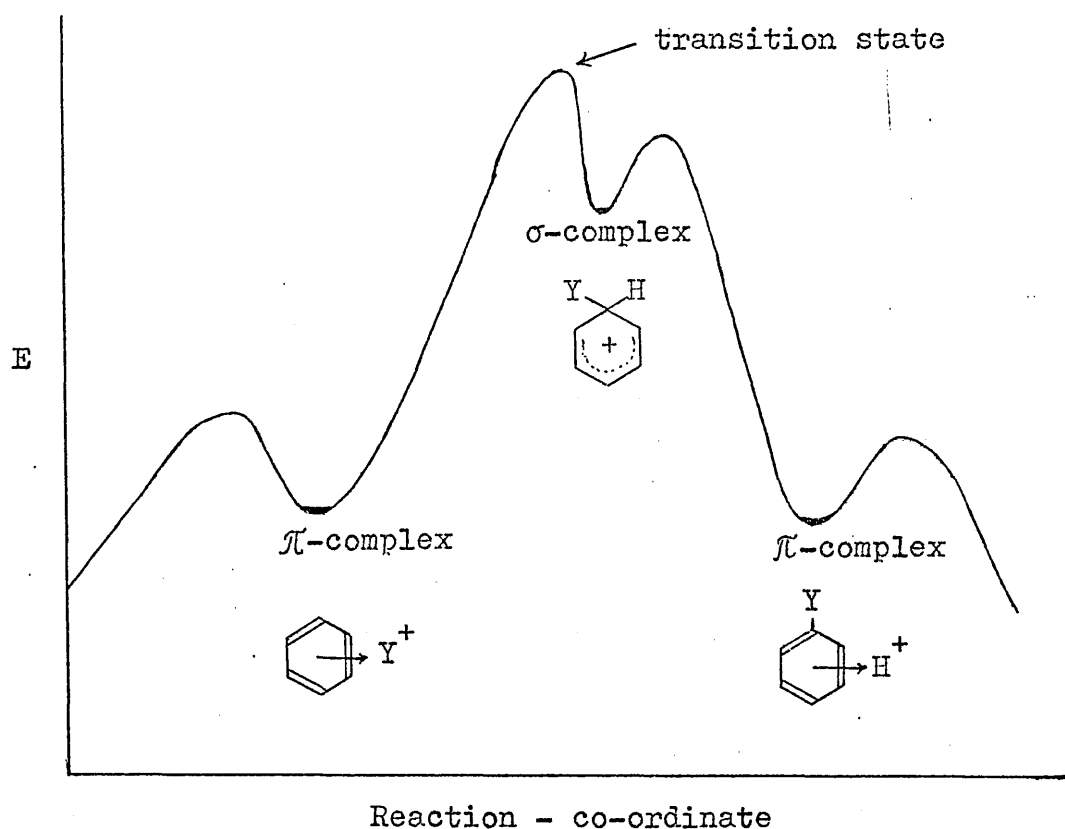
In all the cases the latter path is followed by the reaction.

Formation of the π -complex, by the approaching electrophile and the delocalized π orbitals of the aromatic systems may be the first phase of the reaction. This complex is held by a loose association among the two reactants and is not localized at a particular carbon atom of the ring but is held by the π cloud. In the second phase of the reaction, two π electrons are isolated at one carbon atom of the nucleus thus changing to an sp^3 hybridised tetra-hedral configuration, on which the electrophile becomes actually bonded, the covalent pair being supplied by the former. The resulting, temporary electron deficiency is accommodated in the π -orbitals of the residual aromatic system. This structure is labelled as σ -complex. From this, in the last phase, a proton departs and the final product regains delocalized π -orbitals and the characteristic aromatic stability.

The gain in stabilization helps to provide the energy required to break the strong C-H bond and expel a proton.



This energetic profile of an aromatic substitution in which the transition state on the rate determining step resembles σ -complex is shown below:



This mechanism requires conversion of two π -complexes through an intermediate σ -complex. The formation of a nonlocalized π -complex from the reactants was at first considered to be rate determining; on this basis the rate should be substantially independent of the nature of the substituents in the ring, although the distribution of

products should be governed by the same factors as in the σ -complex route. Later this rate determining step was only considered likely for strongly exothermic reactions,²⁷ and the slow step was suggested to be the conversion of a localized π -complex into σ -complex²⁷. Therefore both rate and products would be dependent on the substituent in a manner similar to that for the σ -complex.

π - COMPLEX: ITS NATURE AND FORMATION:

The properties of the two types of complexes (σ and π) are markedly different. This is seen in the addition compound formed by aromatic hydrocarbons with hydrogen chloride (π complexes) and with hydrogen chloride in presence of aluminium chloride (σ -complexes). While π -complexes are colourless and do not conduct (non-ionic), have low heats of formation and are largely dissociated in solution even at temperature of about -70° ; σ -complexes are coloured and conducting (ionic). When deuterium chloride is used instead of hydrogen chloride, the π -complexes being non-ionic cause no deuterium to be incorporated in an aromatic compound, while σ -complexes being ionic provide a pathway for the exchange of deuterium for hydrogen.

DEWAR'S π -COMPLEXES:

Dewar pointed out the resemblances in a filled p-orbital of an atom to the π -orbital of an olefin or an aromatic ring. To form a so called molecular bond, holding two electrons only, the potential adduct should have a vacant low lying orbital. Filled π -orbitals, typically, donate to p or d and sometimes hybrid orbitals

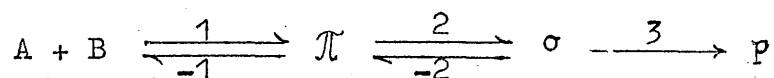
of electrophiles. The p-orbital of a complexed electrophile must have its axis perpendicular to the plane of an aromatic ring, to overlap efficiently with the appropriate orbital of the latter and must be situated on the periphery while a vacant d-orbital can however occupy six fold axis; as the symmetry requirements of the overlapping orbital can now be met.

As stability of these complexes does not depend on van der Waals interactions and is due to the transfer of electrons from donor to acceptor to create a dative covalency, the Dewar's π -complexes in contrast to the molecular complexes, were considered to be formed essentially irreversibly in many reactions.

As the ground state in Dewar's π -complexes is stable, destabilization of first excited state is followed and typically the separation of the two states is too large for charge transfer spectra to occur at wavelengths higher than where the components of the complex absorb. As a result, characteristic spectra are only found in weakly bonded π -complexes e.g. where π -d rather than π -p overlap occurs, as in the adducts of halogens and aromatics. For most examples of interest the π -complex has only one bonding molecular orbital which is occupied by two electrons. The calculated heats of formation of complexes of the types (Ph, x^+) , $(\text{C}=\text{C}, \text{x}^+)$, and $(\text{Ph}^+, \text{Ph}^+)$ gave values (depending on the choice of parameters) in the range of 30-80 kg.cal. mole⁻¹ which although approximate, were considered to justify belief in the existence of these species as intermediates rather than transition states²⁸. The

formation of these complexes can have no consequences on kinetics or products if the complex lie at low - energy levels relative to intermediates or transition states that occur further along the reaction co-ordinate, nor can kinetics or the dependance of rate on medium distinguish between, for example, a bimolecular reaction and a unimolecular reaction of a preformed complex of the same components. Again as the substituent effect does not confirm the formation of a complex, it does suggest that the transition state of the reaction is similar to the complex owing to the similarity between substituent effects on rate and those on the formation of a related complex.

In the following postulated scheme, preferred by Dewar;



either: (a) step 1 is fast and step 2 is slow, both being irreversible.

(b) step 1 is slow and step 2 is fast again both being irreversible.

step 3 is fast in both schemes.

Other combinations of fast, slow, irreversible and reversible steps are possible, some of which would result in a build-up of π or σ -complexes during the reaction depending on the mechanism.

The stabilities of π -complexes depends on the total electron density in the aromatic nucleus which according to the dipole moment measurements²⁹ decreases in the order

R = tert Bu > iso-Pr > Et > Me. The rate of

chlorination of PhR is in the opposite order and is determined by effects which come into operation when the aromatic sextet is considerably more deformed than it is in a π -complex.

It was concluded that only the occurrence of π -complexes could satisfactorily account for the migration of substituents that are sometimes observed during Ar S_E2 reactions. The occurrence of π -complexes is probable in e.g. (a) adducts of hydrofluoric acid and benzene (b) the dipole moment of aluminium trichloride in benzene which is believed to be due to the π -complex formed. Another argument to support the π -complex route³⁰ was that localization of the electrophile into a σ -complex would destroy the aromatic character of the substrate; but a molecular orbital investigation of the σ -complex with benzene has convincingly shown that interaction of the methylene hydrogen with the residual π -orbital creates appreciably large bond orders between the tetrahedral carbon and its trigonal neighbours and restores the otherwise lost aromatic character of the ring to a very considerable extent³¹.

4,8,32,33

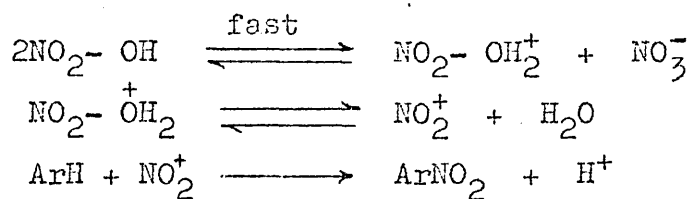
ELECTROPHILIC SUBSTITUTION OF PHENOLS:

Phenol and its homologues are weak acids. The presence of an electron withdrawing group, particularly in the o- and / or p- positions enhances, while that of electron donating group suppresses, the acidic character of phenols. Intra molecular hydrogen bonding also tends to reduce the acidity of phenols. The solubility of phenols in alkali also decreases with the increase in the size and the number of the alkyl substituents. The toxicity of the homologues of phenol decreases and its germicidal value increases as the alkyl substituent becomes more complex. Acidic character seems to be more in halogenophenols due to -I effect of the halogen which seems to be greater than its +M effect. The acidic character of phenol is also lowered by 12%, by ring deuteration and it therefore appears that deuterium is more electron releasing than protium.³⁴

A group activates benzene systems to electrophilic attack by +I or +M effect. Thus activation will be shown by an increase in the rate of electrophilic attack, compared with benzene and in the case of a +M substituent by o- and p- substitution. This section describes the attack of phenols by known electrophiles in an attempt to determine the electronic effect of -OH group upon the ring.

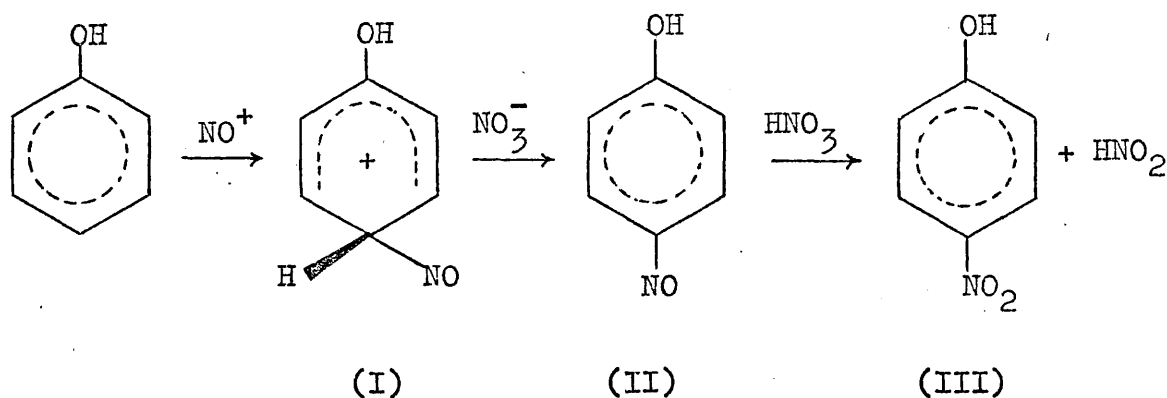
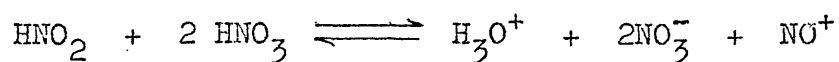
NITRATION:

The generally accepted mechanism involves the rapid protonation of the nitric acid to form the nitric acidium ion which could be considered to be a nitrating species.



The existence of the nitronium ion, the accepted reagent in such processes has been established independently by cryoscopic measurements and the examination of Raman spectra³⁵, and by isolation of nitronium salts (e.g. nitronium perchlorate)³⁶.

Phenol and other highly reactive aromatic compounds are found to undergo ready nitration even in dilute nitric acid and at a far more rapid rate that can be explained on the basis of the concentration of the nitronium ion that is present in the mixture. This has been shown to be due to the presence of nitrous acid in the system which nitrosates the reactive nuclei via the nitrosonium ion:



No nitrous acid need to ^{be} present initially in the nitric acid, for a little of the latter attacks phenol oxidatively to yield HNO_2 . Its concentration thus remains constant throughout the reaction and speeds up the process.³⁷ p-Nitrosophenol (II) has been isolated from the product of an interrupted aqueous nitration of phenol.³⁸ The rate determining step is again believed to be the formation of the intermediate (p- nitrosophenol) II. Nitration by NO_2^+ also takes place simultaneously, the relative amount by the two routes depends on the conditions.

The nitration of phenol gives entirely o- and p-substituted phenols. Homologues also give nitro derivatives with the nitro group o- and p- to the -OH group. It has been shown³⁹ that in acid - aqueous solution, mono nitration products of phenol consists of ortho and para nitrophenols only and the proportion of m-isomeride constitutes less than 0.1% of the mixture. The proportion of these products, though, vary with HNO_2 content of an aqueous acid nitration medium.³⁷

As the nitrosating species compared to nitrating species are weak electrophiles only highly activated nuclei like phenol undergo nitrosation to give ortho and para nitrosophenol.⁴⁰ The suggestion of prior nitrosation in the case of phenol,³⁷ as it also involves electrophilic attack by NO^+ , allows the deduction from nitration products to still hold.

In di alkyl phenols,⁴¹ substitution at ortho and para position to -OH group was favoured as is expected e.g. 3,4-xyleneol when nitrated with nitric acid in acetic acid

medium gave 6-nitro 3,4-xyleneol. The nitration of 2,6-dimethyl anisole⁴² and 2,6-xyleneol⁴³ occurs mainly at position 4 and thus 4-nitro-2,6-dimethyl anisole (50%) and 4-nitro 2,6-xyleneol were the products obtained. The nitration of 2,4-xyleneol⁴³ by fuming nitric acid in acetic acid medium and little water gave 6-NO₂, 2,4-xyleneol in a very high yield. When 3,5-xyleneol was nitrated with nitric acid in acetic acid medium, the products obtained were: 4-nitro, 3,5-xyleneol (29.2%) and 2-nitro, 3,5-xyleneol (18.3%) by the procedure described.⁴⁴ The latter when further nitrated gave 2:4-dinitro, 3,5-xyleneol (84.6%).

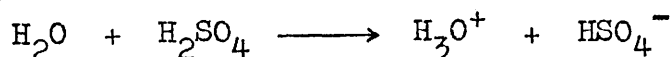
The -OH group thus overcomes the directive effect of the -CH₃ group, itself directing and activating to electrophilic attack.

It is found that C-D or a C-T bond is just as likely to be broken during the process of nitration as is a C-H bond in similar condition and position. Substitution of a C-H bond with a C-D bond does not affect the activation energy for attack by NO₂⁺ at that position.⁴⁵

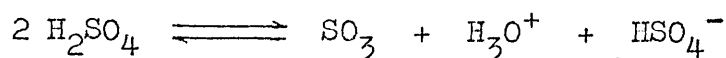
SULPHONATION:^{2,6}

In sulphonation, carried out in concentrated H₂SO₄ (containing small amounts of water) the most likely attacking reagent appears to be SO₃ molecule or its 'solvate' (SO₃·H₂SO₄) as the concentration of SO₃ will be inversely proportional to [H₃O⁺] and to [HSO₄⁺] i.e.

$$[H_2O]^2 \quad 46$$



Along with SO_3 , both of these ions are produced from H_2SO_4 as follows:



As the concentration of the species H_2SO_4 may vary in the acid range studied in the sulphonation kinetics (92-99% H_2SO_4)⁴⁷ and that the activity coefficients of one or more of the species in the equilibrium⁴⁸ may change with the acidity of the medium, the suggestion that SO_3 is the principal sulphonating species must therefore be accepted with some caution.

Sulphonation is a reversible process, the equilibrium favouring the forward process at high acidities and the reverse process of desulphonation at low ones.

It has been long known⁴⁹ that sulphonation at lower temperature favoured the ortho isomer. Obermiller⁵⁰ showed that with H_2SO_4 , even at low temperature, no more than 40% of ortho phenol sulphonic acid was formed along with the para isomer, and phenol hydrogen sulphate, while some workers⁵¹ reported a slightly higher o- content at all temperatures.

As expected, in sulphonation also, substitution occurs at ortho and para position of the phenol and -OH group activates the nucleus to electrophilic attack. The sulphonation of 3,4-xylenol with conc. H_2SO_4 ⁵² produces 6- SO_3H . 3,4-xylenol and p- sec. alkyl phenols gave p- sec. alkyl phenol o- sulphonic acids.⁵³ Sulphonation of the condensation compounds of alkyl phenols with ethylene oxide by adding SO_3 or SO_3 diluted with an inert gas is also reported.⁵⁴

Monosulphonic acids of a phenol (e.g. guaiacol, o-chlorophenol) were also obtained by treating

the molten phenol with liquid SO_3 in approximate stoichiometric proportions.⁵⁵ The 2- SO_3H , 3,5-xyleneol was best prepared by the action of cold $\text{H}_2\text{SO}_4\text{-H}_2\text{O}$ mixture on 3,5-xyleneol.⁴⁴ Here the sulphonation occurs ortho to -OH as expected.

The deuterated aromatics⁵⁶ are sulphonated more slowly than the corresponding protonated compounds and the reaction also shows a solvent isotopic effect being slower in deuterium containing media.⁵⁶

DEUTERATION:

The qualitative study of deuteration of aromatic nucleus by deuterioacids concluded⁵⁷ that hydrogen exchange is a typical electrophilic substitution. It is a reversible substitution completely balanced except for isotopic differences.

The hydrogen exchange follows the usual orientation laws for electrophilic aromatic substitution. In case of phenol and anisole, facile deuteration was observed. The exchange takes place at the three nuclear positions. This number is determined by the deuterium uptake, with allowance for any side chain deuteration. The three exchanging protons in the case of phenol were those of the o- and p- positions, as formally proved by Best and Wilson.⁵⁸ All hydrogen except m-hydrogen, participated equally in the D-H exchange. No significant difference in the rate of reaction at o- and p- position was found to exist.⁵⁹ The determination of D in the phenol which was deuterated with D_2O in sealed ampoules (quartz) at 250° , also showed that only less than 1% of D had regrouped to the m-position

from the HO-location.⁵⁹

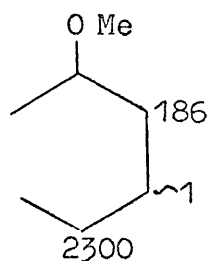
The H- arrangement in tagged phenol (PhOD) to C_6H_4DOH , with D passing from the hydroxyl group to three possible positions in the ring which have equal probability is found to be kinetically of first order.⁶⁰ The nuclear hydrogen of the phenol were successfully deuterated in acidic medium by M. Koizumi as described.⁶¹ Tyron, Brown and Kharasch⁶² used deuterio alcohol to deuterate phenol and phenol ethers and also studied to set up a quantitative basis for comparison of variously substituted phenols and their ethers with respect to the rates of exchange of nuclear hydrogen atoms.

2,4
MERCURATION:

The best known reaction for the replacement of hydrogen of an aromatic ring by a metal atom is mercuration. In a polar medium and suitable conditions there is strong evidence that an electrophilic reagent is involved. Benzene⁶³ or toluene⁶⁴ when treated with mercuric acetate in acetic acid, the selectivity of the reagent increases linearly with the concentration of perchloric acid, when used as the catalyst, until this concentration is equal to that of mercury acetate.⁶⁴ The reaction is of first order with respect to both, the substrate and the Hg(II) ion, and the attacking entity is supposed to be a mercuric ion complexed with the anion from the catalyzing species.⁶³

The substitution takes place at ortho and para positions, as expected. Brown and his collaborators⁶⁵ measured the distribution of reactivity on the benzene

ring by orienting substituents for mercuration by mercuric acetate in acetic acid at 25°. For anisole the partial rate factors are found to be:



Kobe and Doumani⁶⁶ reviewed direct and indirect methods of mercuration and found that mono substituted aromatic compounds e.g. phenol usually led to ortho and para derivatives.

