Some aspects of the chemistry of reactive intermediates

SOME ASPECTS OF THE CHEMISTRY

OF REACTIVE INTERMEDIATES

by

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SUMMARY

The formation of naphthalenes from 2-alkyl benzobarrelenes in the presence of alkyl nitrite is shown to proceed by '1,4' addition of nitrosonium ion to the benzobarrelene to form an unstable nitroso-benzobarrelene which fragments to give the observed products. Synthetic approaches to the nitrosobenzobarrelene system are described; addition of arynes to substituted nitrosobenzenes yields N-hydroxycarbazoles and to phenyl triaryl stannanes benzobarrelenes were obtained; dehydrobromination of α-bromobenzobarrelenone oximes is shown to give naphthalenes, nitrosoacetylene was not detected.

1-Phenyl-3,3-dimethyl triazene decomposes in the presence of acid in benzene containing tetracyclone or 1,2-dichloroethane containing anthracene to give products derived from benzyne and phenyl radicals. The analogous 2,3,4,5-tetrahalogenophenyl triazenes do not however lead to arynes. The formation of benzyne is shown to proceed via the diazonium ion which decomposes to benzyne by an E1 c.b. mechanism. The effects of halogen substitution in the ring on the formation of arynes are discussed.

The mechanism of formation of arynes from o-carboxy-3,3-dimethyl triazenes is shown to involve formation of the respective benzenediazonium--2-carboxylates. Evidence is presented to show that o-carboxytetrahalogenobenzenediazonium salts decompose to benzyne in a concerted fashion. Re-examination of the decomposition of benzenediazonium-2-carboxylate itself shows that the results obtained previously to establish a stepwise decomposition were incorrect.

Further evidence indicates that the decomposition is largely solvent dependent and is better accounted for by a concerted mechanism.

ACKNOWLEDGEMENTS

Acknowledgement pages in theses are commonly given over to short apologetic phrases for long suffering chemical widows or statements proclaiming inspirational leadership from supervisors. Although neither of my supervisors would claim any transcendental qualities I should like to thank Dr. Heaney for managing to counteract my innate sense of pessimism (which I like to call realism) with an unlimited capacity for optimism. Without this I doubt whether some of the work would have reached a successful conclusion. I should also like to thank Dr. Mason for his assistance in the somewhat lengthy process of preparing this text, and for negotiating my return to Loughborough.

This work would not have been possible, of course, without a research studentship from the S.R.C. to whom I am duly grateful and also for their provision of spectral facilities through the P.C.M.U. On a further technical note I must acknowledge the typist, whose name escapes me, for doing an excellent job.

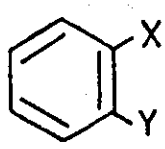
During the course of this research the knowledge and techniques acquired have come about through a process of discussion with either members of staff or fellow research students, often in the university bar, which probably explains some of the more lateral thinking in this thesis. The research in the laboratory has always been conducted on an open basis and I thank all the other students and technicians who have contributed to this atmosphere.

CHAPTER 1

THE NITROSONIUM INDUCED DISPROPORTIONATION OF SUBSTITUTED BENZOBARRELENES TO NAPHTHALENES

Introduction

The chemistry of aryne intermediates[1] has been well documented during the last twenty years. The parent intermediate, benzyne, is formed by elimination of adjacent groups in the aromatic ring to leave two sp^2 hybridised orbitals, orthogonal to the π-system, into which two electrons must be accommodated. Although there have been a few



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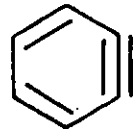

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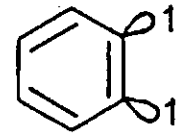

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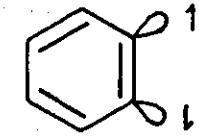
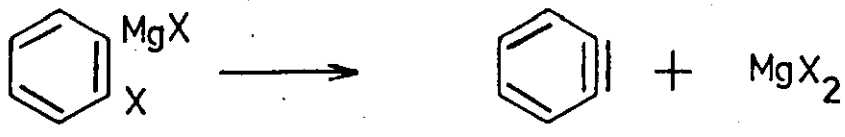


(4)

claims[2] to the existence of the triplet state(3), the vast bulk of experimental evidence is that benzyne is in the singlet state (4) with a bond order of ca. 2.5. Thus overlap between the two orbitals does not quite produce a full triple bond. Benzyne is obviously inherently unstable, its half-life has been estimated at 10^{-4} secs., and thus there must be a considerable driving force for the elimination of both X and Y. Historically the first methods used, involved the elimination of halogen acids by extremely powerful basic reagents, commonly sodamide in liquid ammonia. In these cases the scope for the reaction is limited due to the nucleophilic properties of the base which tends to react with the aryne as it is formed.

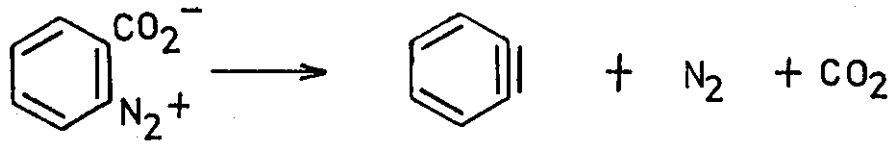
Later methods of formation of arynes have concentrated on using the thermodynamic stability of X and Y as the driving force for the reaction. Thus arynes are formed readily from o-halophenylmagnesium halides or lithio reagents, the high lattice energy of the metal halides

being a key factor. Again the reaction medium is basic and precludes



the use of many compounds such as ketones or aldehydes.