Phenol when treated with mercuric acetate in boiling water, followed by addition of sodium chloride gave *o*-chloro mercuri-phenol.⁶⁷ With mercury acetamide⁶⁸ the corresponding phenols yield 4-hydroxymercuri 2-nitrophenol and 2-hydroxy mercuri 4-nitro phenol, 1-hydroxy mercuri β -naphthol, 4-hydroxy mercuri α -naphthol, tris-hydroxy mercuri phloroglucinol. Phenols can be mercured by Ar_2Hg compounds⁶⁹ at 50-150° for 1-12hrs. yielding mono, di- and tri- mercuri derivatives. The rates of mercuration depend on aromatic substituents which can be placed in a descending reactivity order: *p*- $\text{H}_2\text{N}\cdot\text{C}_6\text{H}_4$, *o*- $\text{HO}\cdot\text{C}_6\text{H}_4$, *p*- $\text{MeO}\cdot\text{C}_6\text{H}_4$, *m*- $\text{O}_2\text{N}\cdot\text{C}_6\text{H}_4$, *o*- $\text{O}_2\text{N}\cdot\text{C}_6\text{H}_4$ and $\text{HO}_2\text{C}\cdot\text{C}_6\text{H}_4$.

Mercuration is a reversible process. As for example Dimroth observed that phenylene dimercury diacetates are demercured by hydrochloric acid.⁷⁰ Demercuration affects the distribution of mercuration products (ortho and para)

with time e.g. in toluene.⁷¹

Rate of mercuration of hexa-deuterobenzene is found⁷² to be 4.7-6.7 times smaller than the rate of mercuration of benzene. Although the mechanism is not established, the isotope effect shows that if the mechanism is S_E2 with the prior formation of a cyclohexadienylium adduct, then proton loss from the adduct must be rate-controlling step.

HALOGENATION:^{2,4,5,6}

Halogenation could take place by molecular halogen or by positive halogen which may possibly be a free ion e.g. Cl^+ (chlorinium ion) and the cations derived from these by co-ordination with a neutral nucleophilic species e.g. $ClOH_2^+$ (hypochlorous acidium ion). Molecular halogen, which is a weak electrophile due to its "non polar" bond, is polarized by a Lewis acid catalyst. The polarization is considerably more powerful in the case of positive halogen.

IODINATION:

As molecular iodine is the least reactive halogens in aromatic substitution and as the reaction is reversible so that the hydrogen iodide produced in the reaction must be removed to allow the reaction to complete; iodination of aromatic compounds by molecular iodination is not much known.

Iodination of phenol by iodine in water is known^{73,74} and ortho and para orientation is observed.⁸³ Under these conditions the absolute rate of the corresponding iodinating term in the iodination of phenol is more rapid by a large factor than that of aniline, as expected⁷⁶ if

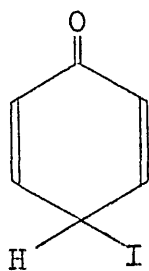
reaction occurs on PhO^- but not on PhOH .⁷⁵ Thus iodination in each case is either effected by H_2OI^+ or I^+

$$-d [\text{I}_2]/dt = k' [\text{PhO}^-] [\text{H}_2\text{OI}^+] \dots(1)$$

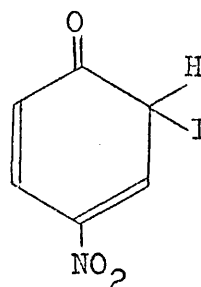
$$-d [\text{I}_2]/dt = k'' [\text{PhO}^-] [\text{I}^+] \dots(2)$$

While ICl , an iodinating species is found to be the reagent in acetic acid, in aq. HCl its reaction has been interpreted as involving a positive iodinating species. Berliner studied⁷⁷ the iodination of 2,4-dichlorophenol and anisole by ICl in aq. HCl and on similar kinetic grounds has reached the conclusion that a positive iodinating species is involved in the reaction. Recently it has been shown that iodination in aqueous solution can equally well be interpreted as involving molecular iodine. From the observations of the effect of the concentration of iodide ion on the rate and on the kinetic isotope effect for the iodination of 4-nitrophenol, it has now been concluded that molecular iodine is the reagent.⁷⁸

Where as in most eletrophilic substitution there is no isotopic effect and the intermediate is apparently converted very rapidly into the products relative to its rate of reversion to reactants, a large isotope effect should occur in the iodination of phenols if reaction takes place on the phenoxide ion, for the intermediates formed in e.g. para substitution of phenol and in substitution of 4-nitrophenol are I and II respectively and these cyclohexadienones are isolable under suitable conditions.

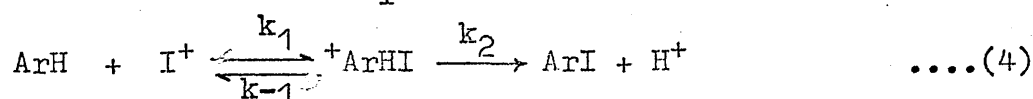
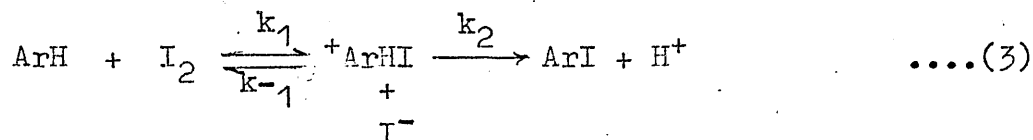


I



II

Grovenstein and Kilby⁷⁹ observed that the iodination of 2,4,6-trideuterophenol by iodine is markedly slower than that of phenol; the hydrogen isotope effect is in the ratio 1:4. This isotope effect gives no positive evidence as to the nature of iodinating species and both equations (3) and (4) may therefore represent the reaction where $k_{-1} > k_2$.



In phenol molecule, I enters para and then ortho to the -OH group when iodinated by the method described.⁸⁰ Similarly 3,4-xylenol when iodinated gave 6-iodo-3,4-xylenol. While 3,5-xylenol gave a di-iodo-3,5-xylenol as the product. Tronov and Kolesnikova⁸¹ iodinated benzene and alcoholic solutions of phenol in the presence of pyridine, nitrobenzene etc. and the reaction was carried

out at 20°. Rate of iodination was increased in pyridine and decreased in nitrobenzene. Iodination products obtained were: 77% p- and 23% o- iodophenol.

Iodine monochloride in dioxane has been used in the iodination of phenol and resorcinol by the method described,⁸² and mixed o-, p- iodophenols and 2,4,6-triiodo-resorcinol were respectively obtained. Resorcinol when treated with ICl in dioxane in presence of sodium bi-carbonate gave an oil which slowly yielded some 4-iodo-resorcinol.⁸²

BROMINATION:^{2,4,5,91}

Molecular bromine is considered to be the attacking species in the bromination of phenols and anisoles by bromine in water,^{83,84} or by bromine in nitromethane⁸⁵ or carbon tetrachloride.⁸⁶ Molecular bromine may also be obtained from N- bromoamides, which can be of use in brominations of aromatic compounds.⁸⁷ Bromination by a solution of bromine in acetic acid or aqueous acetic acid also involves molecular bromine.^{88,89}

Solutions of bromine are in general less reactive than solutions of chlorine and therefore are convenient to brominate aromatic compounds containing fairly powerfully ortho and para directing substituents. Polar conditions, polar catalysts and high reactivity of the substrate leads to nuclear substitution; thus anisole and phenolic ethers can be brominated directly using these reagents.⁹⁰ Usually substitution is preferred at the para position to the directing group, if available.

In general phenols are more readily halogenated in

polar solvents, as the bromination of phenol in carbon tetrachloride proceeds very slowly in the absence of water, but addition of water leads to the very rapid formation of tribromophenol.⁹² Thus the hypobromous acid formed by hydrolysis is very potent compared to the bromine molecule, as a brominating agent. On other hand, m-nitrophenol is brominated by bromine water about a thousand times as fast as by aq. hypobromous acid and here the activity was ascribed to bromine atoms probably carrying positive charge. However no distinction can be made between Br^+ and H_2OBr^+ as the attacking entity on the basis of the results obtained so far⁹²⁻⁹⁵ and an attempt to distinguish between them has been unsuccessful⁹⁷ as, in the bromination of aromatic compounds by hypobromous acid in aq. HClO_4 at 25° , $\log_{10} k_2$ varies linearly with both -Ho and -Jo.

A suspension of phenol when treated with bromine in hydrobromic acid as described⁹⁸ and when the crude product obtained is filtered, washed, dried and recrystallised gave 87% yield of 2,4- dibromophenol. Phenol does not give tribromophenol until more than two molecular equivalents of bromine have been added.⁹⁸

Phenols when brominated by means of bromide-bromate solution, generally gave ortho and para brominated derivatives.⁹⁹ De La Mare and Ridd⁵ showed that considerable, but not exclusive, p- orientation is observed when phenolic ethers and phenols are brominated, e.g. anisole when brominated by bromine in acetic acid gave 90% yield of p- bromoanisole.

2,5,-Me₂ C₆H₃OH on bromination is reported¹⁰⁰ to give 4-2,5-Br,Me₂C₆H₂OH in good yield. Yanovskaya, Terente'v and Belen'kiĭ used dioxane dibromide for bromination of various phenolic ethers and phenols.¹⁰¹ By the method described; bromination of phenol gave 88% p-Br C₆H₄OH. Similarly anisole gave 57% of para derivative. 3,5-xylenol and resorcinol gave 75% and 97% of their 4-Bromo derivatives, respectively. By varying the quantity of the reactants resorcinol was also brominated to give 4,6-dibromo derivative. Guaiacol was also found to give 88% of 5-bromo-guaiacol.

Bromination was also accomplished by treating the aromatic compound with IBr.¹⁰² By following the procedure anisole, 2,6-xylenol and o-cresol are found to give p-bromo-anisole, 4-bromo-2,6-xylenol and 5-bromo-o-cresol respectively.

N-bromo-succinimide in CCl₄ has been used to brominate the xylenols.¹¹⁰ Here the nuclear bromination of xylenols follows the same rules as for aromatic substitution with elemental bromine. 2,3-xylenol, when treated with equimolar amount of N-bromo-succinimide and two molar equivalents respectively gave 20% of 4-bromo derivative and 80% of 4,6-dibromo derivative of the xylene. Similarly 3,4-xylene gave 25% of 2-bromo derivative and 2,6-dibromo derivative of xylene when treated with one mol. and two mol. of N-bromo-succinimide.

2,4,5,91

CHLORINATION:

The chlorination of phenols by hypochlorous acid in aqueous solution has been studied by Soper and Smith¹⁰³

and conclusion was drawn that the reaction is either between the hypochlorite ion and unionised phenol or between the unionised hypochlorous acid and the phenoxide ion. The second of these alternatives was supported by detailed analysis of kinetics. If a little hydrochloric acid was added to a solution of phenol or a phenolic ether and hypochlorous acid, a rapid reaction ensued, the rate being independent of the phenol concentration, the chlorine generated attacking the phenol or phenolic ether, instantaneously. This proved chlorine molecule to be a more powerful chlorinating agent than the hypochlorous acid molecule.

Molecular chlorine was also found to be the reactive species¹⁰⁴ in the chlorination of aromatic ethers using chlorine in acetic acid.¹⁰⁵ As in bromination, molecular chlorination is achieved by N-chloro-amides, acidified by hydrochloric acid.¹⁰⁵

Recently, the acidified hypochlorous acid is believed to have a positive chlorinating species,^{93,106,107} though there is some doubt as to the exact nature of the reagent. No distinction can be drawn between Cl^+ and H_2OCl^+ as the significant halogenating species. Evidences show that the hypochlorous acidium ion is not reactive enough to attack any but the most activated nuclei; less reactive aromatics being attacked by Cl^+ . Although thermodynamic calculations of the equilibrium constants for the formation of both H_2OCl^+ and Cl^+ ¹⁰⁸ does not support the kinetic evidence and the problem is as yet not resolved.

Chlorination of phenol with chlorine gave a mixture of mono chloro phenols which vary in composition from

p-/o- 17:1 in molten phenol¹⁰⁹ to 1:28 in CCl_4 .¹¹¹ While with copper (II) chloride p-/o- ratio of the chlorophenols varied from 6:1 to 10:1 in an irregular fashion, indicating a marked preference to p-orientation.¹¹² On other hand Crocker and Walser¹¹³ obtained equal amounts of o- and p-chlorophenol by reacting phenol with aqueous CuCl at 275°.

Treatment of aqueous phenol with chlorine¹¹⁴ and of molten phenol with chlorine¹¹⁵ gave high yields of 2,4-dichlorophenol. Molten phenol when sprayed with chlorine at initial temperature of 50° and final temperature of 75° gave 98% yield of 2,4,6-trichlorophenol.¹¹⁶

m-Xylenol when chlorinated by HCl in water and in presence of Cu_2Cl_2 , as described¹¹⁷ gave an organic layer which was subjected to gas liquid chromatography for separation and was identified to contain: m-xylenol 3.0, o-Cl-xylenol. 3.0, dichloro-m-xylenol 0.4, and p-Cl-xylenol 93.62%, thereby indicating remarkable preference for p-substitution. Crocker, Henry and Walser¹¹⁸ obtained p-chloro derivatives of phenol, m-xylenol and o-cresol in ~ 90% yield, by chlorinating with CuCl_2 in a toluene suspension and in aqueous solution.

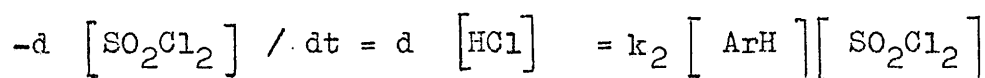
As expected chlorination of phenol always takes place at ortho and para position to -OH group sequential whether substitution or oxidation products¹¹⁹ are the final result.

SULPHURYL CHLORIDE AS AN ELECTROPHILE:

Compounds such as paraffin hydrocarbons, aliphatic acids, aromatic hydrocarbons, aldehydes etc. can be chlorinated in the dark by using sulphuryl chloride in presence of a catalyst, e.g. organic peroxide, far more rapidly and conveniently than is possible by the use of elementary chlorine and light as a source of chlorine atoms.¹²⁰ In aliphatic substitutions and in the reactions of some aromatic hydrocarbons with sulphuryl chloride at 80°, the reaction is suggested to undergo a homolytic mechanism.¹²¹ The homolytic mechanism was also found in cases where the aromatic ether has been isolated by distillation from a solution in diethyl ether.¹²² Compounds such as 1-bromo-2,4-dimethoxybenzene, 1-chloro-2,4-dimethoxybenzene and anisole gave high second order rate constants. Although good second order plots were obtained during 70% reaction, the order of reaction could not be strictly defined. More over, when purified by steam distillation from FeSO₄ the compounds mentioned, gave far low^{er} second order rate coefficients.¹²² In these anomalous reactions, the structures of ethers does not play a major role in determining the rate and it can be ascribed to the attack by chlorine radicals on the ether thereby undergoing homolytic reaction.

Sulphuryl chloride has also been used exclusively for the chlorination of phenols,¹²³ phenolic ethers,¹²⁴ reactive aromatic hydrocarbons¹²⁵ and other aromatic nuclei in presence of halogen carriers.¹²⁶ Highly activated aromatic compounds are believed to undergo an electrophilic attack by sulphuryl chloride from the

nature of substitution products obtained, at room temperature and in the absence of a catalyst.¹²⁷ The conclusion drawn by the detailed study of the kinetics of reaction of 3,5-dimethyl-anisole^{128,130} was that the reaction proceeds via a bimolecular mechanism, involving one molecule of each reagent in the rate determining stage and is of second order. The substitution occurs readily at room temperature and the products formed are similar to those formed by the molecular chlorination¹²⁵ and are those expected from a heterolytic process.¹²⁴



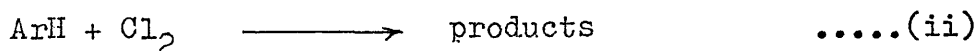
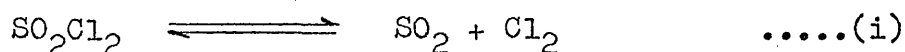
The heterolytic mechanism is further supported by the fact that the rate coefficient ($3.8 \times 10^{-4} \text{ M}^{-1} \text{ sec}^{-1}$) is unaltered by the presence of light, iodine, or benzoyl peroxide, although an alkyl peroxide might be expected to be a more efficient initiator, as shown in some reactions of sulphuryl chloride.¹²¹ The magnitude of the effects of the methyl groups in the series of increasing reactivity in anisole, 3-methyl-anisole, 3,5-dimethyl-anisole and 2,3,5-trimethyl anisole is more in keeping with a heterolytic than with a homolytic mechanism.¹²⁸ The reaction is also sensitive to the solvent used and rate coefficient increases with the increase of dielectric constant of the solvent, for example in the reaction of 3,5-dimethyl anisole with sulphuryl chloride as the solvent is changed from benzene ($k_{\text{rel}} = 1$) through chlorobenzene (10) and *o*-dichlorobenzene (40) to nitrobenzene ($> 10,000$).¹²⁸

The chlorination of naphthalene and its derivatives¹²⁹ e.g. 2-methoxy-naphthalene, by sulphuryl chloride strongly suggest it to be an electrophilic process, since the reactivity is sensitive to structure in the direction that electron release to the reaction centre accelerates and electron withdrawal retards the reaction.

From the stoichiometry of the reaction the heterolytic process involving electrophilic attack upon the benzene ring system must be by some species derived from one molecule of sulphuryl chloride. If solvated and unsolvated forms of the same electrophile are considered to be equivalent, four possible sources of electrophilic chlorine can be suggested:

(1) MOLECULAR CHLORINE:

The suggestion that molecular chlorine formed by the slow reversible decomposition of sulphuryl chloride (sequence i), can be the electrophile is rejected by the fact that the reaction is not inhibited by added sulphur dioxide.



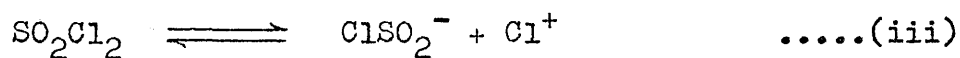
The linearity of the second order plots for the reaction of 3,5-dimethyl anisole with sulphuryl chloride at 25°, show that the sulphur dioxide produced during the reaction also has no effect.¹²⁸ The reaction is of first order in aromatic compound demonstrating the absence of the involvement of a rate-determining formation of molecular chlorine which is expected to show a zero order

kinetics in aromatic compound instead, due to its high reactivity with the anisole.¹²⁸

Molecular chlorine does contribute slightly in the reaction by sulphuryl chloride in nitromethane but in a less polar solvent like chlorobenzene, there was no evidence of its intervention.¹³²

(2) CHLORINIUM ION, Cl^+ :

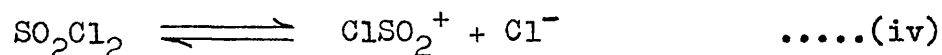
This ion could be produced by direct heterolysis of sulphuryl chloride equation (iii). The hydrogen chloride formed during the reaction ought to introduce a marked retarding effect and so should the development of sulphur dioxide on the second order coefficient during the chlorination by way of the pre-equilibrium:



The equilibrium $Cl^+ + Cl^- \rightleftharpoons Cl_2$ lies far to the right and a decrease in the rate of the reaction should occur. Contrary to this the second-order rate constant for chlorination is unaltered during 70% of reaction. Thus the role of chlorinium ion as the effective electrophile is not likely.^{128,130}

(3) CHLOROSULPHINIUM ION, $ClSO_2^+$:

The development of chloride ion, formed by the heterolysis equation (iv), again should retard the rate



of reaction, with time. More-over such an electrophile would be expected to act as a source of electrophilic sulphur and to form arenesulphonyl chlorides, which are found¹²⁸ to be formed only in traces.

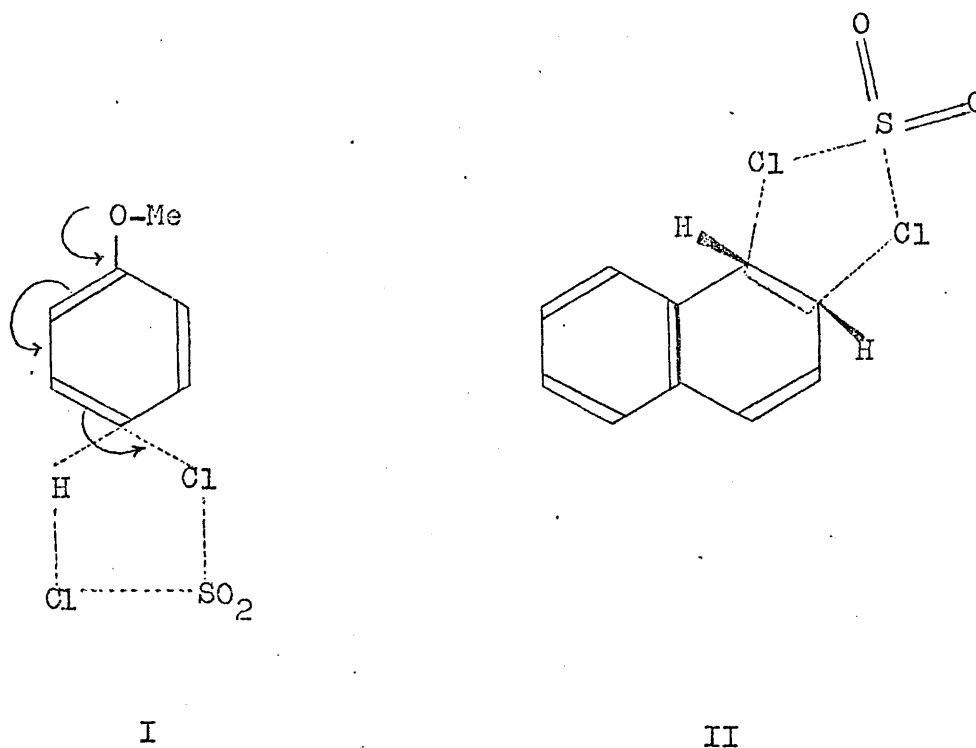
(4) MOLECULAR SULPHURYL CHLORIDE $\text{Cl}^+-\text{SO}_2\text{Cl}$

The electrophile which attacks phenols and aromatic ethers under the condition mentioned¹²⁸ is rather more mild towards aromatic systems than molecular chlorine, which allows an important deduction about the nature of the electrophile.

The molecular sulphuryl chloride can act as a direct source of electrophilic chlorine through the incipient heterolysis^{136,137} $\overset{\delta+}{\text{Cl}}-\overset{\delta-}{\text{S}}\text{O}_2\text{Cl}$ and this way the lack of effect of sulphur dioxide and hydrogen chloride upon the rate of substitution can be explained,¹²⁸ since the liberation of both these entities would occur either at or after the transition state. In the case of alkyl benzenes too, the nature of products, and the sensitivity of the reaction to substituent effects, the view that molecular sulphuryl chloride attack the aromatic system by a heterolytic mechanism is strengthened.¹³²

TRANSITION STATE:

The increase in the rate coefficient for the reaction of 3,5-dimethyl anisole with sulphuryl chloride in chlorobenzene with the change in dielectric constant of the solvent¹²⁸ indicates the formation of a transition state more dipolar than the reactants themselves. This possibly might be cyclic, as shown for anisole (I)¹²⁸ and naphthalene (II).¹²⁹



The kinetics indicate that the transition state incorporates one molecule of the aromatic system and one of the sulphuryl chloride. The high response of reactivity to change in structure is a clear indication that the electrophilic character of chlorine dominates the electronic requirements of the reaction up to the point at which the energy barrier is passed.¹²⁸ Brown's σ^+ for aromatic ethers gives a reaction constant, ρ , of -4.0 ± 0.2 indicating that considerable charge is being developed in the transition states of the reactions, and hence that a heterolytic mechanism is involved.¹²²

REACTION MECHANISM & KINETIC STUDY OF THE REACTIONS OF
HIGHLY ACTIVATED SYSTEMS WITH SULPHURYL CHLORIDE:

Sulphuryl chloride being a mild reagent is successfully used on highly activated systems. Besides the polarity of

solvent, the reaction was also strongly influenced by the effects of substituents of the aromatic ether or phenols. Some of the compounds whose kinetics have been studied and which are of some interest in conjunction with the present work, are given below; along with their observed rate constants.

TABLE 1

Comparison of rate constants for reactions of ArOH and ArOMe respectively with SO_2Cl_2 in PhCl at $25^\circ 122$, $^* -131$

$[\text{ArOH}] = [\text{ArOMe}] = \sim 0.10 \text{ M.}$

<u>Compounds</u>	$\frac{k_2}{(1.\text{mole}^{-1}\text{sec}^{-1})}$
anisole	ca. 6×10^{-7}
<u>m</u> -methyl anisole	2×10^{-5}
2,3,-dimethyl anisole	2.4×10^{-5}
3,5-dimethyl anisole	3.8×10^{-4}
2,3,5-trimethyl anisole	1.7×10^{-3}
*2,3,6-trimethyl anisole	5.0×10^{-6}
*2,3,5,6-tetramethyl anisole	3.0×10^{-6}
*meta-methyl phenol	6.4×10^{-5}
*3,5-dimethyl phenol(xylenol)	5.0×10^{-4}
*2,3,5-trimethyl phenol	5.0×10^{-3}
*2,3,6-trimethyl phenol	1.7×10^{-4}
*2,3,5,6-tetramethyl phenol	4.0×10^{-3}

TABLE 2

Kinetics of reaction of 3,5-dimethyl anisole and sulphuryl chloride at 25.° 128

[ArOMe]	[SO ₂ Cl ₂]	solvent	$\frac{10^4 k_2}{(1.\text{mole}^{-1}\text{sec}^{-1})}$
0.1361 M.	0.1000 M.	PhCl	3.96 ± 0.12
0.2506 M.	0.1000 M.	PhCl	3.82 ± 0.03
0.2523 M.	0.490 M.	PhCl	3.78 ± 0.08
0.2326 M.	0.2000 M.	PhH	0.40 ± 0.01
0.1635 M.	0.1678 M.	<i>o</i> -C ₆ H ₄ Cl ₂	13 ± 2
0.1553 M.	0.962 M.	PhNO ₂	> 3800

TABLE 3

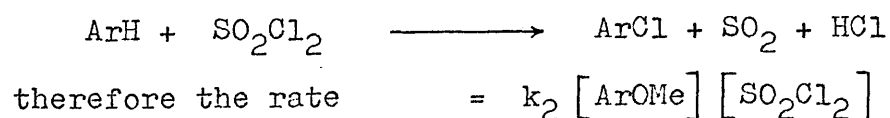
Kinetics of reaction of 3,5-xyleneol with SO₂Cl₂ at 25.° 131

[ArOH]	[SO ₂ Cl ₂]	solvent	$\frac{k_2}{(\text{M}^{-1}\text{sec}^{-1})}$	$\frac{k_3}{(\text{M}^{-2}\text{sec}^{-1})}$
0.020 M.	0.0907 M.	PhCl	9.8x10 ⁻⁴	1.1x10 ⁻¹
0.040 M.	0.0907 M.	PhCl	8.8x10 ⁻⁴	3.3x10 ⁻²
0.060 M.	0.0907 M.	PhCl	9.0x10 ⁻⁴	5.6x10 ⁻²
0.240 M.	0.0615 M.	PhCl	8.8x10 ⁻⁴	3.5±0.5x10 ⁻³
0.246 M.	0.0805 M.	PhCl	10.9x10 ⁻⁴	
0.50 M.	0.0860 M.	PhCl	16.7x10 ⁻⁴	
0.498 M.	0.0961 M.	PhH	7.60x10 ⁻⁵	6.5x10 ⁻⁴
0.2505 M.	0.0961 M.	PhH	1.59x10 ⁻⁴	6.0x10 ⁻⁴
0.0423 M.	0.0981 M.	<i>o</i> -C ₆ H ₄ Cl ₂	2.65x10 ⁻³	
0.0213 M.	0.0981 M.	<i>o</i> -C ₆ H ₄ Cl ₂	2.89x10 ⁻³	

The rate coefficients of the phenols (Table 1) are seen to increase as the number of the methyl groups in the benzene nucleus increases. This was explained by the electron releasing ability of the methyl group towards the benzene ring, thereby increasing the nucleophilicity of the nuclear carbon atoms. An exception was 2,3,5,6-tetramethyl phenol, which reacts fractionally slower than 2,3,5-trimethyl phenol. The relative rates of 3-methyl, 3,5-dimethyl and 2,3,5-trimethyl derivatives are comparable with those of the analogous anisoles but 2,3,6-trimethyl and 2,3,5,6-tetramethyl phenol react noticeably faster than the analogous anisoles.

COMPARISON BETWEEN PHENOLS AND ANISOLES:

The kinetics of reaction of 3,5-dimethyl anisole with sulphuryl chloride has been studied in detail (Table 2).¹²⁸ The second order rate coefficient does not alter with changes of the concentration of either reactant, the reaction is therefore proceeding by a bimolecular mechanism involving one molecule of each reagent in the rate determining stage. The quantitative determinations of hydrogen chloride and sulphur dioxide formed from the reaction, together with the isolation and identification of the organic products, show that the reaction can be expressed by the equation:¹²⁸



In contrast, the k_2 values of 3,5-xyleneol are not consistent and change considerably over the concentration range studied¹³¹ (Table 3). It was suggested¹³¹ that the

mechanism is quite different from that of analogous anisole and possibly could be that the total order of the reaction is third, shown by the following kinetic formula:

$$\text{Rate} = k_3 [\text{SO}_2\text{Cl}_2] [\text{ArOH}]^2$$

Again, the variation of these values (Table-3) over the whole range of concentration studied, does not favour the explanation that the reaction is of third order. It was suggested that the order of the reaction may be changing from third to second as the concentration of xylenol decreases and that the second molecule of xylenol at high concentration, could be removing SO_2Cl^- or Cl^- from the transition state thus giving the chlorinated xylenol as the product, while at low concentration of xylenol the reaction is of second order as seen by the consistent k_2 values. In the solvent benzene, which is a poorer ionising solvent than chlorobenzene again, a second molecule is needed to complete the transition from reaction intermediate to the products, especially at high concentration of xylenol. While in *o*-dichlorobenzene, a more polar solvent than chlorobenzene, second order reaction is favoured at low concentration of xylenol, as it will solvate the reaction intermediate more efficiently than chlorobenzene, making a second xylenol molecule unnecessary for the completion of the reaction.

SCOPE OF THE PRESENT WORK:

The reaction of sulphuryl chloride with substituted aromatic ethers and phenols is studied to verify the nature of the electrophile (ie. molecular sulphuryl chloride), the role and magnitude of effect of methyl groups upon the reactivity of the phenol system and to study other effects

e.g. steric effect, electromeric effect etc. etc, affecting the molecules during the course of reaction and above all to determine the rate of reaction.

The compounds studied in the following work are 3,5-dimethyl anisole, 2,4-xylenol, 2,6-xylenol, 2,3,5-trimethyl phenol, 2,3,6-trimethyl phenol and 3,5-ditertiary butyl phenol besides 3,5-xylenol which was studied in great detail as its k_2 values were reported to vary over a concentration range (cf. 3,5-dimethyl anisole). As the change in dielectric constant of the solvent affects the rate of reaction,¹³¹ solution of sulphuryl chloride in benzene, chlorobenzene and *o*-dichlorobenzene are used to chlorinate the phenols. A search for the possible formation of a complex under the different reaction conditions which could affect the course and rate of reaction was undertaken. Investigation of the substitution product is also done to understand the nature of the electrophile, the complex and the course of reaction.

CHAPTER II
EXPERIMENTAL

EXPERIMENTAL

PURIFICATION AND SYNTHETIC PROCEDURE:

The reagents and solvents used in the kinetic study were purified and prepared as follows:

PURIFICATION OF AROMATIC SUBSTRATES:

The phenols (solids) were recrystallised by petroleum ether (60-80°C.) and their purity was established by their melting points as given below:

3,5-xyleneol 64°C. (lit, ¹⁴⁰64°C.), 2,6-xyleneol 45.5°C.
 (lit, ¹⁴⁰49°C.), 3,5-ditertiary butyl phenol 95°C.
 (lit, ¹⁴¹94-5°C.), 2,3,5-trimethyl phenol 95°C. (lit, ¹⁴⁰95°C.),
 2,3,6-trimethyl phenol 61°C. (lit, ¹⁴²62°C.)

The following liquids were purified by fractional distillation:

2,4-xyleneol, 211.3°C./760mm. (lit, ¹⁴⁰210°C./760mm.), 3,5-dimethyl anisole, 193°C./760mm. (lit, ¹⁴³194°C.)

The purity was further confirmed by gas liquid chromatography.

PURIFICATION OF SULPHURYL CHLORIDE:¹²⁸

The commercial sulphuryl chloride was purified by fractional distillation; the yellow coloured fore-run which contained free chlorine and/or sulphur dioxide was rejected and the apparatus was flushed with carbon dioxide before the distillation was resumed. The fraction at b.p. 69.2°C./760mm. a water white product, was collected. The standard solutions of sulphuryl chloride were made immediately after purification and also used only while clear and colourless.

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PURIFICATION OF SOLVENTS:

The three solvents used in the preparation of sulphuryl chloride solutions were benzene, chlorobenzene and o-dichlorobenzene. These were purified by steam distillation from sodium hydroxide and then washed with dilute sulphuric acid and water, and dried over calcium chloride and phosphorous pentoxide and fractionally distilled. The physical constants were: benzene b.p. $80.2^{\circ}\text{C.}/756\text{mm.}$ o-dichlorobenzene b.p. 180.5°C. and chlorobenzene b.p. 131.8°C. at 762mm.

PREPARATION OF STANDARD SOLUTIONS:

The solution of sulphuryl chloride were first made by weight and then were corrected by titrating the overall SO_2 in the solution, after reacting it against a substantial quantity of 3,5-xylenol, as given below: Sulphuryl chloride solution (5ml.) was added to 3,5-xylenol (c. 0.5g.) in an iodine flask, stoppered, and left to react for at least 24 hours. Water (100ml.) and a little potassium iodide were added. The solution was then titrated with 0.1N iodine, using starch indicator. From the titre value, the concentration of the sulphuryl chloride solution was then calculated.

At times a change in molarity was due to a fall in the concentration of sulphuryl chloride in the solution and the formation of free sulphur dioxide. The correct strength was found as follows:

Sulphuryl chloride solution (10ml.) were treated with 0.1N iodine solution (10ml.). The mixture was titrated against 0.1N sodium thiosulphate soln. using starch as the indicator. Any change in the iodine concentration gave the

value of free sulphur dioxide in the sulphuryl chloride soln., which is then corrected.

Hydrolysis of freshly made sulphuryl chloride soln. has shown¹³⁶ that the sulphuryl chloride was 99.5-99.8% pure.

SYNTHESIS:

Some compounds used in the kinetic study were synthesised as follows:

SYNTHESIS OF 4-CHLORO, 3,5-XYLENOL:¹³³

A soln. of 3,5-xyleneol (10g ; 0.85M) in chloroform (100ml.) was cooled in an ice bath (1-5^oc.) and sulphuryl chloride (11.2g ; 0.85M) added dropwise while stirred. After the addition was complete, stirring was continued for another 2-4 hours. Chloroform was then distilled off under reduced pressure. The reaction product after redissolution in ether, was washed with 0.5% sodium bicarbonate soln. and dried over sodium sulphate. The solvent was distilled off and the residue purified by fractional crystallization from petroleum ether (60-80^oc.). The yield of 4-chloro 3,5-xyleneol obtained was about 80%.

The course of reaction was followed by thin layer chromatography to check the purity of the product formed and completion of the reaction. The samples were drawn out from the reaction flask at intervals and run on silica gel thin layer plates, using benzene as the mobile phase. The spots were developed in the iodine chamber. The disappearance of the spot on t.l.c., assigned to 3,5-xyleneol (r.f. value .128), suggests that the xyleneol has been completely used up in the reaction and the

chlorination has completed. The only remaining spot on the t.l.c. plate was assigned to 4-chloro, 3,5-xylenol (r.f. value .160) which determines the purity of the product formed and which is further confirmed by the melting point determination of the product after recrystallization of the compound with pet. ether (60-80°C.). The m.p. is found to be 114.5°C. (lit, ¹⁴⁴115°C.).

SYNTHESIS OF 2,4-DICHLORO, 3,5-XYLENOL: ¹⁴¹

The above procedure of preparing the monochloro xylenol was adopted by using two molar proportions of sulphuryl chloride. The progress of the reaction was again followed by t.l.c. method described. This time, the stirring of the reaction mixture was continued until the gradual disappearance, first of the spot assigned to 3,5-xylenol and then that of 4-chloro xylenol is completed. The presence of the only remaining spot assigned to 2,4-dichloro 3,5-xylenol (r.f. value .4615) suggests the completion of the reaction and its purity which is further confirmed by the m.p. 94.5°C. (lit, ¹⁴⁵96°C.) of the recrystallized dichloro xylenol.

The yield of the dichloro xylenol obtained by this method is above 50%.

SYNTHESIS OF 4-CHLORO, 3,5-DIMETHYL ANISOLE: ¹³⁴

A solution of 4-chloro, 3,5-xylenol (157.67g. ; 1.0M) and sodium hydroxide (40g. ; 1.0M) in 200ml. of water is heated under reflux and stirred while dimethyl sulphate (97ml. ; 1.0M) is added slowly. The mixture is then refluxed for another 3 hours, after which the upper oily layer of the reaction mixture is removed and the remaining aqueous layer is extracted with ether. The combined oily

layer and the ethereal extracts are combined and washed with dilute aqueous sodium hydroxide solution, dried over anhydrous sodium sulphate and fractionally distilled, there by giving 4-chloro, 3,5-dimethyl anisole b.p. $96^{\circ}\text{C.}/6\text{m.m.}$ (lit, $^{146}94-96^{\circ}\text{C.}/6\text{m.m.}$) in about 80% yield.

The purity of the product was confirmed by g.l.c. (10% carbowax column, temp. 130°C.) and a single peak of retention time 18 minutes is obtained under standard analytical conditions.

61 SYNTHESIS OF 2,4,6- D_3 -3,5-XYLENOL:

In a sealed tube, 10g. 3,5-xyleneol was heated with 5g. heavy water and 0.4ml. concentrated hydrochloric acid at 100°C. , for one hour. On cooling the tube was opened and the solvent ($\text{D}_2\text{O}, \text{H}_2\text{O}$ & HCl) was removed at reduced pressure. The phenol residue, thus obtained was dissolved in dried carbon tetrachloride, and dried using calcium carbonate in small amounts. The organic layer was filtered quickly from the dessicant and evaporated to give 2,4,6- D_3 -3,5-xyleneol.

The n.m.r. spectrum of the product showed 52% deuteration at 2,4,6 positions of the ring.

SYNTHESIS OF O-DEUTERO-3,5-XYLENOL:

The xyleneol was dissolved in carbon tetrachloride (dried) and to it was added heavy water in enough quantity to exchange with phenolic hydrogen. This mixture was shaken for about two minutes and then left to stand. The organic layer was separated by means of a separating funnel and evaporated under reduced pressure. The phenol residue was recrystallised with petroleum ether ($60-80^{\circ}\text{C.}$) which had been dried over sodium.

The n.m.r. spectrum of the sample showed the absence of the signal (chemical shift 5.5p.p.m.) assigned to -OH group of the xylenol.

KINETIC PROCEDURE:

Weighed amounts of the phenols to be studied kinetically were dissolved in the solution (50ml.) of sulphuryl chloride in the particular solvent (benzene, chlorobenzene, and o-dichlorobenzene) in a graduated flask. The molarity of the sulphuryl chloride solution also was varied. The flask was kept in the thermostat at 25^oc., through out the reaction. At reasonable intervals, 5ml. of the reaction mixture were drawn out by pipette and transferred to conical flasks containing water and little potassium iodide. The pink colour of the reaction mixture was discharged by mixing with potassium iodide solution and the reaction was thus said to be quenched. The sulphur dioxide was estimated by titrating against standard 0.1N iodine, using starch as the indicator.

Standard kinetic equations for second order reactions were used for calculating the rate constant:

$$(i) \quad \text{when } [ArOH] \gg [SO_2Cl_2] \quad ([SO_2Cl_2]_0 = \underline{a} \\ -k_2t = \frac{2.303}{b} \log_{10} \frac{a}{a-x} \quad [ArOH]_0 = \underline{b}.)$$

Values of $\log a/a-x$ were plotted against time.

$$(ii) \quad \text{when } ArOH \equiv SO_2Cl_2$$

$$k_2t = \frac{1}{(a-x)} - \frac{1}{a}$$

Values of $1/a-x$ were plotted against time.

(iii) when the initial concentrations are not equal:

$$\frac{dx}{dt} = k(a-x)(b-x)$$

which gives $k_2 t = \frac{2.303}{(a-b)} \log_{10} \frac{a(b-x)}{b(a-x)}$

Values of $\log \frac{b-x}{a-x}$ were plotted against time.

Firstly the k_2 values were obtained by plotting the graphs but later on were calculated from each point and corrected.

In the case of 2,4-xylenol, 2,6-xylenol, 3,5-ditertiary butyl phenol, 2,3,5-trimethyl phenol and 2,3,6-trimethyl phenol, kinetic studies were done in the solvent chlorobenzene (Table I). The investigation included where phenol (concentration $\sim 0.1M$ and $\sim 0.2M$) was reacted with sulphuryl chloride soln. (conc. $\sim 0.1M$); and where phenol was in comparatively great excess ($\sim 0.2M$) to sulphuryl chloride ($\sim 0.05M$).

The kinetic study of 3,5-dimethyl anisole was done in benzene (Table II). Standard solutions of sulphuryl chloride of different molarity (~ 0.07 to $\sim 0.2M$) were made in benzene and reacted with anisole at different concentrations ($\sim 0.1-0.5M$). Thus investigation ranged over the possibilities where

- (a) Anisole and sulphuryl chloride are in equal initial concentrations.
- (b) Anisole and sulphuryl chloride are in unequal initial concentrations.
- (c) Anisole is in great excess in relation to sulphuryl

chloride.

The ambiguous results, of the kinetics of 3,5-xylenol, obtained so far raised the need to explore the reaction mechanism in the three solvents (benzene, chlorobenzene and *o*-dichlorobenzene) and in the mixed solvent (benzene and chlorobenzene). In the first case standard solutions of sulphuryl chloride of the molarity of $\sim 0.1M$ were made in benzene, chlorobenzene and *o*-dichlorobenzene. 3,5-xylenol (molarity varying from $\sim 0.025M$ to $\sim 0.4M$) reacted with these solutions, thereby covering all possible ranges as mentioned in the case of 3,5-dimethyl anisole. The k_2 values were obtained for the reaction in the solvent benzene (Table III), chlorobenzene (Table IV); and *o*-dichlorobenzene (Table V).