The most widely used method involves the elimination of stable gaseous molecules. Benzenediazonium-2-carboxylate,[3] (5) formed by diazotisation of anthranilic acid, fragments at ca. 40°C to give benzyne, carbon dioxide, and nitrogen. The reaction conditions are neutral and the diazotisation may be performed in situ thus avoiding the isolation of the explosive diazonium salt. Many other methods are

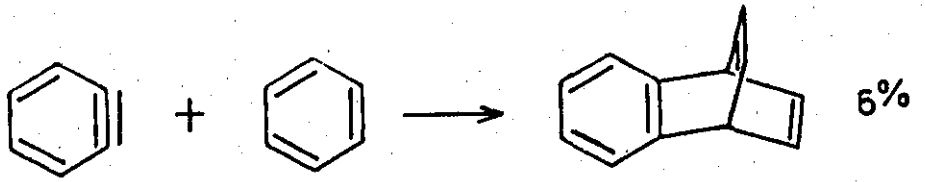


(5)

known but have not found such wide applicability, mainly due to inconvenience in preparing starting materials.

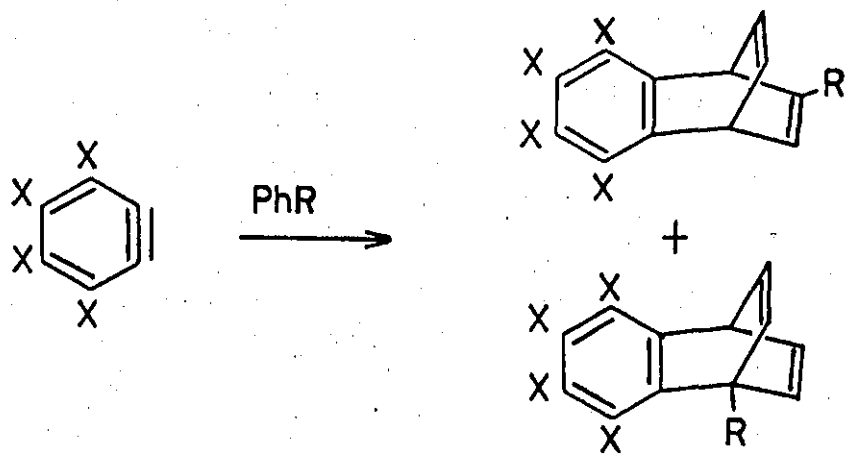
The chemistry of benzyne is that of an electrophilic species and the intermediate responds to a variety of reagents. The two main classes of reaction are nucleophilic additions and cycloadditions. Many nucleophiles react with arynes, the mode of addition being controlled largely by inductive effects of other substituents, to form compounds often inaccessible by other means. Cycloadditions are possible in which

benzyne shows itself to be an extremely powerful dienophile. Arynes will react with many dienes in the Diels-Alder reaction to form benzobicyclosystems.[1] This reaction is so facile that cycloaddition to benzene is observed, albeit in low yield. The product (6) is the bicyclic molecule benzobarrelene.



(6)

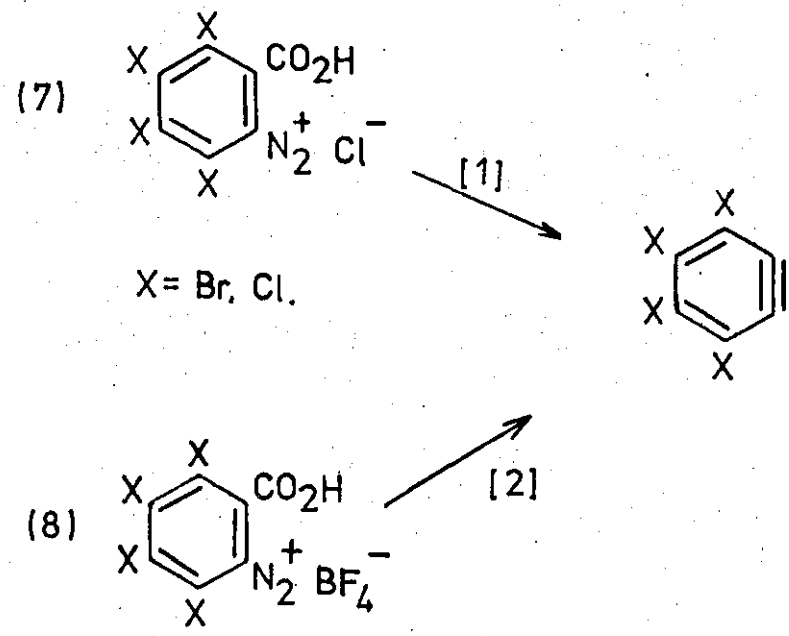
Halogenated arynes[4] are far more electrophilic than benzyne itself and undergo cycloaddition reactions with aromatic compounds to give halogenated benzobarrelenes often in high yield. With substituted aromatic compounds the two isomeric products are usually formed; with



X= [5] F, [6] Cl, [7] Br, [7] I,

simple alkyl groups the non-bridgehead isomer predominates. The methods of formation of tetrahaloarynes are extensions of the usual methods, either from organometallic precursors or from tetrahalogenoanthranilic