For mixed solvent kinetic studies, the three molarities taken of 3,5-xylenol were $\sim 0.025M$, $\sim 0.1M$ and $\sim 0.25M$. These were reacted with $\sim 0.1M$ of sulphuryl chloride solutions made in the following mixed solvent media:

- (1) 10% chlorobenzene + 90% benzene
- (2) 20% chlorobenzene + 80% benzene
- (3) 40% chlorobenzene + 60% benzene
- (4) 50% chlorobenzene + 50% benzene
- (5) 60% chlorobenzene + 40% benzene
- (6) 80% chlorobenzene + 20% benzene
- (7) 90% chlorobenzene + 10% benzene

The k_2 values were obtained (Table VI) and compared.

As the main product 4-chloro, 3,5-xylenol was found to form a complex with sulphuryl chloride in the solution. (method discussed later in the chapter). Its effect on the rate and mechanism of the reaction needed further

investigation besides the polarity effect of the solvent and solvent mixtures as described.

This was done by adding a variable amount of 4-chloro, 3,5-xyleneol ($\sim 0.01M$ - $\sim 0.15M$) to the main reacting entities of 3,5-dimethyl anisole ($\sim 0.3M$) and sulphuryl chloride (molarity varying from $\sim 0.05M$, $\sim 0.1M$ and $\sim 0.2M$). The studies were done in benzene (Table VII) and chlorobenzene (Table VIII).

The behaviour of the complexes formed by 2,4-dichloro 3,5-xyleneol and 4-chloro, 3,5-dimethyl anisole with sulphuryl chloride were also investigated. Variable quantities of the above mentioned compounds were added to the $\sim 0.3M$ of 3,5-dimethyl anisole which was then reacted with $\sim 0.1M$ solution of sulphuryl chloride. In the case of dichloro xyleneol, studies were done in benzene and chlorobenzene both (Table IX) while in the case of chloroanisole it was restricted to chlorobenzene only (Table X).

To find if 3,5-ditertiary butyl phenol, which also happens to form a complex with sulphuryl chloride, could influence the reaction velocity and mechanism of 3,5-dimethyl anisole and sulphuryl chloride, the phenol was added in ~ 0.01 , ~ 0.05 , ~ 0.1 and ~ 0.15 molarity to $\sim 0.3M$ of the anisole which was reacted with ~ 0.05 , ~ 0.1 and $\sim 0.2M$ solutions of sulphuryl chloride in chlorobenzene, (Table XI) as described before.

To determine the role of substitution of ring hydrogens of 3,5-xyleneol at the positions 2,4 and 6, the deuterated 3,5-xyleneol was reacted with sulphuryl chloride solution of $\sim 0.1M$ strength. To avoid experimental errors, the comparison of the kinetics of deuterated

xyleneol with the xyleneol itself was done by reacting the latter with the same sulphuryl chloride solution used above and under similar conditions. The molarity of the two xyleneols studied were ~ 0.05 , ~ 0.1 and $\sim 0.2M$ and the k_2 values obtained, compared (Table XII).

Similarly 3,5-xyleneol was also kinetically compared with the xyleneol where the -OH had been deuterated to -OD. Reaction condition and the molarities involved were similar to what has been described above, and the k_2 values obtained are compared (Table XIII).

STOICHIOMETRIC ANALYSIS:

For the determination of hydrogen chloride and sulphur dioxide formed during the course of reaction of and aromatic substrate with sulphuryl chloride in a solvent (benzene, chlorobenzene, dichlorobenzene or mixture of solvents), the following standard solution were made:

FOR DETERMINATION OF CHLORIDE:

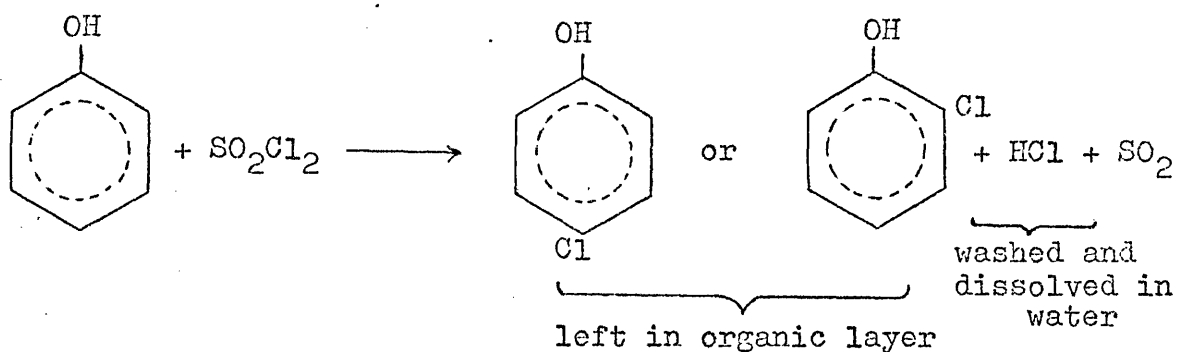
A solution of silver nitrate (0.1N) was made and standardised against standard sodium chloride solution (0.1N) [Mohr's method].¹³⁵ The silver nitrate solution was then used to standardise a freshly prepared solution of potassium thiocyanate (0.1N) [Volhard's method].¹³⁵

FOR DETERMINATION OF SULPHUR DIOXIDE:

A solution of iodine (0.1N) was prepared and standardised against standard (0.1N) solution of sodium thiosulphate.¹³⁵

GENERAL PROCEDURE:

The general course of reaction is:



The aromatic substrate (0.1M) was treated with sulphuryl chloride solution (~0.1M) in an iodine flask and left for at least 24 hours. The reaction mixture was washed several times with water to dissolve hydrogen chloride and sulphur dioxide. This aqueous portion was in turn washed with ether to regain any organic component lost to the water layer and combined with the organic layer left above. This organic combined layer was kept for the analysis of the products and their identification, while the aqueous washings were combined and diluted to a volume of 500mls.

DETERMINATION OF CHLORIDE:

30mls. of silver nitrate solution (0.1N) were added to a portion of 25mls. of the diluted aqueous solution mentioned above. The chloride precipitated as silver chloride and the resulting silver ion concentration was found by back titration with potassium thiocyanate [Volhard's method] and thereby percentage of hydrogen

chloride was calculated (Table 1).

DETERMINATION OF SULPHUR DIOXIDE:

This was found by titrating a 25ml. portion of diluted aqueous solution with the iodine solution (0.1N) using starch as the indicator¹³⁵ and thereby calculating the percentage of sulphur dioxide evolved in the reaction.

TABLE 1

Phenol	Solvent	% HCl	% SO ₂
2,3,5-trimethyl phenol	chlorobenzene	92	58**
2,3,6- " "	"	98	90
2,6-xylenol	"	94	52**
2,4- "	"	86	84*
3,5- "	"	92	97
" "	benzene	90	93
3,5-dimethyl anisole	"	92	76
3,5-xylenol	10% chlorobenzene	70	70*
	+90% benzene		
" "	90% chlorobenzene	86	93
	+10% benzene		

* Reaction not complete.

** probable loss of sulphur dioxide - slow reaction.

ANALYSIS AND IDENTIFICATION OF PRODUCTS PRESENT INORGANIC LAYER:

G.L.C. analysis used a 5' length of absorbant and a flow rate of the carrier gas (nitrogen) of 45mls./minute. In preparative g.l.c. the length of column was 15' and the flow rate of the carrier gas was maintained at 120mls./minute.

The n.m.r. studies of the products, complex etc. were done on Varian A-60A, HA-100 and HR-220 n.m.r. spectrometers. The mass spectroscopy of the products were done on VG Micromass 12 magnetic deflection mass spectrometer.

GENERAL PROCEDURE:

The combined organic layer was first concentrated under reduced pressure and then separated by chromatographic techniques. The purified compounds thus obtained were subjected to structural analysis.

3,5-XYLENOL:

To separate and confirm the identity of the main product formed in this reaction, the organic layer was subjected to column chromatography using alumina (10% moisture content) as the stationary phase and benzene as the mobile phase. The main product after separation and recrystallisation (pet. ether 60-80c.) had m.p. 114.5c. The i.r. spectrum (1% soln. in CS_2) showed -OH absorption at $3590cm^{-1}$, C-Cl stretching vibration at $690cm^{-1}$ and C-H deformation at $840cm^{-1}$. In the n.m.r. spectrum, the two equivalent methyl groups gave rise to a singlet at 2.3p.p.m., the two equivalent aromatic protons (C_2 -H and C_6 -H) were identified by a sharp singlet at 6.55p.p.m.

and the phenolic hydroxyl group was confirmed by the peak at 4.96p.p.m. Thereby confirming that the main product of chlorination of 3,5-xylenol is 4-chloro, 3,5-xylenol.

For analytical g.l.c. of the organic products from the reaction of 3,5-xylenol with sulphuryl chloride in different solvents, the retention times of 3,5-xylenol and synthesised 4-chloro and 2,4-dichloro, 3,5-xylenol were first found under similar conditions to help to identify them in the chromatograms of the organic layers. Under standard analytical conditions, the column used was 5% 2,4-xylenol phosphate (NAW) and the temperature was kept at 162^oc.

All the chromatograms showed an unidentifiable peak, designated as "unknown". The retention times were:

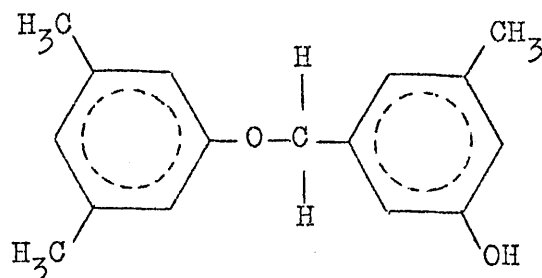
3,5-xylenol	-	4 minutes 57 sec.
4-chloro 3,5-xylenol	-	23 minutes 24 sec.
2,4-dichloro 3,5-xylenol	-	11 minutes
"unknown"	-	3 minutes 9 sec.

The percentage of the compounds formed in different solvents were:

TABLE 2

SOLVENT	COMPOUND	% FORMED
Benzene	3,5-xylenol (left unreacted)	14.4
	4-chloro, 3,5-xylenol	47.56
	2,4-dichloro 3,5-xylenol	—
	unknown	37.9
Chlorobenzene	3,5-xylenol (left unreacted)	—
	4-chloro, 3,5-xylenol	55.74
	2,4-dichloro 3,5-xylenol	29.07
	unknown	15.17
10% Chlorobenzene + 90% Benzene	3,5-xylenol (left unreacted)	45
	4-chloro, 3,5-xylenol	41.1
	2,4-dichloro 3,5-xylenol	—
	unknown	14.0
90% Chlorobenzene + 10% Benzene	3,5-xylenol (left unreacted)	25
	4-chloro, 3,5-xylenol	63.7
	2,4-dichloro 3,5-xylenol	2.3
	unknown	9.0

Mass spectroscopy of the unknown component observed in the chromatograms, suggested it to be a dimer of molecular weight 242 and the most possible structure that can be assigned to it, was:



3,5-DIMETHYL ANISOLE:

The organic layer containing the products of chlorination of 3,5-dimethyl anisole was analysed by g.l.c. under the standard analytical conditions and on:

column	-	10% carbowax
temperature	-	131°c.

Separation and purification of the compounds was done by preparative g.l.c. (column 15% carbowax, temperature 131°c.)

The details obtained from the chromatograms are:

TABLE 3

Compounds	Retention time	% formed
3,5-dimethyl anisole	4 minutes 57 sec.	39.7
product (1)	15 minutes	55.67
product (2)	19 minutes 27 sec.	4.63

The unreacted dimethyl anisole itself, was identified by its retention time.

The n.m.r. spectrum of product (1) shows two equivalent methyl groups as a singlet at 2.25p.p.m., two equivalent aromatic protons (C_2 -H and C_6 -H) as a sharp singlet at 6.5p.p.m. and the $-OCH_3$ group as a singlet at 3.58p.p.m., thereby confirming it to be 4-chloro, 3,5-dimethyl anisole.

The product (2) obtained in small proportion is assumed to be 2,4-dichloro 3,5-dimethyl anisole.

2,6-XYLENOL:

Analytical g.l.c. of this organic layer was accomplished on:

column - 5% S.E.52
 temperature- 82°c. maintained for 25 minutes and then increased to 180c. at the rate of 24°c./minute.

The compounds were purified by preparative g.l.c. (column- 15% S.E.52, temperature 80°c.)

The details obtained are:

TABLE 4

Compound	Retention time	Melting point	% formed
2,6-xylenol	5 minutes 51 sec.	45°c.	59.18
product (1)	19 minutes 7 sec.	80°c.	40.37
product (2)	42 minutes 31 sec.	—	0.438

While the unreacted xylenol itself, was identified by its melting point and retention time under similar analytical g.l.c. conditions, product (1) was identified to be 4-chloro, 2,6-xylenol by its n.m.r. spectrum which

shows two equivalent $-\text{CH}_3$ groups give rise to a singlet at 2.16p.p.m., two equivalent protons ($\text{C}_3\text{-H}, \text{C}_5\text{-H}$) are again identified as a singlet at 6.96p.p.m. while a broad peak at 4.53p.p.m. represented the phenolic $-\text{OH}$ group.

Product (2) which appears on the chromatogram at high temperature of 180°C . is expected to be a dimer rather than a chlorinated product. It could not be collected in sufficient amount to carry out detailed analysis for its structure.

3,5-DI-TERTIARY BUTYL PHENOL:

The organic layer was analysed on:

column - 10% S.E.30 length 7'
 temperature - 175°C .

The compounds formed as observed on analytical chromatogram are then separated and purified by preparative g.l.c.

(column 15% S.E.30, temperature 150°C .)

The compounds obtained from the chromatogram are:

TABLE 5

Compound	Retention time	Melting point	% formed
3,5-ditertiary butyl phenol	5 min. 17 sec.	94°C	53
product (1)	6 min. 40 sec.		40.9
product (2)	14 min. 30 sec.	140°C	6

While the unreacted 3,5-ditertiary butyl phenol was identified by its melting point and retention time under similar analytical conditions, the structures of the two products formed were found by the help of n.m.r. spectroscopy.

The n.m.r. spectrum of product (1) shows two non-equivalent $-C(CH_3)_3$ groups coupled as doublets at 1.28 and 1.48p.p.m. The two non-equivalent aromatic protons (C_4-H, C_6-H) are also coupled to give rise to a quartet at 7.0-7.13p.p.m. while the phenolic $-OH$ is identified as the singlet at 6.03p.p.m. Therefore product (1) is 2-chloro, 3,5-ditertiary butyl phenol.

The n.m.r. spectrum of product (2) shows two equivalent $-C(CH_3)_3$ groups as a sharp singlet at 1.46p.p.m., the two equivalent aromatic protons (C_2-H, C_6-H) as a singlet at 6.88p.p.m. and the broad peak at 5.1p.p.m. representing the phenolic $-OH$, suggesting the product to be 4-chloro, 3,5-ditertiary butyl phenol. This was further confirmed by mass spectroscopy.

2,3,5-TRIMETHYL PHENOL:

The organic layer containing the product of chlorination of the phenol was analysed by g.l.c. under the standard analytical conditions and on:

column	-	10% S.E.30	length 7'
temperature	-	131°c.	

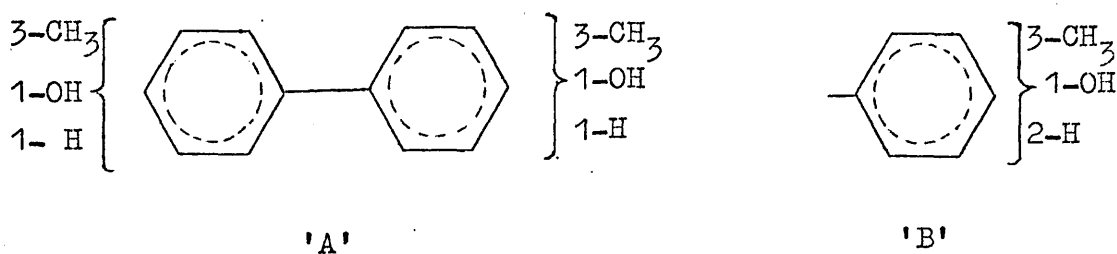
Separation and purification of the compounds was done by preparative g.l.c. (column 15% S.E.30, temperature 130°c.)

The details obtained from the chromatogram and the melting points of the compounds are:

TABLE 6

Compound	Retention time	Melting point	% formed
2,3,5-trimethyl phenol	6 mins. 6sec.	95°c.	17.5
product (1)	8 mins. 4sec.	50-51°c.	8.52
product (2)	20 mins. 8sec.	103-104°c.	73.96

While the unreacted phenol was identified by its melting point and retention time under similar analytical g.l.c. conditions, product (1) was investigated by means of mass spectroscopy and n.m.r. spectroscopy (including double resonance on a 100 MHz instrument.). The n.m.r. implies it, to be a mixture of two compounds A and B due to two spectrums nearly super imposed on each other. As 'A' contains 1-H (proton), 1-OH and 3-CH₃ groups while 'B' contains 2-H (protons), 1-OH and 3-CH₃ groups. It would suggest 'A' as a dimer and 'B' as half of this dimer molecule, which exist in the ratio of 30% and 70% respectively. The structure of the dimer seems to be symmetrical.



Product (2) was identified to be 4-chloro, 2,3,5-trimethyl phenol by its melting point and n.m.r. spectrum which shows one aromatic proton (C_6-H) at 6.55p.p.m., a phenolic $-OH$ group as a broad peak at 4.58p.p.m. and the three unequivalent $-CH_3$ groups (C_2, C_3, C_5) as a triplet at 2.3, 2.26 and 2.15p.p.m.

2,3,6-TRIMETHYL PHENOL:

Analytical g.l.c. of the organic layer was accomplished on:

column - 5% S.E.52 (NAW) length 7'
 temperature - 152 $^{\circ}$ c.

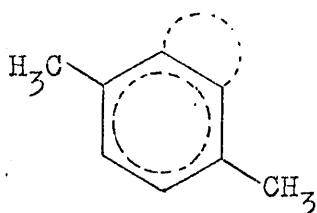
The compounds were purified by preparative g.l.c. (column 15% S.E.52, temperature 125 $^{\circ}$ c. and increased after the solvents have come off, to 155 $^{\circ}$ c.)

The details obtained are:

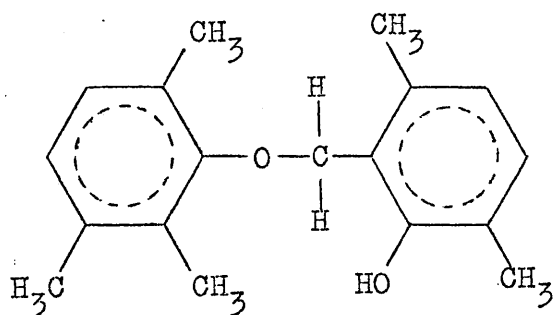
TABLE 7

Compounds	Retention time	Melting point	% formed
2,3,6-trimethyl phenol	8 min. 6 sec.	60.5 $^{\circ}$ c.	4.31
product (1)	4 min. 4 sec.	————	0.5
" (2)	12 min. 4 sec.	62-63 $^{\circ}$ c.	10.77
" (3)	22 min.	86-87 $^{\circ}$ c.	59.27
" (4)	29 min. 4 sec.	58-60 $^{\circ}$ c.	25.1

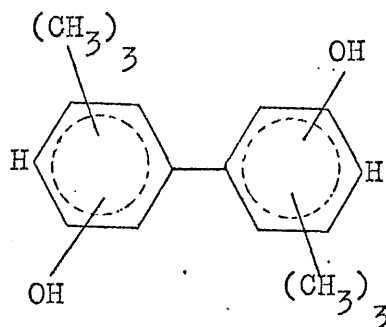
The unreacted phenol was identified by its melting point and characteristic retention time. Product (1) was studied by mass spectroscopy which suggests it to be a dimer of molecular weight of 270. The predominant signal at 104. of a symmetrical molecular ion ie.



suggests it to be a dimer of a symmetrical structure e.g.

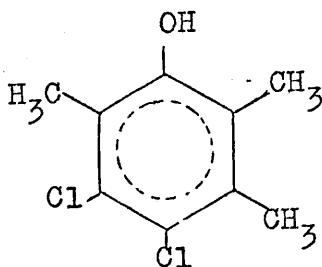


Structure of product (2) was investigated with the help of mass spectroscopy and n.m.r. spectroscopy (including double resonance on a 100MHZ instrument). From the information available it may be labelled as a dimer with a symmetrical structure e.g.



Product (3) was identified by its melting point and n.m.r. spectrum which shows an aromatic proton (C_5-H) at 7.05p.p.m., a phenolic $-OH$ group represented as a broad peak at 4.45p.p.m. and the three $-CH_3$ groups at 2.16-2.3p.p.m., thereby confirming it to be 4-chloro, 2,3,6-trimethyl phenol.

The mass spectroscopy of the product (4) suggests the product to be a dichloro compound, of the structure:



2,4--XYLENOL:

The products in the organic layer could not be separated and thus the analysis of the compounds was not done.

INVESTIGATION OF HYDROGEN BONDING IN 3,5--XYLENOL BY N.M.R.METHOD:

High resolution proton magnetic resonance was used to investigate the properties of the phenolic -OH group and its hydrogen bond formation among the molecules of xylenol itself or with the solvent used in the chlorination.

Solutions of 3,5-xylenol were made in carbon tetrachloride (Table- 8), benzene (Table- 9), chlorobenzene (Table-10) and ortho-dichlorobenzene (Table-11) and diluted successively to cover the range of concentrations (0.5 to 0.015M) at which kinetic studies were done.

The study of the hydrogen bond and its shift in the above mentioned solvents at various dilutions were done at 25^oc. The maximum concentration approximated to a saturated solution (0.5M) and the minimum (0.015M) was determined by the sensitivity of the spectrometer. The measurements were carried out on an Varian A60A spectrometer at 60MHZ. The chemical shift of the p.m.r. signals were measured with respect to tetramethyl silane (TMS) (internal standard).

$$\text{Chemical shift} = \frac{\Delta f}{60}$$

where Δf is the distance between the signal of TMS and the line under investigation (in $\text{herz}^{\frac{1}{2}}$).

TABLE 8

Chemical shift of hydrogen bond of 3,5-xylenol in carbon tetrachloride:

molarity	0.4877	0.2438	0.1219	0.0609	0.3048	0.0152
chemical shift (p.p.m.)	5.95	5.33	4.91	4.4	4.266	4.23

TABLE 9

Chemical shift of hydrogen bond of 3,5-xylenol in benzene:

molarity	0.517	0.2585	0.1292	0.0646	0.0323	0.0161
chemical shift (p.p.m.)	4.61	4.26	4.033	3.91	3.81	3.78

TABLE 10

Chemical shift of hydrogen bond of 3,5-xylenol in chlorobenzene:

molarity	0.5009	0.2504	0.1252	0.0626	0.0313	0.0156
chemical shift (p.p.m.)	5.21	4.71	4.516	4.4	4.33	4.18

TABLE 11

Chemical shift of hydrogen bond of 3,5-xylenol in o-dichlorobenzene:

molarity	0.5009	0.2504	0.1252	0.0626	0.0313	0.0156
chemical shift (p.p.m.)	5.4	4.983	4.75	4.683	4.6	4.5

STUDY OF THE COMPLEX BY ULTRA VIOLET SPECTROSCOPY:

As the study of reaction mechanism of chlorination of 3,5-xylenol by sulphuryl chloride was the important part of the work, ultra violet spectroscopy of the reactants, products and the complex especially was studied.

First of all mono and dichloro 3,5-xylenol were studied under the following conditions:

(a) Where the two reactants are in comparative strength:

~0.1M in 4-chloro, 3,5-xylenol or 2,4-dichloro, 3,5-xylenol and ~0.1M, ~0.2M and ~0.4M in sulphuryl chloride in carbon tetrachloride.

(b) Where the chloro xylenols are dissolved in an excess of sulphuryl chloride in carbon tetrachloride:

~0.025M 4-chloro, 3,5-xylenol or 2,4-dichloro, 3,5-xylenol in ~0.2M, ~0.4M and ~0.5M solution of sulphuryl chloride in carbon tetrachloride and the spectras were recorded.

Reference solution of particular chloro xylenol of equivalent molar concentration in carbon tetrachloride was used.

The complex formation by the two reactants was confirmed by the distinctive absorption away from the region of absorption of the xylenol and chloro xylenols. While 3,5-xylenol absorbs at 275 μ . and 283 μ . wavelengths, the complex formed with sulphuryl chloride (which itself absorbs at 220 μ . in the solution of n-hexane) showed a distinctive absorption at 300 μ . Similarly 4-chloro, 3,5-xylenol which has peaks at 279 μ . (ϵ , 2096) and 287 μ . (ϵ , 2077)¹⁴¹ showed the characteristic absorption of its complex with sulphuryl chloride at 293-310 μ . In the case of 2,4-

dichloro,3,5-xyleneol the absorptions were at 281 μ . (ϵ ,4601), 286 μ . (ϵ ,2460) and 290 μ . (ϵ ,2610) showed the formation of its complex with sulphuryl chloride at 307-313 μ . A shift in the absorption is observed at different solution of variable strength of the reactants.

The extinction coefficients were calculated and the Ketelaar equation was applied from which values of K_c of the complex were obtained. If only a fraction of the donor and acceptor were complexed even in the presence of a large excess of the other component, K_c and E_{DA} can be evaluated simultaneously.

$$\frac{1}{E_a - E_A} = \frac{1}{K_c C_D (E_{DA} - E_A)} + \frac{1}{E_{DA} - E_A}$$

as E_A is zero, the equation becomes:

$$\frac{1}{E_a} = \frac{1}{K_c C_D (E_{DA})} + \frac{1}{E_{DA}}$$

where:

E_{DA} = extinction coefficient of donor- acceptor complex.

K_c = complex constant.

C_D = concentration of donor.

E_A = extinction coefficient of acceptor.

E_a = apparent extinction coefficient.

The K_c and E app.ex. values were not satisfactory and were thus not included.

The u.v. study of the complex was repeated in the case of 4-chloro,3,5-xylenol, where:

- (a) $\sim 0.01M$, $\sim 0.025M$, $\sim 0.05M$ and $\sim 0.1M$ of 4-chloro,3,5-xylenol were dissolved in $\sim 0.1M$ sulphuryl chloride in carbon tetrachloride.
- (b) $\sim 0.1M$, $\sim 0.2M$ and $\sim 0.4M$ of 4-chloro,3,5-xylenol were dissolved in $\sim 0.05M$ of sulphuryl chloride in carbon tetrachloride.

Reference solutions of equal strength in carbon tetrachloride were used.

Lastly the kinetic study of the complex formation in the case of 4-chloro,3,5-xylenol was attempted, but again ended with unsuitable results.

It was found that 3,5-dimethyl anisole and 3,5-ditertiary butyl phenol also made their respective complexes with sulphuryl chloride and absorbed at characteristic wavelengths.

While 3,5-ditertiary butyl phenol (in n-hexane) absorbed at 263μ . and 270μ ., its complex with sulphuryl chloride absorbs at 290μ . Similarly the complex of 3,5-dimethyl anisole and sulphuryl chloride absorbs at $300-301\mu$. away from the absorption region of the anisole itself, which is at 275μ . and 282μ .

The correct measurements of the extinction coefficients for the complexes too was not possible due to ever changing concentration of the two reactants, in the solution under study, responsible for forming the complex. The u.v. study of the complex was done on SP800 and Perkin Elmer 124 machines.

STUDY OF THE COMPLEX BY N.M.R. SPECTROSCOPY:

To understand and establish the nature of complex formed by 3,5-xyleneol, 4-chloro,3,5-xyleneol and 3,5-ditertiary butyl phenol with sulphuryl chloride, n.m.r. spectrums of the reacting species were recorded. While the study of the xyleneols was done in benzene, that of ditertiary butyl phenol was done in chlorobenzene, the solvent used for its kinetic studies.

The detailed information about the complex is obtained by running the region of study at sweep width of 100Hz. and expanding it. The spectrums are discussed in Chapter III.

CHAPTER III

DISCUSSION

DISCUSSION

THE REACTIVITY OF THE PHENOLS AND THEIR COMPARISONS:

In all phenols (except 3,5-xyleneol) a consistency was observed in the rate constants (Table I) of the various substituted phenols studied when the concentrations of the phenol and sulphuryl chloride were:

- (i) phenol \equiv SO₂Cl₂
 (ii) phenol $>$ SO₂Cl₂
 (iii) phenol \gg SO₂Cl₂

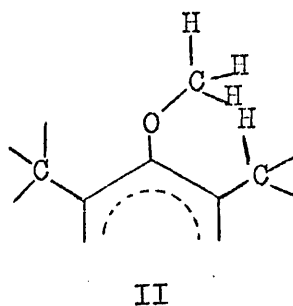
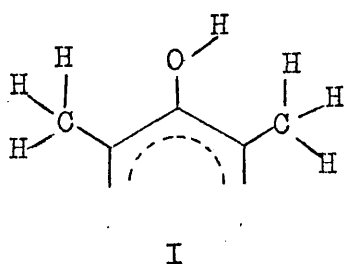
The k_2 values obtained in all the above ranges of concentration of the two reactants confirm it to be a bimolecular reaction of second order i.e. there has to be a collision between a molecule of phenol and a molecule of sulphuryl chloride to complete the reaction. The experimental results are analogous and showed little variation in rate of reaction and were consistent with the kinetic formula:

$$\text{Rate} = k_2 [\text{ArOH}] [\text{SO}_2\text{Cl}_2]$$

Although at the high concentration of phenol it was expected that any effect due to inter and intra molecular bonding among the phenol molecules and the solvent effect if any would be much easier to be noticed. As all the reactions are done in chlorobenzene (except that of 3,5-dimethyl anisole which is done in benzene) and under similar conditions, their k_2 values can be compared to explain the reactivity of the phenols in accordance to their molecular structure towards a mild reagent like molecular sulphuryl chloride.

As the -OH group of a phenol exhibits weak -I and

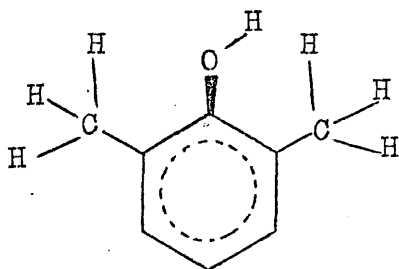
strong +M effect and makes o- and p- positions reactive through sharing the electron density of oxygen via the conjugated system, it is the p- position which is largely preferred to the o- position. The high reactivity of 2,3,5-trimethyl phenol can be attributed to the $-CH_3$ groups at position 3 and 5 which exhibit +I and +M effects, owing to hyperconjugation as well as the +I effect of the 2-Me group, making the p- position more reactive. The mesomeric effect of the oxygen would also help to stabilize the transition state. Moreover, in relative high concentration of sulphuryl chloride the ortho position is available to undergo further substitution. In 2,3,6-trimethyl phenol none of the above factors are as fully developed. The coplanarity of the $-OH$ group with the ring may not be as good as in 2,3,5-trimethyl phenol (I) due to steric interactions thus not making the electrons so available to the para positions. This would reduce the stabilization derived from the mesomeric effect of oxygen. This effect is much more obvious in the case of 2,3,6-trimethyl anisole (II)^{131,139} due to the bulk of $-OCH_3$ group which is prevented by the two ortho substituents from being coplaner with the aromatic ring and thus giving a low k_2 value of $5.0 \times 10^{-6} M^{-1} sec^{-1}$ at $25^\circ C$.



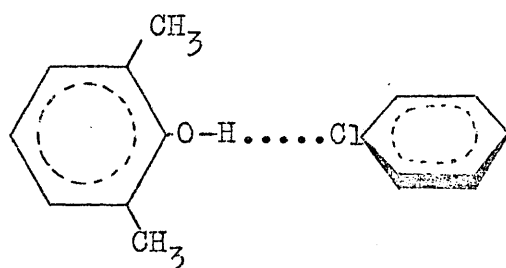
On the other hand the k_2 values of 2,3,5-trimethyl anisole are similar to its analogous phenol as expected.¹³¹ In other words the availability of electrons at para position would be more in 2,3,5-trimethyl phenol than in 2,3,6-trimethyl phenol. Which is confirmed by the product analysis of the two phenols. While in 2,3,5-trimethyl phenol 4-chloro product is obtained in 90% yield on the basis of phenol consumed. Similarly in 2,3,6-trimethyl phenol 4-chloro product is obtained in 62% yield.

The size of SO_2Cl_2 does not seem to matter in approaching the para position of 2,3,5-trimethyl phenol; the two $-\text{CH}_3$ groups ^{do not} seem to obstruct it in any way. On the other hand they must be acting as an impetus to the reaction by making the para position more reactive by means of hyperconjugation and the I & M effects.

2,6-xyleneol¹³⁶ and 2,3,6-trimethyl phenol seem to have much in common. The important similarity is the presence of two ortho substituents which may force out $-\text{OH}$ group out of plane. The two $-\text{CH}_3$ groups in both phenols will not be sterically affecting the para position of the ring. To cause non-coplanarity between the lone pair of oxygen and the ring the two $-\text{CH}_3$ groups force the $-\text{OH}$ group out of plane.



At high concentrations of phenols intermolecular bonding¹³⁶ between two phenol molecules can not be disregarded, therefore affecting the rate of reaction. Besides these difficulties interaction between 2,6-xylenol derivatives and the solvent molecule would also be hampered by the two $-CH_3$ groups, as it would not be easy for a planer molecule like chlorobenzene to penetrate to sterically shielded $-OH$ group in 2,6-xylenol and 2,3,6-trimethyl phenol unless it approaches it at the right angle.



This similarity in the two phenols is shown by the comparable k_2 values obtained. The fractionally higher reactivity of 2,3,6-trimethyl phenol to that of 2,6-xylenol can be attributed to the presence of the third $-CH_3$ group in the former which must have a hand in making the para position of the trimethyl phenol more reactive than that of 2,6-xylenol. In 2,6-xylenol thus as expected 59.18% of the xylenol remains unreacted. The main product of chlorination was 4-chloro,2,6-xylenol in 40.37% yield. The other product in about 0.438% yield was unidentifiable and is again expected to be a dimer.

The solvent effect in 2,4-xylenol and 2,3,5-trimethyl phenol would be greater as these phenols would not need

any particular arrangement to approach the solvent molecule. The interaction between the lone pair of oxygen and the π cloud of the ring would be the same in the two phenols. The non availability of the preferential para position in 2,4-xylenol would make considerable differences as is witnessed by its low k_2 values which is not far from that of 2,6-xylenol. Thus where as in 2,6-xylenol the degree of conjugation of the hydroxyl group (due to steric hinderance) is in question, in 2,4-xylenol it is the non availability of the p- position to undergo reaction. Besides, the $-\text{CH}_3$ group at para position could be thought to oppose the +M effect of the $-\text{OH}$ group as it is known⁶ to lower the acidity of phenol quite appreciably thereby decreasing its reactivity a great deal. Understandibly the only possible product in this case would be 6-chloro, 2,4-xylenol.

The coplanarity or non-coplanarity of the directive group through steric hinderance is the important feature on which depends the reactivity of an aromatic nuclei rather than the easy or difficult access to the position under attack. This is noticed in the case of 3,5-ditertiary butyl phenol where despite the presence of the bulky *t*- butyl groups at position 3 and 5, para substitution does take place to some extent. This also proves the marked preference to para position despite the restricted approach to the reactive centre by sulphuryl chloride. Although both ortho and para positions would have their reactivity enhanced by the two tertiary butyl groups present at positions 3 and 5 by means of hyperconjugation etc., simultaneously by contrast the bulk of the group would narrow down the vicinity of para

position (to a large extent) and ortho position (to a small extent). Now as only the less reactive ortho centre would mainly undergo substitution, most of the phenol is expected to remain behind unreacted. The other factor adding to its unreactivity could be inter and intra molecular bonding which can be expected among aromatic systems having bulky and branched substituents like tertiary butyl groups. As expected in the lines of argument put forward, 2-chloro, 3,5-ditertiary butyl phenol is obtained as the main product of chlorination in 87% yield besides 4-chloro, 3,5-ditertiary butyl phenol which is obtained in 13% yield on the basis of phenol consumed.

In 2,4-xyleneol, position 6 would be far more easily approachable by the attacking electrophile than the 2 and 6 positions of 3,5-ditertiary butyl phenol thereby making former a much more reactive aromatic nuclei than the latter. In all the predominant factor of steric hinderance would make 3,5-ditertiary butyl phenol slower by a factor of nearly 10 in comparison to 2,3,6-trimethyl phenol, 2,6-xyleneol and 2,4-xyleneol and by a factor of nearly 20 in comparison to 2,3,5-trimethyl phenol.

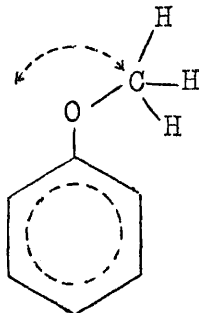
The experimental results obtained in the case of the analogous reaction of 3,5-dimethyl anisole (Table II) over a range of concentration showed little variation in the rate of reaction and were consistent with the kinetic formula:

$$\text{Rate} = k_2 [\text{ArOMe}] [\text{SO}_2\text{Cl}_2]$$

The k_2 values were quite in agreement with the values obtained from the study done in chlorobenzene^{128,131}

(considering the polarity of the solvents ie. benzene and chlorobenzene). The lone pair of electron of oxygen present in the $-OCH_3$ group would be co-planer with the benzene ring activating it towards the electrophilic attack by sulphuryl chloride. The increase in rate of the reaction with the increase in dielectric constant of the solvent proves the successful interaction between the solvent and the ether molecule.

While it has been reported¹³⁹ that ortho attack becomes progressively less as anisole becomes more heavily substituted, the para position here would be much more preferred than the ortho, not only due to +I and +M effect of $-OCH_3$ but also due to some steric hinderance at the ortho position exhibited by the bulky $-OCH_3$ group and the rotation of the O-Aryl bond.



Moreover approach of the reagent is inhibited by crowding between $-OCH_3$ and $-CH_3$ ¹³⁹, but not between two $-CH_3$ groups as shown in all the above cases.

At the end of the reaction carried out in solvent benzene only, 92.4% of 4-chloro derivative is obtained. The other derivative, which is believed to be 2,4-dichloro, 3,5-dimethyl anisole, is obtained in 7.6% yield on the basis of phenol consumed.

MECHANISM AND NATURE OF THE ELECTROPHILE:

The detailed study of the compounds discussed indicates that the mechanism proceeds via a bimolecular mechanism involving one molecule of each reactant in the rate determining stage and is of second order. As the products are similar to those obtained by chlorination with molecular chlorine¹²⁵ the reaction may involve a heterolytic mechanism. This is further supported by the magnitude of the effect of methyl groups already described (Chapter I). Molecular chlorine, chlorinium ion and chlorosulphonium ion are rejected as the possible electrophile. The mild nature of the electrophile involved and the lack of effect of SO₂ and HCl evolved during the reaction suggests that the electrophile is $\overset{+}{\text{Cl}}-\overset{-}{\text{SO}}_2-\text{Cl}$.

KINETICS AND REACTION MECHANISM OF THE REACTION BETWEEN 3,5-XYLENOL AND SULPHURYL CHLORIDE:

The second order rate constant of chlorination of 3,5-xylenol with sulphuryl chloride was not found to be consistent at all concentrations of xylenol studied (~0.025 to ~0.4M) as was found in the case of the analogous ether, 3,5-dimethyl anisole. The plots were however linear up to 80-90% of the reaction. In all the three media (benzene, chlorobenzene and *o*-dichlorobenzene), in which the reaction was carried out, the k_2 value obtained increased with the increase in concentration of xylenol.

In the molarity range of the xylenol used (0.025 to 0.4M) the k_2 values increased from 9.0×10^{-5} to 3.22×10^{-4} l.mole.⁻¹sec.⁻¹ in benzene (Table III), from 3.2×10^{-4} to 1.36×10^{-3} l.mole.⁻¹sec.⁻¹ in chlorobenzene (Table IV), and

from 6.3×10^{-4} to $1.5 \times 10^{-3} \text{ l. mole.}^{-1} \text{ sec.}^{-1}$ in o-dichlorobenzene (Table V). Though the change of k_2 values obtained could be explained on the basis of the increasing polarity of the three solvents:

benzene < chlorobenzene < o-dichlorobenzene,

the change in the k_2 values in one particular solvent (Table III, IV, V) also seems dependent on the concentration of xylenol in the reaction mixture; the concentration of sulphuryl chloride ($\sim 0.1M$) was the same in all the reaction mixtures.

HYDROGEN BONDING OF THE PHENOLIC -OH GROUP:

The n.m.r. study of the hydrogen bonding of the phenolic -OH group with the solvent was done by tracing its chemical shift in the three solvents (described in Chapter II). This shows a steady increase in the degree of H-bonding with the increase in concentration of xylenol in the solution. The phenolic -OH of one xylenol molecule can be involved in an intermolecular bonding with that of another xylenol molecule. This might inhibit the observed reactivity of the xylenol as its concentration in reaction mixture increased but this is not found. This intermolecular bonding, even if it exists, is not very effective in slowing down the rate of reaction, though this would depend on the solvating power of the solvent too. On the other hand, H-bonding with the solvent could help to explain an increase in the reaction rate with the increase in the concentration of xylenol. Solvent with high dielectric constants would solvate xylenol more and thus the interaction through H-bonding would make the

aromatic system highly reactive. This was confirmed by the chemical shift values obtained for similar concentrations of xylenol in benzene, chlorobenzene and o-dichlorobenzene (Table 9,10,11). Again the change in the overall range within one solvent gives an idea of the extent of the interaction between xylenol and solvent molecules, a property which basically stems from the polarity of the solvent and determines the extent of H-bonding. Thus the bonding is minimum in benzene and maximum in o-dichlorobenzene. The stereo-chemistry of 3,5-xylenol does not seem to oppose it in any way. The results of this study are very much in line with the observed rate of reactions of xylenol with sulphuryl chloride in the three solvents.

As the benzene molecule has a dispersed weak negative charge rather than a strong negative charge assigned at a particular position, it would not be so successful in linking up with -OH as a chlorobenzene or a o-dichlorobenzene molecule either of which could make use of the lone pair of electrons of Cl and make xylenol much more reactive (both by -I and +M processes).