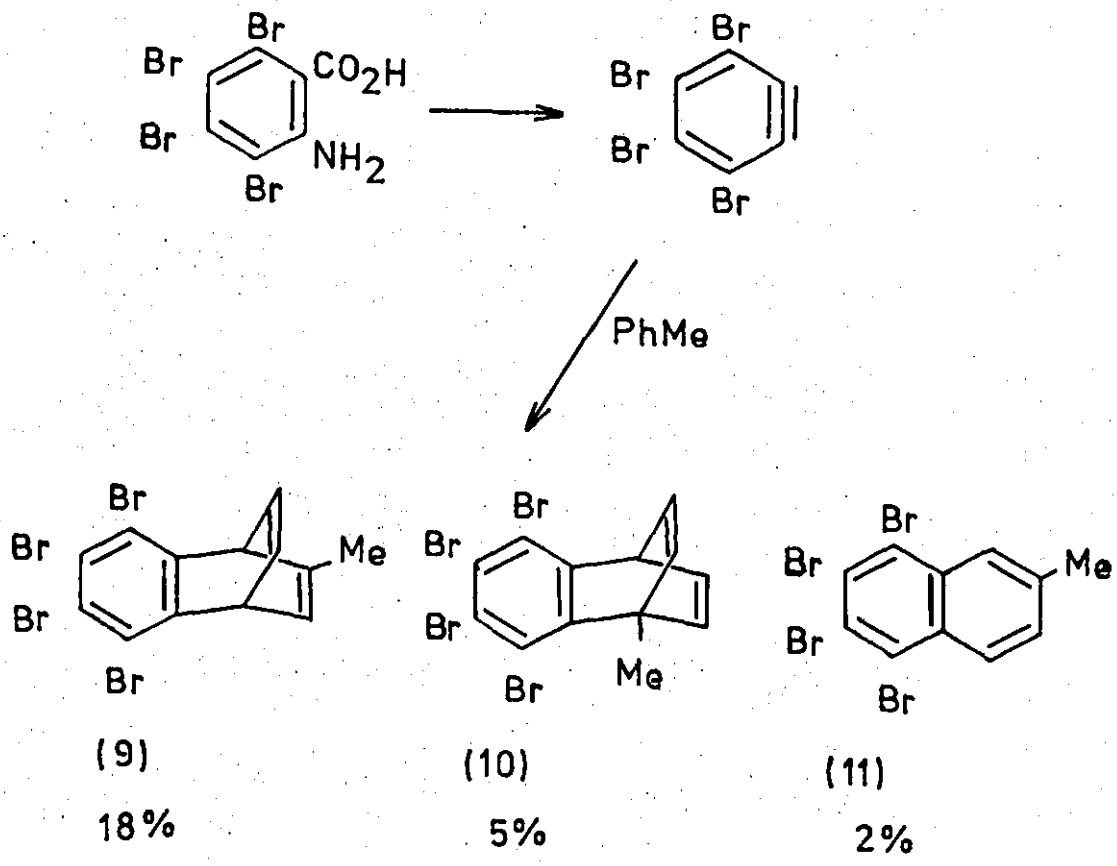
acids. The diazonium carboxylates are unstable and cannot be isolated although diazonium salts such as (7) or (8) are isolable and decompose to tetrahalogenobenzyne on heating; the fluoroborate salts require the use of base, e.g. pyridine to remove the fluoroboric acid. The liberated



[1] $-HCl, N_2, CO_2$. [2] $-HBF_4, N_2, CO_2$

HCl from the diazonium salt (7) sometimes reacts with the newly formed tetrahalobenzyne.

Alternatively tetrahaloanthranilic acids may be diazotised under aprotic conditions to give the diazonium-2-carboxylates which spontaneously fragment to tetrahalobenzyne. In this way tetrabromobenzyne was reacted with a variety of aromatic compounds[7] to form the corresponding benzobarrelenes. In addition to the expected cycloaddition products, it was found that in some cases a halogenated naphthalene was also being formed. Thus when tetrabromoanthranilic acid was aprotically diazotised in toluene in the presence of isoamyl nitrite the products were not only



(9)

18%

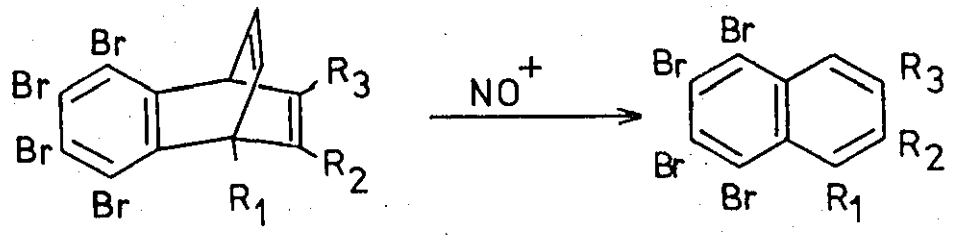
(10)

5%

(11)

2%

the two expected benzobarrelenes (9) and (10) but also the naphthalene (11). Other aromatic substrates such as t-butylbenzene and o-xylene also gave rise to naphthalene products. It was further established that the genesis of the naphthalene was a non-bridgehead benzobarrelene and that isoamyl nitrite appeared to be the agent initiating the conversion. Thus when the toluene adduct (9) was stirred overnight in benzene, containing isoamyl nitrite and a trace of acetic acid, 5,6,7,8-tetrabromo—2-methyl—naphthalene was formed in 12% yield. No naphthalenes were produced when both double bonds were substituted. This led to the generalised reaction (Scheme 1). Work was initiated to examine the mechanism of the reaction.