KINETICS OF 3,5-XYLENOL IN MIXED SOLVENT MEDIA:

The intent behind carrying out these reactions (ie. of xylenol [0.025- 0.25M] and sulphuryl chloride [0.1M]) in a mixed solvent medium of benzene and chlorobenzene of varying ratio of concentrations, was to separate and identify the two effects due to (a) polarity of the solvent (b) increase in xylenol concentration (Table VI).

As chlorobenzene was increased and benzene was decreased in the solvating medium from the solvent mixture

10% chlorobenzene + 90% benzene to 90% chlorobenzene + 10% benzene, an apparent increase in k_2 values was observed. In all mixed solvent mediums, an increase in xylenol concentration brings a remarkable increase in k_2 values, e.g. in the solvent media (10% chlorobenzene + 90% benzene) xylenol of $\sim 0.25M$ strength gave the rate constant of $2.0 \times 10^{-4} \text{ l. mole.}^{-1} \text{ sec.}^{-1}$ which was comparable to that found with xylenol of $\sim 0.025M$ strength when chlorination was done in the solvent media containing 50-60% chlorobenzene. The effect of xylenol upon the rate of substitution in such solvent mixtures was much greater than those of chlorobenzene or of benzene (Table VI). This demonstrates the deep involvement of xylenol in speeding up the rate of reaction even in less polar medium. Similarly the rate of reaction increases quite dramatically with the increase of xylenol concentration within each of the solvent mixtures (Table VI).

The analysis of the products formed in reactions in benzene, chlorobenzene and mixed solvents of 10% chlorobenzene + 90% benzene and 90% chlorobenzene + 10% benzene (Table 2) brought forward some interesting facts. As expected in benzene, a poorer solvent than chlorobenzene, the rate of reaction was slow and therefore at the end of the reaction some of the xylenol is expected to remain unreacted, while in chlorobenzene most of the xylenol is expected to undergo chlorination.

The reactions were done for stoichiometric analysis in the above mentioned solvent mixtures at concentrations of $\sim 0.1M$ of 3,5-xylenol and $\sim 0.1M$ sulphuryl chloride solution. The results obtained from the analysis of the

products tallied with that expected. While in benzene 14.4% 3,5-xyleneol was left unreacted, at the end of reaction, in chlorobenzene no trace of xyleneol was found. The main product of chlorination was 4-chloro, 3,5-xyleneol, though in chlorobenzene some (29.07%) 2,4-dichloro, 3, 5-xyleneol was also found to be formed. Again as expected the yield of 4-chloro, 3,5-xyleneol formed in benzene was less (47.5%) than in chlorobenzene (55.7%). This suggests that, while in chlorobenzene 4-chloro, 3,5-xyleneol is made to undergo further chlorination, in benzene the 4-chloro, xyleneol molecule, is not encouraged into further chlorination by sulphuryl chloride. Analysis of the reaction products formed in the mixed solvent mediums also demonstrates the role played by the polarity of the solvent in a similar way. In all the above cases a dimer was also formed and this was found to be formed in more quantity in a less polar medium.

KINETICS OF 2,4,6-D₃-3,5-XYLENOL AND O-DEUTERO-3,5-XYLENOL AND THEIR COMPARISON WITH 3,5-XYLENOL:

To establish the role of the -OH group and the three aromatic protons in 3,5-xyleneol (ie. 2-H, 4-H and 6-H) during its reaction with sulphuryl chloride, the above mentioned deuterated compounds were prepared and studied (as described in Chapter II). Kinetics was done in chlorobenzene (Table XII, XIII). An expected decrease in the k_2 values of 2,4,6-D₃-3,5-xyleneol in comparison to 3,5-xyleneol was observed (TableXII). As a C-D bond would be less polarized than the C-H bond and being strong and short in length, it would not be substituted as easily as a C-H bond. The polar effect of the solvent (chlorobenzene)

and the polarization of the directing group (phenolic -OH) would be same in both cases, making the overall reaction rate slower for 2,4,6-trideutero-3,5-xyleneol than found in 3,5-xyleneol. As the assumption is usually made that isotopes do not show different substituent effects, the difference in reactivity between isotopically different systems must be due to an influence upon a bond-breaking process in the rate determining step of the reaction sequence.

In the case of o-deutero-3,5-xyleneol (Table XIII), the rate of reaction is faster than 3,5-xyleneol in all three concentrations studied, suggesting that intermolecular bonding between xyleneol molecules is discouraged and the interaction with solvent molecule is maintained as before thereby making deutero-xyleneol a much reactive species.

In all the above reactions (involving D₃-xyleneol and o-deutero-xyleneol) the rate of reaction increased with the increase in concentration of the deuterated xyleneol as was the case in 3,5-xyleneol, suggesting that although xyleneol concentration was responsible for the rate of reaction, there was no evidence that the phenolic -OH and the three aromatic protons were directly involved in it.

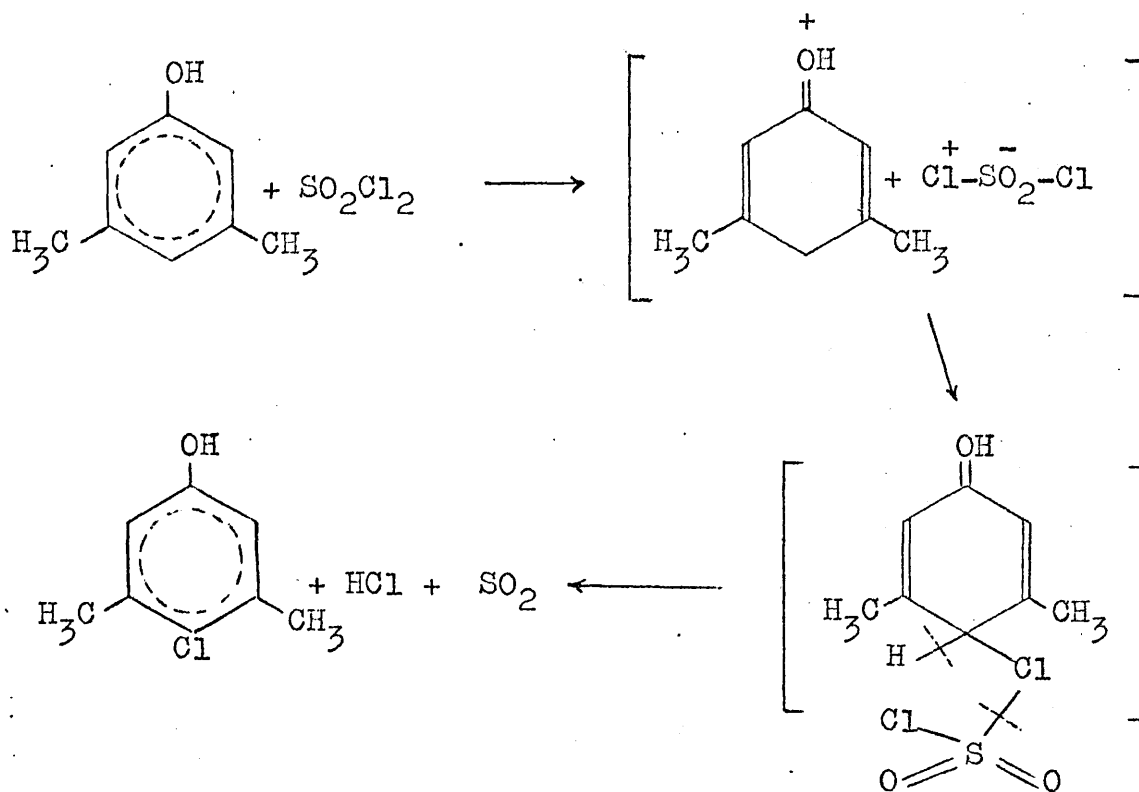
On the basis of the studies described so far and the arguments put forward to explain them, it might be summarised that:

- (1) Polarity of the solvent enhances the reactivity of xyleneol, thus speeding up the attack by sulphuryl chloride.
 - (2) The main product of chlorination, 4-chloro, 3,5-xyleneol is also affected by the surrounding solvent media and the reactants, thus undergoing further chlorination
-

more readily in a more polar solvent.

- (3) The increase in concentration of xylenol in reaction mixtures helps the rate of reaction. This effect is much stronger than changes in the polarity of the medium.
- (4) The H-bonding between a xylenol molecule and a solvent molecule increases with the polarity of the solvent.
- (5) The phenolic -OH might be undergoing some inter-molecular bonding, possibly an opposing feature to the polarizability of the phenolic -OH group.

As the reactions in which a charge is created proceed most rapidly in polar solvents, the speeding up of the above reaction in polar solvents can be explained. As a polar solvent helps to separate the charge in the transition state, in the transition state of 4-chloro, 3,5-xylenol and sulphuryl chloride a polar solvent e.g. chlorobenzene and *o*-dichlorobenzene would be much more successful in doing so than a non polar solvent e.g. benzene, which would rather tend to facilitate the destruction of the charge. On the basis of these arguments the formation of the products (Table 2) can also be explained. The increasing trend in k_2 values in all the three solvents (including benzene), strongly suggests that the polarity of the solvent used is not the only or the main factor.



rate determining transition state

In the solvent media of benzene the first step to produce the 4-chloro derivative is slow, making it difficult to undergo further chlorination due to their small numbers and reactivity. On the other hand in chlorobenzene and *o*-dichlorobenzene the first step is much faster producing substantial amounts of 4-chloro xylenol which would be further attacked by sulphuryl chloride to make a dichloro derivative of xylenol. If this is the reason, then in benzene medium at low concentrations of xylenol, some dichloro product should be expected and at high concentrations of xylenol only 4-chloro product would be expected to be formed, in all the three solvents. As dichloro and trichloro xylenols are prepared when sulphuryl chloride is two and three times in ratio to 3,5-xylenol in the reaction mixture

(Chapter II). Thus at low concentrations of xylenol ($\sim 0.025-0.05M$) and when sulphuryl chloride is more in quantity ($\sim 0.1M$) dichloro and trichloro derivative of xylenol might be formed in a polar medium. In a poor medium like benzene, at least all the xylenol present in the reaction mixture would be used up to form 4-chloro derivative.

Following the argument, when $\sim 0.1M$ of xylenol is reacted with $\sim 0.1M$ of sulphuryl chloride, all of xylenol should be exhausted in a polar solvent, which is found to be the case (Table 2). Therefore at high concentrations of xylenol, more 4-chloro xylenol would be formed. This argument does not so successfully explain the results obtained in benzene, where increases in the concentration of xylenol increases the rate of reaction while analysis of end products shows some xylenol left unreacted.

The increase in the rate of reaction in the three solvents proves that increase in xylenol concentration has not a direct effect on the rate but some particular mechanism which once started, continues due to the greater availability of the xylenol molecules. This is found to be the case in the three solvents. Therefore the end products would vary from mono to di and trichloro xylenols in benzene, chlorobenzene and o-dichlorobenzene at one concentration of 3,5-xylenol. The trend in k_2 values in each solvent would also be due to this mechanism taking place.

EVIDENCE AND STUDY OF COMPLEX FORMATION:

To understand the mechanism and the behaviour of xylenol molecules at all concentrations (though the effect is more obvious with the increase in xylenol concentrations) and in all the three solvents, we need to find out, whether xylenol complexes with sulphuryl chloride. The high reactivity of xylenol with sulphuryl chloride did not permit this but the comparatively less reactive 4-chloro, 3,5-xylenol was found to form a π -complex with sulphuryl chloride, which absorbed at a characteristic wavelength (Chapter II). Similarly 2,4-dichloro, 3,5-xylenol was also found to be complexing with sulphuryl chloride. The extinction coefficient values of the complexes by the ketelaar equation could not be found as K_c appeared to vary with the concentration of the two reactants in the solution and with time. Though by now the importance and activity of the π -complex formed by xylenol and sulphuryl chloride was not in doubt, an attempt to study its kinetics of reaction by u.v. was also a failure. The absorbance of the π -complex, which would be expected to decrease with time and with its continued participation in the reaction, was found to increase and decrease randomly. This suggested that the reaction is proceeding in many stages as the dichloro xylenol, via its π -complex, might be affecting the reaction too. π -Complex formation was also confirmed in 3,5-ditertiary butyl phenol and 3,5-dimethyl anisole, though their role in the reaction was quite different.

EFFECT OF π -COMPLEXES ON THE KINETICS AND MECHANISM
OF THE REACTION:

This π -complex formation between the 4-chloro, 3,5-xylenol and sulphuryl chloride opened a new line of thought and a new mechanism which could satisfy the various results obtained during the study of the reaction. In benzene, a poorer solvent than chlorobenzene, a second molecule of 3,5-xylenol was expected¹³¹ to be needed to complete the transition from reaction intermediates to products. The more polar solvents e.g. chlorobenzene and *o*-dichlorobenzene will solvate the reaction intermediates more efficiently, and thus a second xylenol molecule was not expected¹³¹ to be essential for the completion of the reaction sequence. This was found to be untrue as the trend of the k_2 values obtained over a wide range of concentration of xylenol was similar in all the three solvents except to the extent, and also the k_2 values increased with increased polarity of the three solvents.

As already mentioned, because of the increasing polarity more dichloro product of 3,5-xylenol would be expected to form at low concentrations of xylenol. The 4-chloro, 3,5-xylenol and sulphuryl chloride, by making a π -complex, could further help to convert the mono chloro xylenol into dichloro xylenol. Similarly the π -complex could help to accelerate the chlorination of other 3,5-xylenol molecules into 4-chloro, 3,5-xylenol. Although the higher reactivity of 3,5-xylenol than its 4-chloro product would encourage the formation of more 4-chloro xylenol, the π -complex of 4-chloro xylenol and sulphuryl chloride could collapse to give 2,4-dichloro,

3,5-xylenol and so provide a unique source of this product. This ratio of 2,4-dichloro xylenol to mono chloro xylenol would increase with the concentration of xylenol initially present in the reaction mixture, and undoubtedly with the polarity of the solvent. Therefore at any concentration of xylenol, the ratio of dichloro product to mono chloro product would be more in o-dichlorobenzene than in chlorobenzene and benzene. The π -complex of 2,4-dichloro, 3,5-xylenol and sulphuryl chloride would be much less reactive than the complex of 4-chloro xylenol and sulphuryl chloride and thus would be less obvious.

To illustrate the accelerating role of the π -complex formed between 4-chloro xylenol and sulphuryl chloride much more vividly, the kinetics of the reaction of 3,5-dimethyl anisole and sulphuryl chloride was done in presence of 4-chloro xylenol (Chapter II). This study was done in the solvents benzene (Table VII) and chlorobenzene (Table VIII). The strength of dimethyl anisole was kept to $\sim 0.3M$ so that the difference in the second order rate (which is otherwise consistent in 3,5-dimethyl anisole) could be attributed to the different quantities of 4-chloro xylenol added ($\sim 0.01M$ - $\sim 0.15M$) and the availability of the other reactant, sulphuryl chloride ($\sim 0.05M$, $\sim 0.1M$ and $\sim 0.2M$). The graphs plotted were linear and k_2 values increased with the increase of 4-chloro xylenol content in the reaction mixture.

The difference in the polarities of the two solvents was clearly demonstrated by the two sets of k_2 values obtained from the reactions done in benzene and chlorobenzene. In benzene the second order rate constant

varied from 5.0×10^{-5} to $1.2 \times 10^{-4} \text{ M}^{-1} \text{ sec.}^{-1}$, while in the medium of chlorobenzene it varied from 2.9×10^{-4} to $9.0 \times 10^{-4} \text{ M}^{-1} \text{ sec.}^{-1}$.

In the reactions of a sulphuryl chloride solution of certain strength (e.g. ~ 0.05 , ~ 0.1 and $\sim 0.2\text{M}$) an increase in the amount of 4-chloro, 3,5-xylenol to the reaction mixture of 3,5-dimethyl anisole and sulphuryl chloride was consistently followed by the increase of second order rate constants. The main difference in the above mentioned reactions and the reactions of 3,5-xylenol and sulphuryl chloride in the three solvents is that the amount of 4-chloro xylenol present initially in the reaction mixture is known here while it is difficult to assess in the case of 3,5-xylenol. So in the dimethyl anisole reactions the 4-chloro xylenol will make the π -complex at the first opportunity. As expected the π -complex helps effectively to further chlorinate 4-chloro xylenol to form 2,4-dichloro, 3,5-xylenol and also helps the dimethyl anisole molecule to react. Basically dimethyl anisole would be much more reactive than 4-chloro xylenol and the ability of the latter to form a π -complex in which the SO_2Cl_2 component appears to have increased polarity would accelerate the process of chlorination. Thus the increase in the second order rate constants would be principally attributed to the interaction of 4-chloro, 3,5-xylenol with sulphuryl chloride.

Another interesting fact which has been observed in the k_2 values obtained from the above reactions is that the second order rate constants from all the three concentration of sulphuryl chloride in benzene were consistent

at any one concentration of 4-chloro xylenol in the reaction mixture (Table VII), while in chlorobenzene the second order rate constants fell with the increase in concentration of sulphuryl chloride in the reaction mixture (Table VIII).

Evidently, the activity of the π -complex formed between 4-chloro xylenol and sulphuryl chloride is diminished in a more polar solvent e.g. chlorobenzene, although increased amounts of 4-chloro xylenol still encourage chlorination even in a reaction mixture containing large amounts of sulphuryl chloride (e.g. $\sim 0.2M$). This could be explained by a competition between catalysed and non catalysed substitution taking place, with direct (non catalysed) attack becoming the main feature in the reaction mixtures rich with sulphuryl chloride content. The polarity of the solvent plays its part in here but despite this opposing factor to the activity of π -complex and the slowing down of the reaction, the expected accelerating property of the complex remains (Table VIII).

Similarly addition of 2,4-dichloro, 3,5-xylenol to the reaction mixture of 3,5-dimethyl anisole ($\sim 0.3M$) and sulphuryl chloride ($\sim 0.1M$) in the two solvents (benzene and chlorobenzene), showed a similar trend i.e. the increase in the second order rate constants with the increase in the dichloro xylenol. Obviously this is due to a similar π -complex formed between the dichloro xylenol and sulphuryl chloride, though this would be less activating than of 4-chloro xylenol. This is confirmed by the less impressive increase in k_2 values in this case (Table IX). The 4-chloro xylenol however has more alternative reaction pathways i.e.

- (a) it can form dichloro product.
- (b) it can help dimethyl anisole to react with sulphuryl chloride.
- (c) from (a), the dichloro xylenol could form its π -complex and keep the reaction going at a faster rate.

None of these processes are as favoured for the dichloro xylenol.

The above study of π -complexes was extended to 4-chloro, 3,5-dimethyl anisole also and was done in chlorobenzene (Table X). Here varying amounts of 4-chloro,3,5-dimethyl anisole (which happens to be the major product of chlorination of 3,5-dimethyl anisole (Chapter II)) was added to the reaction mixture of 3,5-dimethyl anisole ($\sim 0.3M$) and sulphuryl chloride ($\sim 0.1M$). As expected, not a much noticeable increase in the second order rate constant was observed when the quantity of 4-chloro, 3,5-dimethyl anisole, introduced to the reaction mixture, was increased.

While 3,5-ditertiary butyl phenol was also found to form a π -complex with sulphuryl chloride (Chapter II), its nature was expected to be some what different than all of π -complexes discussed already, because of steric hinderance. The para position is the preferential position in 3,5-xylenol and 3,5-dimethyl anisole, but the main product of chlorination of ditertiary butyl phenol was 2-chloro, 3,5-ditertiary butyl phenol, which once formed would form a π -complex of a different stereochemistry. Thus the addition of 3,5-ditertiary butyl phenol would be expected to affect the reaction of dimethyl

anisole and sulphuryl chloride in a different way.

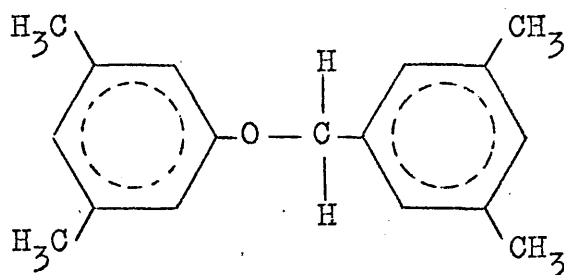
The study was extended to the three concentrations of sulphuryl chloride (ie. ~ 0.05 , ~ 0.1 and $\sim 0.2M$) in chlorobenzene, while 3,5-dimethyl anisole was maintained to one concentration ($\sim 0.3M$). The quantity of 3,5-ditertiary butyl phenol introduced to the above reaction mixture was increased from $\sim 0.01M$ to $\sim 0.15M$ as in the previous studies. The increase of second order rate constants with the increase of the amount of 3,5-ditertiary butyl phenol was more predominant at low concentrations of sulphuryl chloride (ie. $\sim 0.05M$) and dies down with its increase in the solution. Although the rate of reaction was much higher at high concentrations of sulphuryl chloride it remained consistent at all the concentrations of ditertiary butyl phenol, added to the reaction mixture, suggesting that the π -complex formed between ditertiary butyl phenol and sulphuryl chloride has a limited effect in a solution rich with sulphuryl chloride. This is quite different to the observed behaviour of the π -complex of 4-chloro, 3,5-xyleneol at high concentrations of sulphuryl chloride in chlorobenzene, where the impact of the π -complex on the second order rate constant, though lower than in the weak solutions of sulphuryl chloride, firmly depended on the amount of 4-chloro, 3,5-xyleneol introduced in the reaction mixture of dimethyl anisole and sulphuryl chloride. In this case, however, the variable amounts of ditertiary butyl phenol present in the reaction mixture do not affect the second order rate constant at high concentrations of sulphuryl chloride. Therefore dimethyl anisole is expected to

undergo mostly direct substitution.

DIMERIZATION:

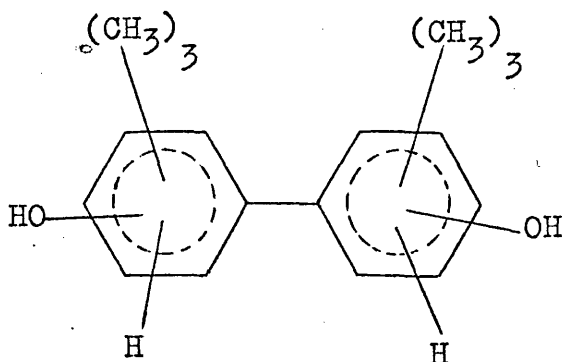
In all reactions of sulphuryl chloride with poly-methyl phenols small amounts of products were found which did not contain chlorine. They appear to be dimers of the original phenol. Mass spectrometry and proton n.m.r. suggested the following structures for the products obtained from 3,5-xyleneol, 2,3,5-trimethyl phenol and 2,3,6-trimethyl phenol.

from 3,5-xyleneol:



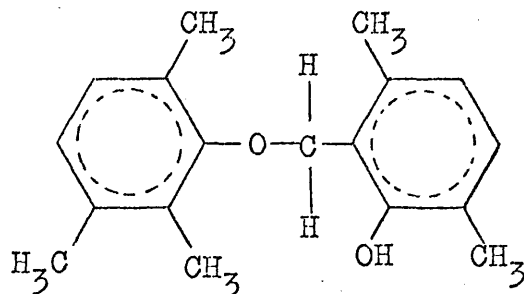
(1)

from 2,3,5-trimethyl phenol:

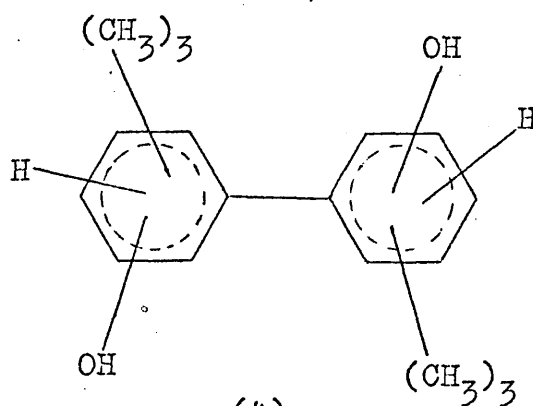


(2)

from 2,3,6-trimethyl phenol:



(3)

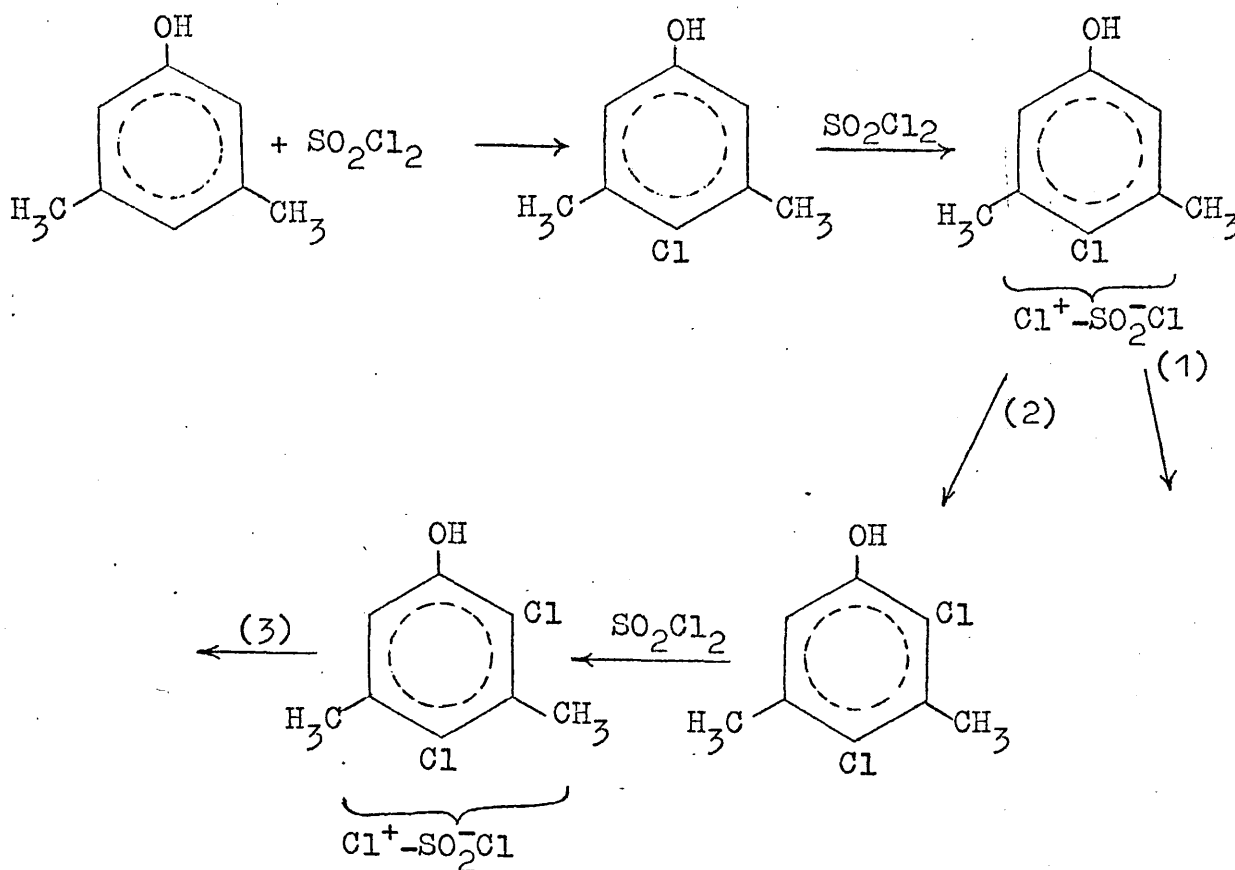


(4)

The oxidative coupling of phenols is a well known process. It is usually thought to involve phenoxyl radicals although structures (2,4) suggest attack by the carbon radical upon the parent phenol. Although the main reaction between sulphuryl chloride and these phenols seems to be a heterolytic process, the incursion of homolytic processes involving for instance chlorine atoms is well known for reactions involving sulphuryl chloride and represent a side reaction which is observed under almost any reaction conditions. It seems that such dimerization reactions reflect a small contribution by such a homolytic process which does not invalidate over general arguments for conditions.

CONCLUSION:

The formation of the π -complex during the reaction of 3,5-xyleneol and sulphuryl chloride is the main feature and the reaction may be summarized diagrammatically as follows:



- (1) might react with xyleneol molecule at high availability of xyleneol.
- (2) might further chlorinate to give dichloro xyleneol.
- (3) might undergo further chlorination or react with xyleneol or 4-chloro xyleneol thus ensuing the process of chlorination.

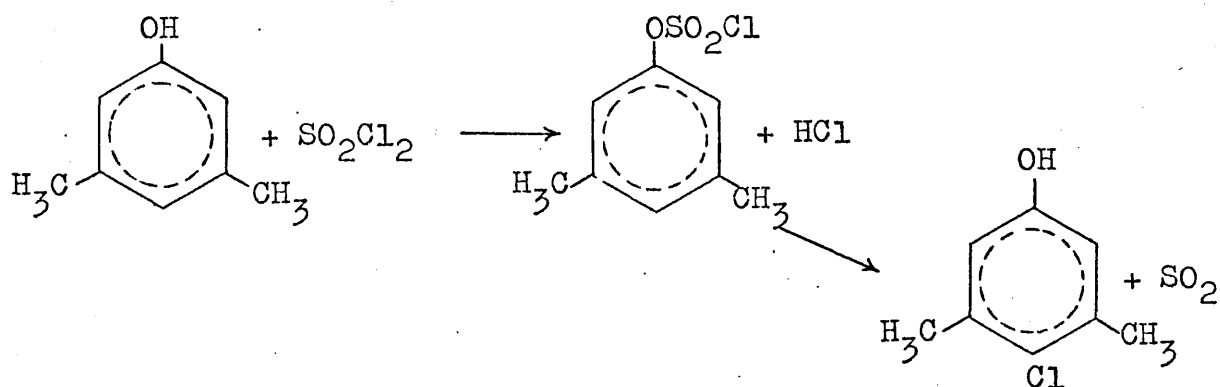
All the stages of reaction mentioned above are affected

and guided by the polarity of the solvent (benzene, chlorobenzene and *o*-dichlorobenzene) and by the concentration of xylenol in the reaction mixture.

The electromeric effect in the xylenol molecule thus making ortho and para positions comparatively rich with the electrons at the time of the approach by molecular sulphuryl chloride might also be responsible for existence of sulphuryl chloride as $\text{Cl}^+ - \text{SO}_2^- - \text{Cl}$. This formation of electrophile might also be due to the π -complex formed between 4-chloro xylenol and sulphuryl chloride which then could provide the attacking species and explain its high reactivity.

The polarised sulphuryl chloride molecule would be much more reactive than a sulphuryl chloride molecule which has not yet undergone the much needed incipient heterolysis to form $\text{Cl}^+ - \text{SO}_2^- - \text{Cl}$ and thus can attack other xylenol or 4-chloro xylenol molecules at a higher rate.

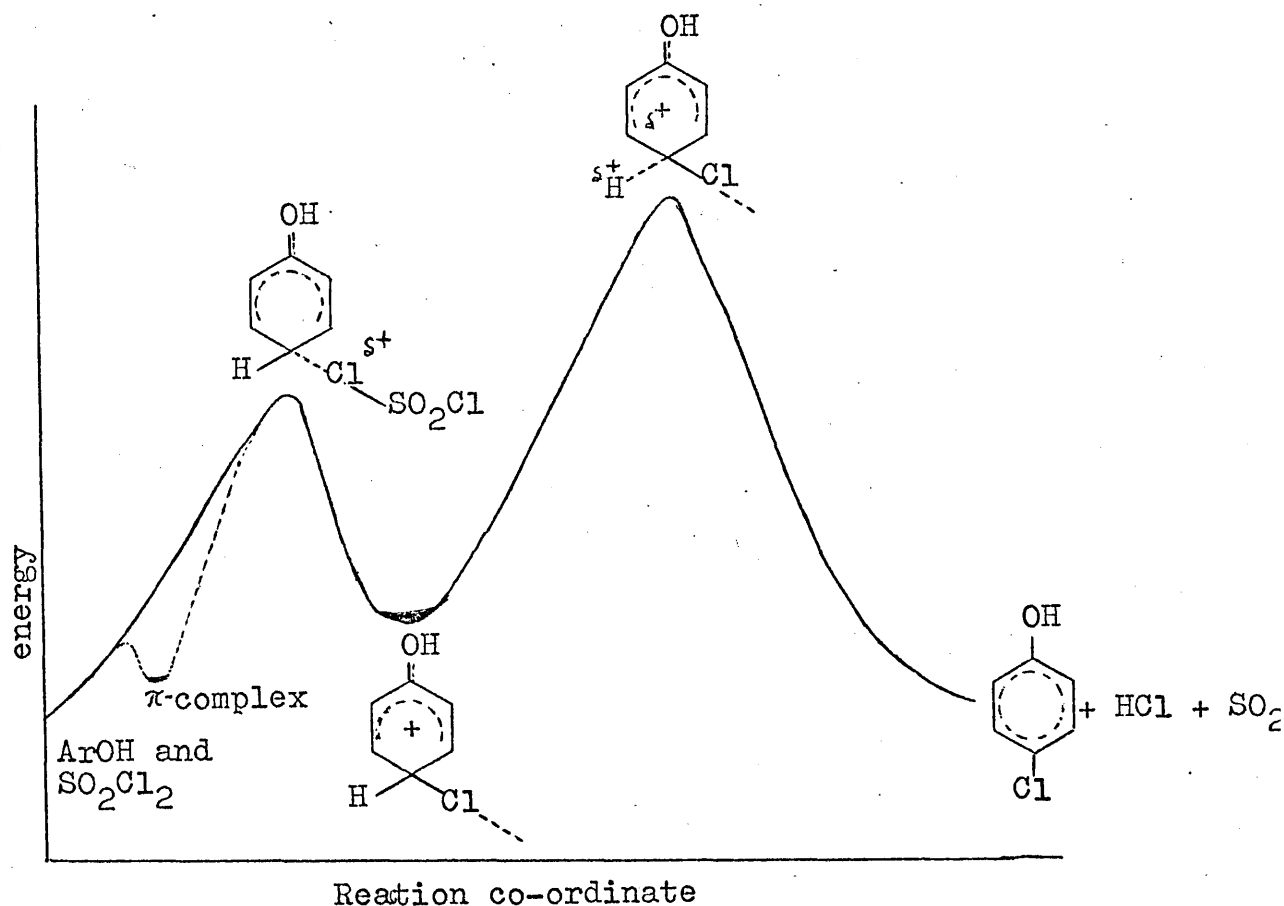
As it has been mentioned, the phenolic -OH bond does not seem to be broken during the reaction (determined by infra red spectrum of the reaction mixture of 3,5-xylenol and sulphuryl chloride at intervals). This would preclude the possibility that the following sequence is involved in the mechanism of the reaction.



Moreover the previous suggestion would not fit well with the observed formation and activity of the π -complex it seems right to suggest that π -complex helps to polarise the attacking species possibly via the chlorine at para positions or the π electrons of the aromatic systems.

The rate determining step must be the simultaneous insertion of chlorine at ortho and para positions and breaking of the C-H bond as was shown by the kinetic study of 2,4,6-D₃-3,5-xyleneol and its comparison with 3,5-xyleneol.

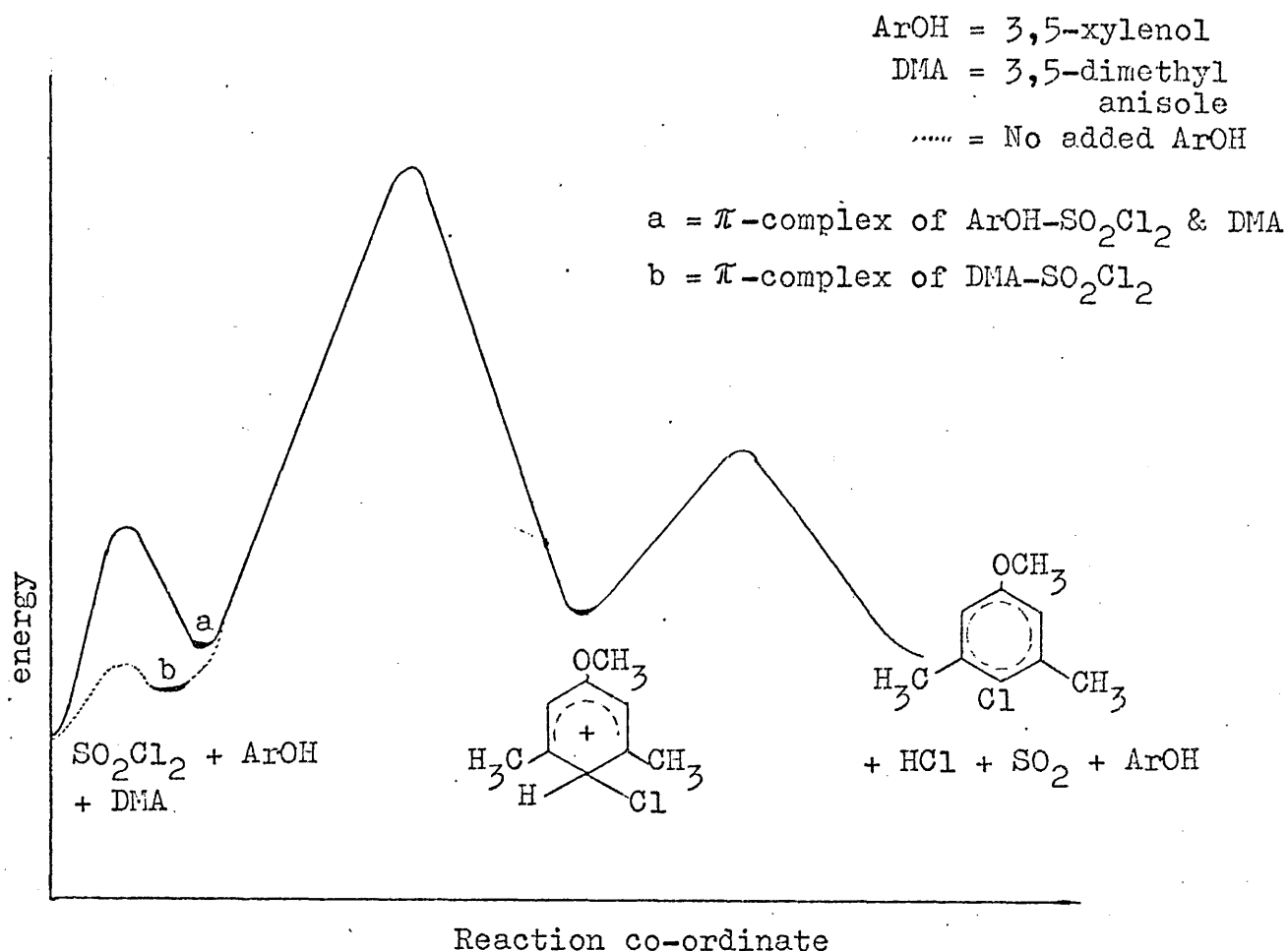
The general mechanism of the reaction of a phenol with sulphuryl chloride could be more digestibly presented by the reaction profile given below which plots the energy of the system against the reaction co-ordinate.



With the approach of the electrophile molecular sulphuryl chloride the bond $\text{Cl}\overset{-}{\text{S}}\text{O}_2-\overset{+}{\text{Cl}}$ would become much more polarized (by induction) and larger, and attack the electron abundant para position created by means of various effects (mesomeric, electromeric etc.) at the time of approach by the electrophile. The first transition state could have the molecule of phenol and sulphuryl chloride partially bonded at the para position. The activation energy of the forward reaction would depend on the stereochemistry of the two molecules and the dipole created in the phenol molecule (as it is this charge distribution which could encourage or discourage the strength of the bonding with the electrophile). This could also effect the stability of the intermediate and to a little extent the rate of reaction. The second transition state is suggested to be the rate determining step, as here hydrogen can break away from carbon and chlorine would be installed in its place.

In case of 3,5-xylenol the π -complex formation between the xylenol and sulphuryl chloride would be an important feature (as shown in the reaction profile). The complexes of 4-chloro xylenol and 2,4-dichloro xylenol with sulphuryl chloride would be comparatively stable than of 3,5-xylenol due to their decreasing reactivity. Here the first transition state is expected to be attained much more quickly due to the high reactivity of the π -complexes.

In the kinetics of 3,5-dimethyl anisole and sulphuryl chloride in presence of 4-chloro xylenol, again there would be two transition states.



Here both dimethyl anisole and chloro xyleneol would form π -complexes with sulphuryl chloride. As known by the kinetic study, it would be the complex of 4-chloro xyleneol which would help to establish the second transition state at a quicker rate and thus affect the overall second order rate constant of the reaction. The intermediate would have hydrogen and chlorine both bonded to the para position of the dimethyl anisole molecule and breaking of C-H bond would be enhanced by the π -complex as shown in the reaction profile.

STRUCTURE OF π -COMPLEX:

The u.v. study of the π -complex formed between the two reactants was not a great help as far as its structure

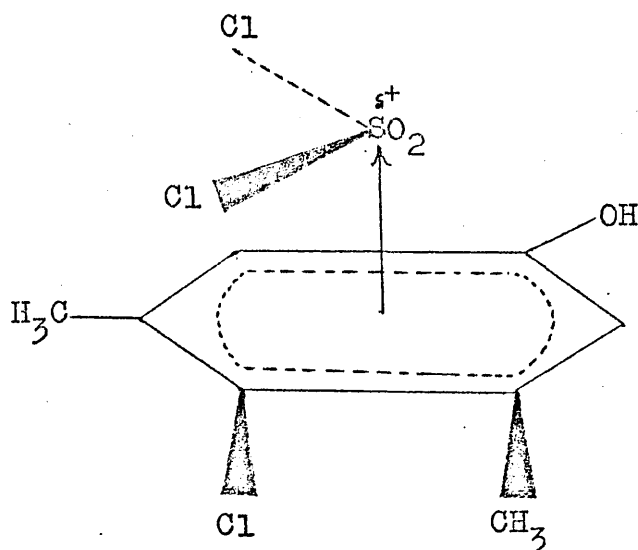
was concerned, and was merely evidence of its formation due to its characteristic absorption. The n.m.r. spectroscopy was thus used (Chapter II) and gave some information regarding its structure.