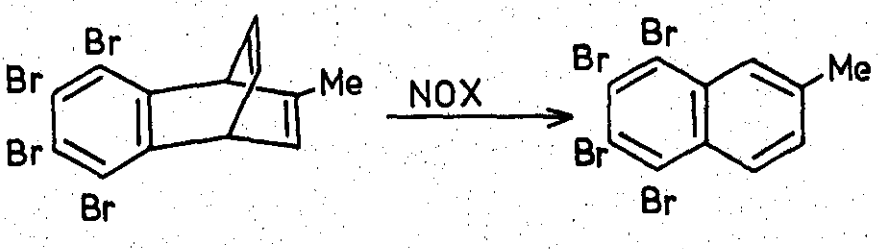


Scheme 1

R_1	=	H	: H	: H	: Me
R_2	=	Me	: Bu^t	: Me	: Me
R_3	=	H	: H	: Me	: H
% Naphthalene	=	6	: 11	: 16	: 13

DISCUSSION

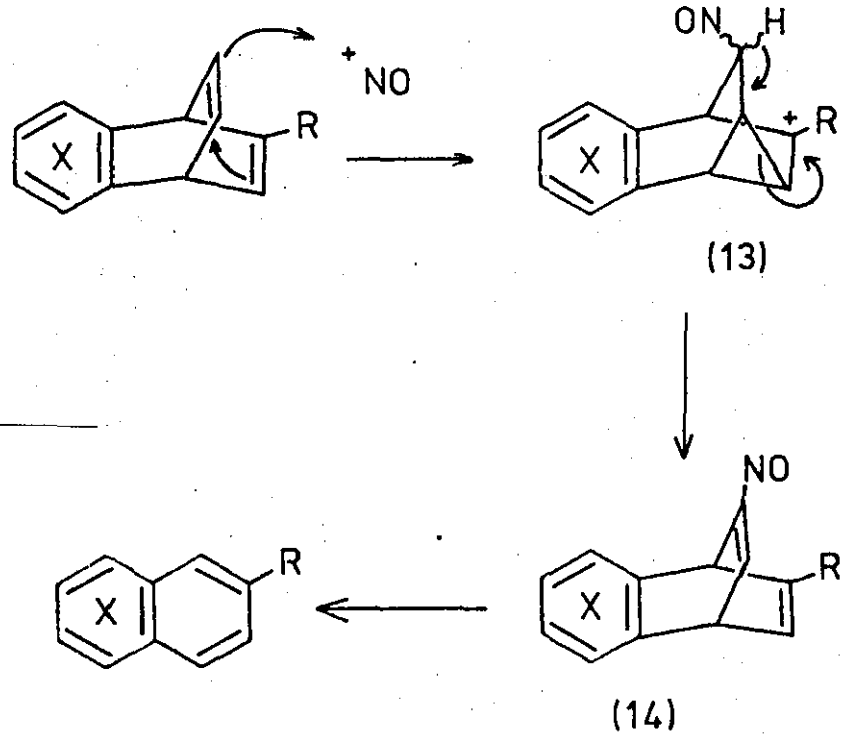
The conversion of non-bridgehead substituted alkyl benzobarrelenes to naphthalenes formally amounts to a reversal of the Diels-Alder reaction. Although these reactions are well known in the case of halogenated benzobarrelenes, the temperatures required to effect this process are of the order of 400°C. Furthermore the acetylene which is lost is generally the most thermodynamically stable,[5a] which normally means the most substituted. As the naphthalenes are formed in the presence of alkyl nitrite at relatively low temperatures and the substituent group is retained in the product it is clear that a simple reverse Diels-Alder reaction does not account for the formation of the naphthalenes. Early indications that the nitrosonium ion was the agent responsible for the conversion were verified by reactions of 2-methyl-tetrabromobenzobarrelene (12) with various nitrosating agents. The reaction time varies with the strength of the nitrosating agent; complete



(12) X = $OCH_2CH_2CHMe_2$ 17%
= Cl 8%
= $OCO.CF_3$ 4%

decomposition of starting material occurs in the case of isoamyl nitrite only after 2-3 days at 80°C, whereas the extremely powerful nitrosating agent, trifluoroacetyl nitrite, gives an instantaneous reaction at room temperature. The yields of the naphthalene produced, generally low, are higher with the weaker nitrosating agent isoamyl nitrite.

In all cases, although the naphthalene was easily isolated, no other products could be identified; they were very polar in nature and did not lend themselves to separation by chromatographic means.[8] This was unfortunate as identification of other products would no doubt have shed some light on the overall mechanism. Based on the knowledge that the nitrosonium ion was the prime agent in the reaction, the following mechanism was devised to account for the products.

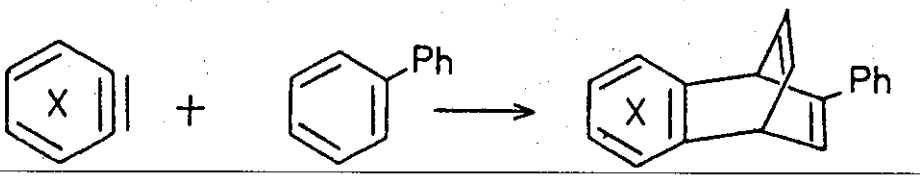


Scheme 2

The initial step is the '1,4' addition of the nitrosonium ion to the homo-conjugated diene system to leave a carbonium ion stabilised by the alkyl group of the parent benzobarrelene. Such '1,4' additions of electrophiles have been well documented on reactions with tetrafluorobenzobarrelene.[9] The stabilisation of the carbonium ion is presumably sufficient to allow a proton loss to occur, rather than it being completely scavenged by nucleophilic species in solution. The various rearrangements possible of this carbonium ion would explain the

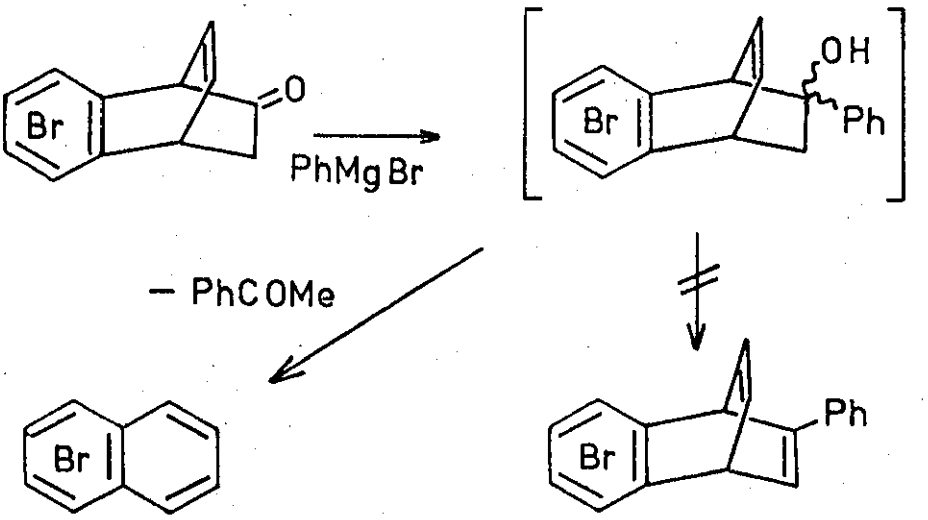
multiplicity of the products and the inherently low yield of the naphthalene. Deprotonation of the carbonium ion as indicated in scheme 2 yields the key intermediate, the nitrosobenzobarrelene (14), which is then envisaged to lose nitrosoacetylene to give the final product.

If the substituent group R in the original benzobarrelene was phenyl then the carbonium ion (13) postulated in the mechanism would be stabilised more efficiently than where R is an alkyl group, and one might expect higher yields of the naphthalene. It was not however possible to test this hypothesis as the non-bridgehead phenylbenzobarrelene required, could not be synthesised. Addition of tetrahalobenzyne



Scheme 3

to biphenyl (scheme 3) has been attempted several times in these laboratories but it has been found impossible to separate the products from the starting material. In a further attempted synthesis, addition of phenylmagnesium bromide to tetrabromobenzobarrelenone surprisingly gave tetrabromonaphthalene.

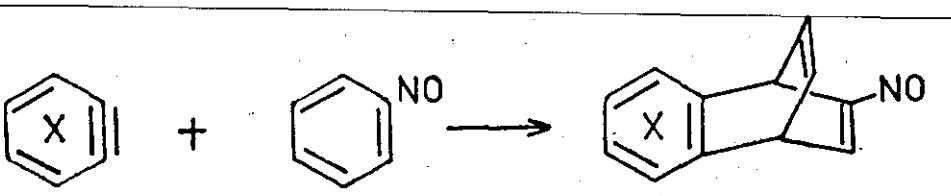


Scheme 4

Subsequent work in these laboratories[10] has shown that once formed, the carbinol, which is isolable at low temperatures, rapidly eliminates acetophenone to give the naphthalene (scheme 4).

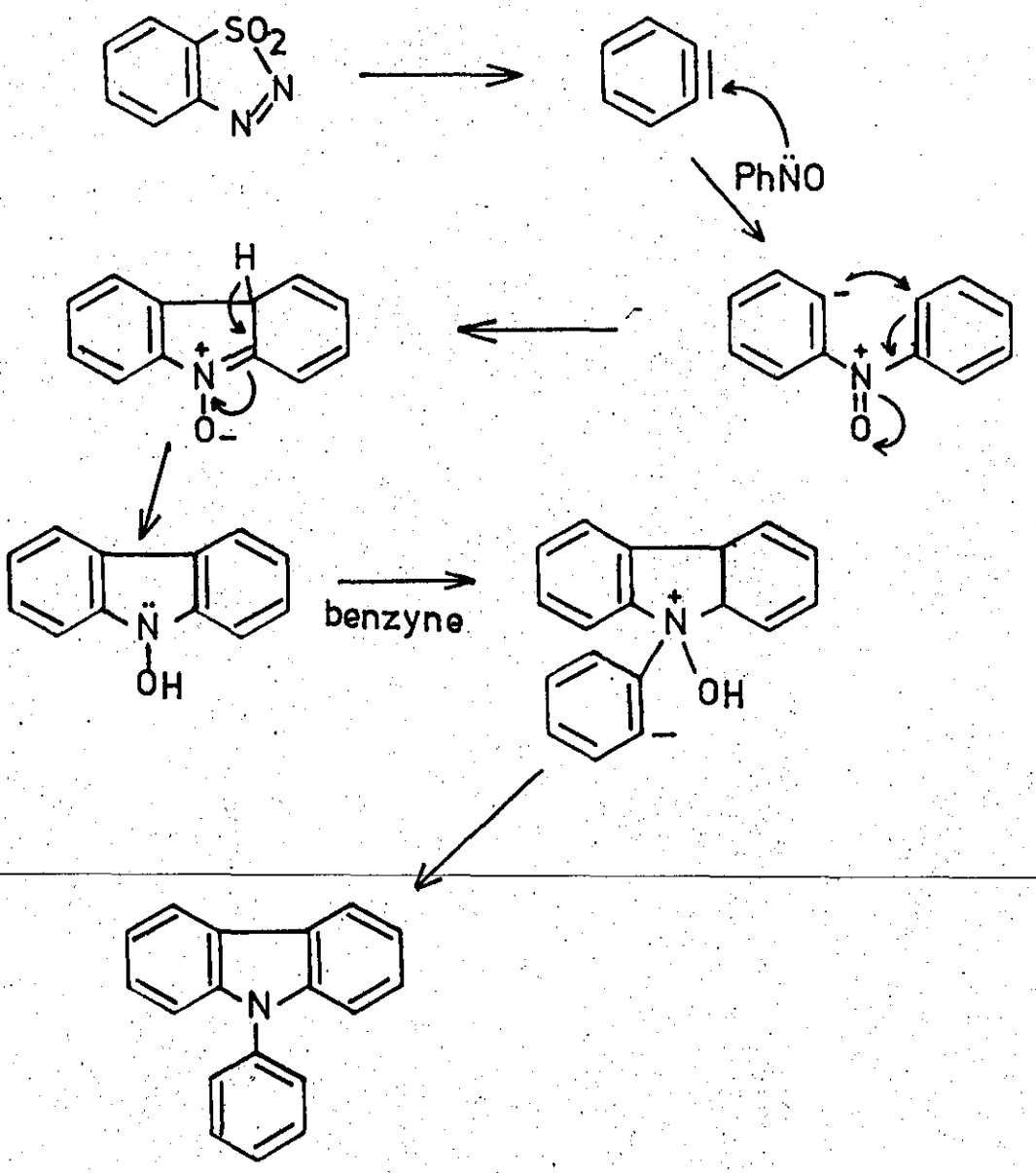
The crux of the mechanism lies in the existence of the nitroso-benzobarrelene and elimination of nitrosoacetylene. Unsaturated nitroso-compounds, other than aromatic ones, are relatively unknown,[11] thus routes to an alternative synthesis of the nitrosobenzobarrelene are correspondingly limited. Nevertheless three basic approaches were used as alternative syntheses.