The n.m.r. spectrum of 4-chloro, 3,5-xylenol and sulphuryl chloride in benzene showed the two $-\text{CH}_3$ groups (originally equivalent represented as a singlet at 2.16 p.p.m.) as unequivalent at 2.08 and 2.28p.p.m. Expansion of the two signals showed them to be further coupled. The phenolic $-\text{OH}$ group remains unchanged at 4.13p.p.m. The aromatic protons (ie. 2-H and 6-H) appear down field at 6.56p.p.m. The uncomplexed 4-chloro, 3,5-xylenol present in the sample showed the two equivalent $-\text{CH}_3$ groups and aromatic protons at 2.16 and 6.28p.p.m. respectively.

A mixture of 3,5-xylenol and sulphuryl chloride in benzene showed the two $-\text{CH}_3$ groups, changing in nature. While the n.m.r. of a mixture of 3,5-xylenol and 4-chloro, 3,5-xylenol in benzene did not show any inter-action between the two molecules.

This suggests that sulphuryl chloride is lying on the planer molecule of xylenol in such a way that the two $-\text{CH}_3$ groups are made unequivalent. The aromatic protons are also affected and could be in the process of making the dichloro product. The π -complex could also be the begining of the dipolar character in the electrophile as $\overset{+}{\text{Cl}}-\overset{-}{\text{SO}}_2-\text{Cl}$.

To explain the foregoing arguments, the following structure can be suggested for the complex.



A similar structure can be suggested for the π -complex formed between 3,5-ditertiary butyl phenol and sulphuryl chloride. The uncomplexed phenol showed the two equivalent $-C(CH_3)_3$ groups at 1.26p.p.m. while the complexed phenol gave the signal at 1.48p.p.m. Which on expansion was found to be coupled.

CHAPTER IV

TABLES

TABLE I

Kinetics of the reaction of sulphuryl chloride with some phenols in chlorobenzene at 25.0°C.

Phenol	Molarity of phenol	Molarity of sulphuryl chloride	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$		
3,5-ditertiary butyl phenol	0.0972	0.0791	7.95	±	$\cdot 04 \times 10^{-5}$
	0.1992	0.0435	6.09	±	$\cdot 03 \times 10^{-5}$
2,4-xyleneol	0.201	0.087	7.6	±	$\cdot 06 \times 10^{-5}$
	0.1258	0.087	2.62	±	$\cdot 002 \times 10^{-4}$
	0.2445	"	2.053	±	$\cdot 01 \times 10^{-4}$
	0.1994	0.0435	1.69	±	$\cdot 01 \times 10^{-4}$
2,6-xyleneol	0.1283	"	2.8	±	$\cdot 01 \times 10^{-4}$
	0.207	0.087	1.488	±	$\cdot 0003 \times 10^{-4}$
	0.2015	0.0435	1.3	±	$\cdot 001 \times 10^{-4}$
2,3,6-trimethyl phenol	0.01074	0.0435	2.135	±	$\cdot 1 \times 10^{-4}$
	0.09868	0.087	3.86	±	$\cdot 007 \times 10^{-4}$
	0.2	"	4.9	±	$\cdot 05 \times 10^{-4}$
2,3,5-trimethyl phenol	0.0998	0.0435	4.72	±	$\cdot 015 \times 10^{-4}$
	0.1	0.087	3.1	±	$\cdot 05 \times 10^{-4}$
phenol	0.1998	"	3.86	±	$\cdot 003 \times 10^{-4}$
	0.2	0.0435	3.327	±	$\cdot 0008 \times 10^{-3}$

TABLE II

Kinetics of reaction of sulphuryl chloride with 3,5-dimethyl anisole in benzene at 25.0°C.

Sulphuryl chloride (M)	3,5-dimethyl anisole (M)	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$
0.0739	0.3	2.6 \pm .01x10 ⁻⁴
"	0.312	2.35 \pm .02x10 ⁻⁴
"	0.5	1.346 \pm .01x10 ⁻⁴
0.1	0.114	1.96 \pm .01x10 ⁻⁴
"	0.307	2.199 \pm .007x10 ⁻⁴
"	0.4987	1.21 \pm .009x10 ⁻⁴
0.1478	0.304	1.784 \pm .02x10 ⁻⁴
"	0.09938	1.752 \pm .01x10 ⁻⁴
"	0.5	1.6 \pm .006x10 ⁻⁴
0.1987	0.09487	1.2 \pm .001x10 ⁻⁴
0.2029	0.2025	1.832 \pm .01x10 ⁻⁴

TABLE III

Kinetics of reaction of sulphuryl chloride with 3,5-xylenol in benzene at 25.0°C.

Sulphuryl chloride (M)	3,5-xylenol (M)	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$
0.09398	0.02439	9.01 ± .06x10 ⁻⁵
"	0.05448	1.16 ± .01x10 ⁻⁴
"	0.04947	6.52 ± .08x10 ⁻⁵
"	0.107	1.19 ± .001x10 ⁻⁴
"	0.1	1.176 ± .007x10 ⁻⁴
"	0.197	1.575 ± .003x10 ⁻⁴
0.0987	0.242	1.44 ± .05x10 ⁻⁴
0.09398	0.2573	1.652 ± .001x10 ⁻⁴
"	0.301	2.20 ± .05x10 ⁻⁴
"	0.4108	2.142 ± .06x10 ⁻⁴
0.0999	0.4083	2.729 ± .008x10 ⁻⁴
0.1	0.4	3.22 ± .1x10 ⁻⁴

TABLE IV

Kinetics of reaction of sulphuryl chloride with 3,5-xyleneol in chlorobenzene at 25.0°C.

Sulphuryl chloride (M)	3,5-xyleneol (M)	k_2 (M ⁻¹ sec. ⁻¹)
0.09142	0.0264	3.237 ± .02x10 ⁻⁴
"	0.05	3.67 ± .09x10 ⁻⁴
0.094	0.0506	2.94 ± .05x10 ⁻⁴
"	0.1022	5.0258 ± .02x10 ⁻⁴
0.09142	0.1	5.73 ± .005x10 ⁻⁴
"	0.15	5.867 ± .004x10 ⁻⁴
0.0979	0.1505	7.01 ± .006x10 ⁻⁴
0.094	0.1976	7.65 ± .02x10 ⁻⁴
0.1028	0.2008	7.68 ± .004x10 ⁻⁴
0.9169	0.2577	1.132 ± .002x10 ⁻³
0.09142	0.2465	8.6 ± .003x10 ⁻⁴
"	0.3996	1.24 ± .002x10 ⁻³
0.0917	0.4012	1.36 ± .01x10 ⁻³

TABLE V

Kinetics of reaction of sulphuryl chloride with 3,5-xyleneol in o-dichlorobenzene at 25.0°C.

Sulphuryl chloride (M)	3,5-xyleneol (M)	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$
0.09302	0.02342	$6.388 \pm .06 \times 10^{-4}$
0.103	0.0259	$6.892 \pm .02 \times 10^{-4}$
0.09302	0.04963	$6.784 \pm .009 \times 10^{-4}$
"	0.04613	$7.214 \pm .04 \times 10^{-4}$
"	0.10248	$1.2 \pm .002 \times 10^{-3}$
0.1001	0.101	$1.316 \pm .02 \times 10^{-3}$
"	0.1506	$1.26 \pm .05 \times 10^{-3}$
"	0.2003	$1.52 \pm .06 \times 10^{-3}$
"	0.2506	$1.403 \pm .02 \times 10^{-3}$
0.09302	0.2376	$2.51 \pm .009 \times 10^{-3}$
"	0.258	$1.522 \pm .008 \times 10^{-3}$
"	0.403	$1.57 \pm .06 \times 10^{-3}$

TABLE VI

Kinetics of reaction of sulphuryl chloride with 3,5-xylenol in mixed solvent at 25.0°C.

Solvent	Sulphuryl chloride (M)	3,5-xylenol (M)	k_2 (M ⁻¹ sec. ⁻¹)
10% chlorobenzene	0.09222	0.0252	5.03 ± .1x10 ⁻⁵
+		0.1005	1.666 ± .02x10 ⁻⁴
90% benzene		0.2494	2.0 ± .003x10 ⁻⁴
20% chlorobenzene	0.09222	0.02518	1.1 ± .01x10 ⁻⁴
+		0.1063	1.76 ± .009x10 ⁻⁴
80% benzene		0.251	2.94 ± .001x10 ⁻⁴
40% chlorobenzene	0.09222	0.026	3.368 ± .02x10 ⁻⁴
+		0.1013	3.555 ± .04x10 ⁻⁴
60% benzene		0.2513	4.173 ± .01x10 ⁻⁴
50% chlorobenzene	0.0901	0.02557	1.82 ± .01x10 ⁻⁴
+		0.1024	3.665 ± .01x10 ⁻⁴
50% benzene		0.2513	4.948 ± .01x10 ⁻⁴
60% chlorobenzene	0.09222	0.02472	2.447 ± .07x10 ⁻⁴
+		0.1002	4.77 ± .04x10 ⁻⁴
40% benzene		0.2505	6.4 ± .03x10 ⁻⁴
80% chlorobenzene	0.09222	0.0269	9.1 ± .002x10 ⁻⁴
+		0.1076	6.25 ± .01x10 ⁻⁴
20% benzene		0.2503	8.658 ± .05x10 ⁻⁴
90% chlorobenzene	0.09222	0.2545	8.747 ± .1x10 ⁻⁴
+		0.1008	6.677 ± .02x10 ⁻⁴
10% benzene		0.2519	1.68 ± .005x10 ⁻³

TABLE VII

Kinetics of reaction of sulphuryl chloride with 3,5-dimethyl anisole in presence of 4-chloro, 3,5-xylenol in benzene at 25.0°c. .

Sulphuryl (M)	3,5-dimethyl anisole (M)	4-chloro,3,5- xylenol (M)	k_2 (M ⁻¹ sec. ⁻¹)
0.05	0.306	0.0115	4.916 ± .01x10 ⁻⁵
"	0.30	0.049	1.1 ± .02x10 ⁻⁴
"	0.291	0.1	1.097 ± .006x10 ⁻⁴
"	0.3023	0.151	1.25 ± .001x10 ⁻⁴
0.09705	0.3	0.0144	7.736 ± .02x10 ⁻⁵
"	0.302	0.0549	9.22 ± .09x10 ⁻⁵
"	0.292	0.1	1.027 ± .001x10 ⁻⁴
"	0.305	0.152	1.172 ± .002x10 ⁻⁴
0.2006	0.288	0.0089	5.37 ± .06x10 ⁻⁵
"	0.3	0.047	7.478 ± .01x10 ⁻⁵
"	0.293	0.1002	9.846 ± .05x10 ⁻⁵
"	0.30804	0.148	1.176 ± .001x10 ⁻⁴

TABLE VIII

Kinetics of reaction of sulphuryl chloride with 3,5-dimethyl anisole in presence of 4-chloro, 3,5-xylenol in chlorobenzene at 25.0°C.

Sulphuryl chloride (M)	3,5-dimethyl anisole (M)	4-chloro,3,5- xylenol (M)	k_2 (M ⁻¹ sec. ⁻¹)
0.05	0.30853	0.0106	7.015 ± .01x10 ⁻⁴
"	0.30157	0.05	6.94 ± .002x10 ⁻⁴
"	0.3043	0.1056	7.24 ± .003x10 ⁻⁴
"	0.299	0.1524	9.042 ± .01x10 ⁻⁴
0.0979	0.2974	0.012	5.313 ± .01x10 ⁻⁴
"	0.3056	0.048	5.763 ± .01x10 ⁻⁴
"	0.3045	0.1064	6.936 ± .04x10 ⁻⁴
"	0.3035	0.152	8.256 ± .008x10 ⁻⁴
0.198	0.307	0.01	2.95 ± .04x10 ⁻⁴
"	0.316	0.05	4.59 ± .02x10 ⁻⁴
"	0.303	0.1	5.589 ± .02x10 ⁻⁴
"	0.299	0.15	6.48 ± .002x10 ⁻⁴

TABLE IX

Kinetics of reaction of sulphuryl chloride with 3,5-dimethyl anisole in presence of 2,4-dichloro,3,5-xylenol in benzene and chlorobenzene* at 25.0°C.

Sulphuryl chloride (M)	3,5-dimethyl anisole (M)	2,4-dichloro 3,5-xylenol (M)	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$
0.0868	0.2986	0.0102	$8.35 \pm .1 \times 10^{-5}$
"	0.2983	0.05	$6.49 \pm .03 \times 10^{-5}$
"	0.3015	0.1001	$6.461 \pm .01 \times 10^{-5}$
"	0.3027	0.1505	$9.623 \pm .04 \times 10^{-5}$
0.09977*	0.3015	0.01033	$3.93 \pm .009 \times 10^{-4}$
"	0.3052	0.0489	$3.40 \pm .02 \times 10^{-4}$
"	0.3056	0.1002	$3.75 \pm .01 \times 10^{-4}$
"	0.3078	0.1506	$5.889 \pm .02 \times 10^{-4}$

TABLE X

Kinetics of reaction of sulphuryl chloride with 3,5-dimethyl anisole in presence of 4-chloro, 3,5-dimethyl anisole in chlorobenzene at 25.0°C.

Sulphuryl chloride (M)	3,5-dimethyl anisole (M)	4-chloro,3,5- dimethyl anisole (M)	$\frac{k_2}{k_1}$ (M ⁻¹ sec. ⁻¹)
0.0997	0.3022	0.0159	3.766 ± .02x10 ⁻⁴
"	0.3	0.0474	4.145 ± .006x10 ⁻⁴
"	0.3069	0.111	4.075 ± .02x10 ⁻⁴

TABLE XI

Kinetics of the reaction of sulphuryl chloride with 3,5-dimethyl anisole in the presence of 3,5-ditertiary butyl phenol in chlorobenzene at 25.0°C.

Sulphuryl chloride (M)	3,5-dimethyl anisole (M)	3,5-ditertiary butyl phenol (M)	k_2 (M ⁻¹ sec. ⁻¹)
0.05141	0.2999	0.011	3.5 ± .05x10 ⁻⁴
"	0.302	0.0508	4.07 ± .01x10 ⁻⁴
"	0.3008	0.1014	4.724± .04x10 ⁻⁴
"	0.3071	0.154	5.047± .03x10 ⁻⁴
0.1028	0.3024	0.0097	4.3 ± .01x10 ⁻⁴
"	0.2977	0.053	4.3 ± .01x10 ⁻⁴
"	0.301	0.102	5.03 ± .01x10 ⁻⁴
"	0.3082	0.15	4.8 ± .01x10 ⁻⁴
0.2056	0.3076	0.0123	6.5 ± .03x10 ⁻⁴
"	0.3016	0.0523	5.67 ± .006x10 ⁻⁴
"	0.3045	0.103	5.878± .06x10 ⁻⁴
"	0.3182	0.14	5.127± .01x10 ⁻⁴

TABLE XII

Comparison of the kinetics of reaction of sulphuryl chloride with 3,5-xylenol and of sulphuryl chloride with 3,5-D₃-xylenol in chlorobenzene at 25.0°C.

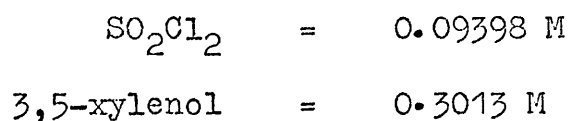
Sulphuryl chloride (M)	3,5-xylenol (M)	3,5-D ₃ -xylenol (M)	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$
0.09142	{ 0.05		3.67 ± .09x10 ⁻⁴
		0.0499	3.22 ± .03x10 ⁻⁴
0.09142	{ 0.1		5.73 ± .005x10 ⁻⁴
		0.0999	5.42 ± .01x10 ⁻⁴
0.1028	{ 0.2008		7.68 ± .004x10 ⁻⁴
		0.2001	6.649 ± .01x10 ⁻⁴

TABLE XIII

Comparison of the kinetics of reaction of sulphuryl chloride with 3,5-xylenol and of sulphuryl chloride with 3,5-OD,xylenol in chlorobenzene at 25.0°c.

Sulphuryl chloride(M)	3,5-xylenol (M)	3,5-OD xylenol(M)	$(M^{-1} \frac{k_2}{sec.}^{-1})$
0.094016	{ 0.05062		$2.948 \pm .05 \times 10^{-4}$
		0.05056	$3.958 \pm .006 \times 10^{-4}$
0.094016	{ 0.1022		$5.02 \pm .02 \times 10^{-4}$
		0.1	$6.542 \pm .009 \times 10^{-4}$
0.094016	{ 0.1976		$7.66 \pm .02 \times 10^{-4}$
		0.2	$1.035 \pm .001 \times 10^{-3}$

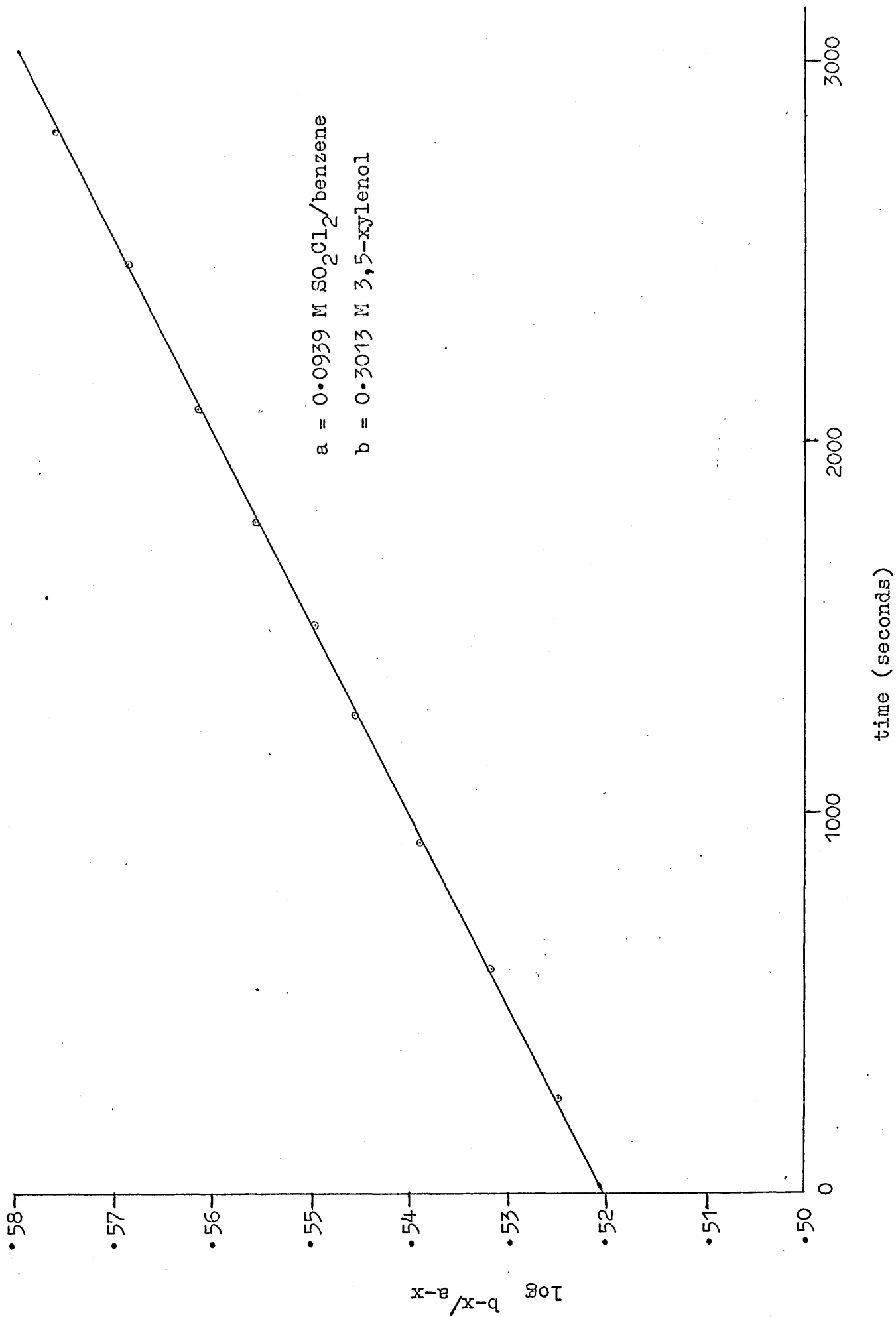
Example of experimental results for kinetic study of reaction of 3,5-xylenol with sulphuryl chloride in benzene at 25.0°C



t (secs.)	V_{I_2} (mls.)	$\log \frac{b-x}{a-x}$	$(M^{-1} \frac{k_2}{\text{sec.}^{-1}})$
324	0.62	0.5258	1.988×10^{-4}
623	0.805	0.5320	2.139×10^{-4}
943	1.02	0.5395	2.296×10^{-4}
1233	1.19	0.5454	2.287×10^{-4}
1530	1.305	0.5496	2.148×10^{-4}
1798	1.47	0.5558	2.211×10^{-4}
2124	1.625	0.5617	2.180×10^{-4}
2483	1.79	0.5681	2.151×10^{-4}
2830	1.97	0.5724	2.173×10^{-4}

$$\text{Mean } k_2 = 2.20 \pm 0.05 \times 10^{-4}$$

$$\text{Mean } k_2 \text{ (graph)} = 2.166 \times 10^{-4}$$



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