Cycloaddition of tetrahalobenzyne and nitroso arenes would in principle be expected to give the nitrosobenzobarrelene system directly (scheme 5). One precedent exists in the literature for the reaction of



Scheme 5

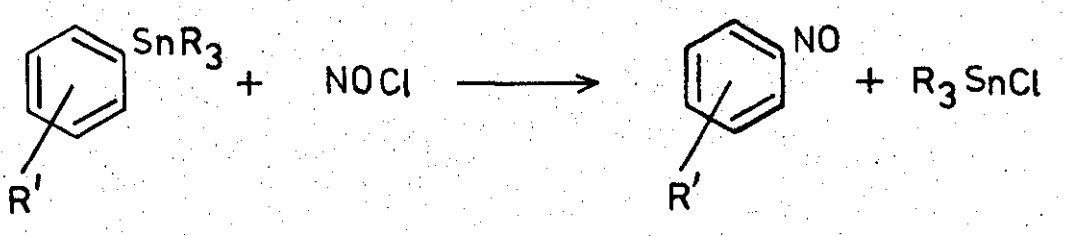
benzyne, generated from benzothiazole-1,1-dioxide, with nitrosobenzene,[12] in which the major product obtained was N-phenylcarbazole. The mechanism of this reaction (scheme 6) involves prior attack of nitrogen on benzyne followed by ring closure to N-hydroxycarbazole and addition of a further molecule of benzyne to give the products.



Scheme 6

With the more electrophilic tetrahalobenzynes and suitably 'electron rich' nitrosobenzenes it is conceivable that cycloaddition across the aromatic ring could occur. Accordingly a series of reactions was performed using tetrabromo- and tetrachlorobenzyne and various substituted nitrosobenzenes. Nitrosobenzene itself was prepared by standard literature procedures[13] while p-nitrosoanisole was prepared by methanolysis of p-nitrosophenol, a modification of the method of Debutts et al.[14] The other substituted nitrosobenzenes were made available by the reaction of trialkylarylstannanes

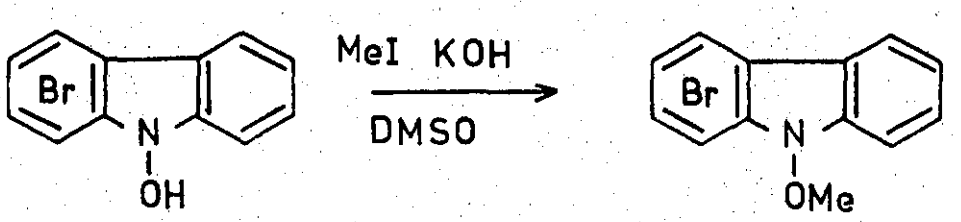
with nitrosyl chloride (scheme 7) as described by Eaborn and Walton.[15] It was generally more convenient to use the tributyl derivatives as, although the yields of nitrosoarene are not as good as the trimethyl derivatives the starting material, tributyltin chloride, is much more readily available.



Scheme 7

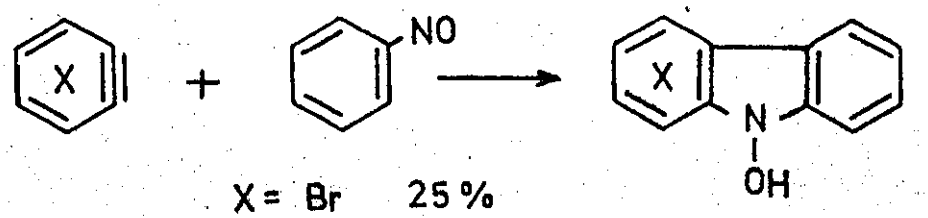
In this way m, and p-nitrosotoluene and o-nitrosoanisole were prepared.

When tetrabromobenzyne, generated by aprotic diazotisation of tetrabromoanthranilic acid, was allowed to react with an excess of nitrosobenzene, the main isolated product was not a phenylated carbazole. Similar products were obtained from tetrachlorobenzyne and benzyne itself, generated from the corresponding anthranilic acids by aprotic diazotisation. The u.v. spectra of the products were very similar to carbazole derivatives and all possessed a strong, sharp absorption in the i.r. spectrum at ca. 3430 cm.$^{-1}$ and the ^{1}H n.m.r. spectra were all essentially the same. The brominated compound gave a methylated derivative with methyl iodide in alkaline dimethyl sulphoxide,[16] (scheme 8). Elemental analysis was consistent with the structures being N-hydroxy carbazoles, the



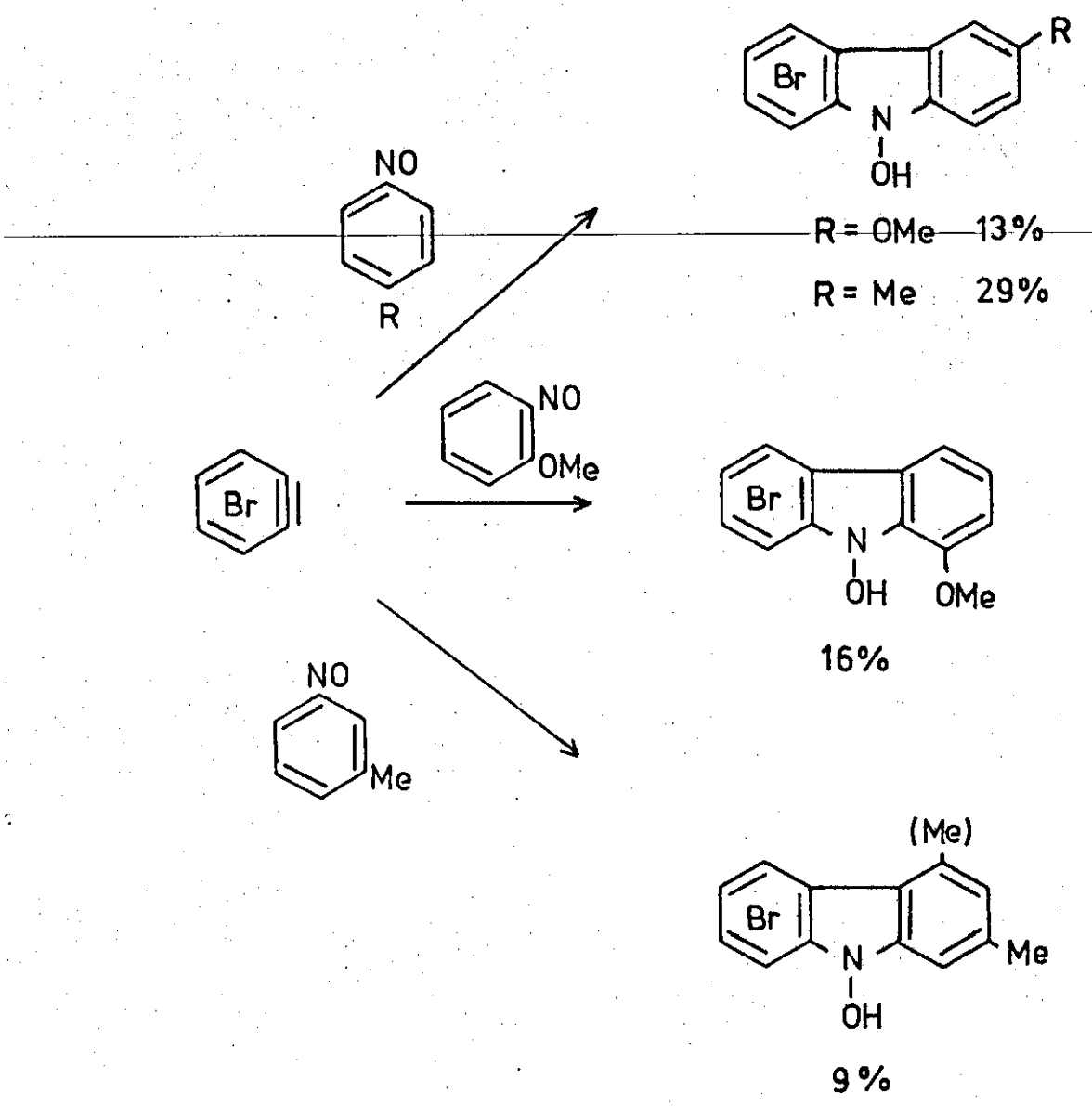
Scheme 8

intermediate postulated on the route to N-phenyl carbazole.



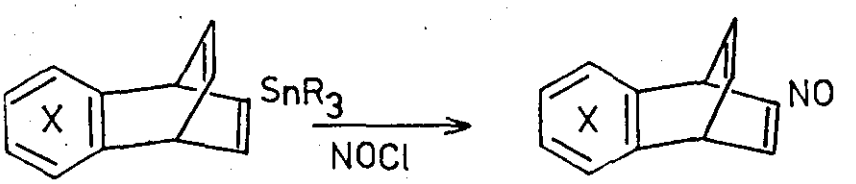
X = Br 25 %
= Cl 20 %
= H 1 %

Reactions of tetrabromobenzyne with o-methoxy, p-methoxy, p-methyl and m-methylnitrosobenzenes gave the corresponding substituted N-hydroxy-carbazoles. The reactions were all very tarry, which is not surprising



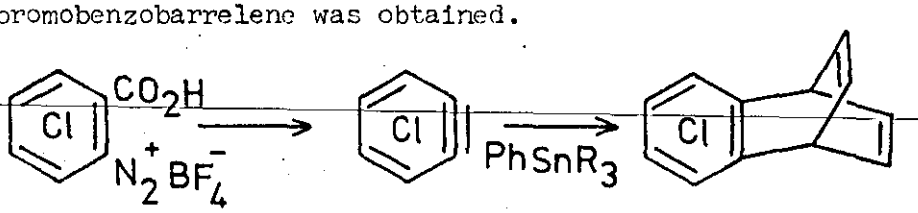
in view of the reactivity of all the reagents in solution, and the yield of N-hydroxycarbazole from benzyne itself was very small compared with the yield of N-phenylcarbazole quoted in the literature. Why this is so and the fact that N-hydroxycarbazole did not go on to form N-phenylcarbazole is presumably due to the different precursors used for the generation of benzyne. In the aprotic diazotisation of anthranilic acid many more reactive species are present compared with the very simple benzothiazole-1,1-dioxide which is thought to yield benzyne at low temperatures by a concerted elimination of nitrogen and sulphur dioxide.[1a,17] In order to prevent the formation of N-hydroxycarbazole derivatives it is evident that the two ortho-positions to the nitroso group must be blocked. Nitrosomesitylene was considered a suitable coreactant and was prepared by the reaction of nitrosyl chloride and mesityltrimethylstannane, the tributyl derivative being difficult to prepare in quantity. When tetrabromobenzyne was allowed to react with nitrosomesitylene no carbazole derivative was formed. The only identifiable product was 2,3,4,5-tetrabromophenyl-isoamyl ether formed by reaction of either isoamyl alcohol or iso-amylnitrite with tetrabromobenzyne.[7] No naphthalenes were detected in the reaction of tetrachlorobenzyne, generated from 2-carboxy-tetrachlorophenyl-3,3-dimethyltriazene, and nitrosomesitylene. Thus although the formation of carbazoles is suppressed addition across the aromatic ring still does not occur.

A second approach to the nitrosobenzobarrelene system utilised the method used in preparing the aromatic nitroso compounds. The reaction of nitrosyl chloride with a trialkylstannyl substituted benzobarrelene could give the nitrosobenzobarrelene (scheme 9).

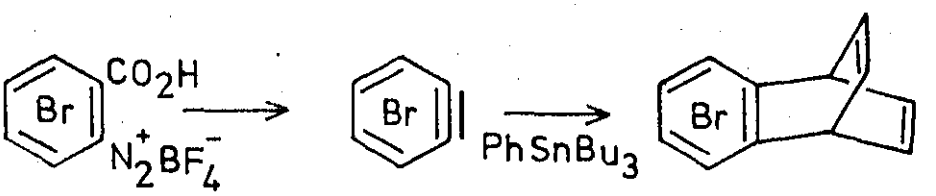


Scheme 9

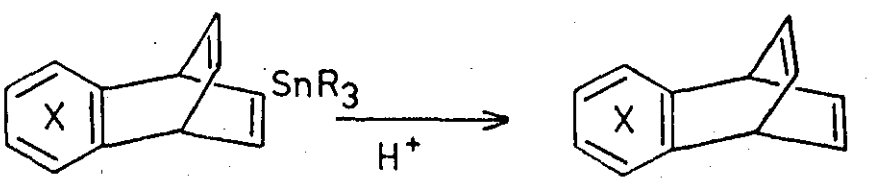
Thus the synthesis of these tin derivatives was attempted by the reaction of tetrabromo and tetrachlorobenzyne with either phenyltrimethyl-stannane or phenyltributylstannane. In the reaction of tetrachlorobenzyne, generated from 2-carboxy-tetrachlorobenzenediazonium fluoroborate, and both trimethyl and tributylphenylstannanes the only product identified was tetrachlorobenzobarrelene. Similarly when tetrabromoanthranilic acid was aprotically diazotised in the presence of phenyltributylstannane, tetrabromobenzobarrelene was obtained.



R = Me, Bu.



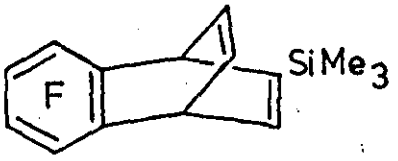
Evidently the trialkyl stannyl benzobarrelene is formed, but undergoes a rapid protonation on work-up to give the observed product,(scheme 10).



Scheme 10

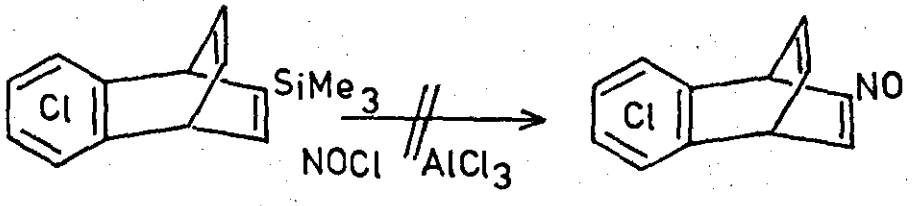
The electrophilic displacement of the trialkylstannyl residue, particularly by acid, is well known in organo-tin chemistry,[18] indeed the ready formation of nitroso-compounds as described is a direct consequence of this.

The carbon silicon bond is much less susceptible to protolysis[19] and the adduct of tetrafluorobenzyne and phenyltrimethylsilane (15) is known.

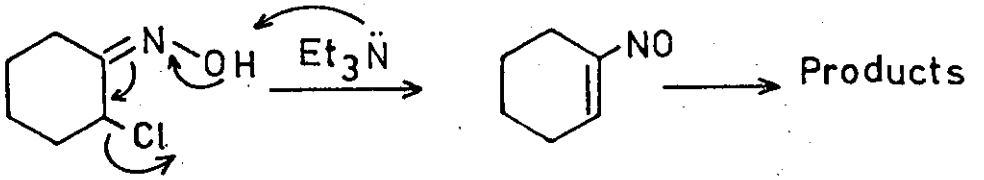


(15)

It was to be anticipated that the reaction with nitrosyl chloride to form a nitroso-compound would need to be catalysed, possibly with a Lewis acid.[15,20] The fluorinated benzobarrelene(15)however reacted rapidly with nitrosyl chloride but no identifiable material was obtained. The chlorinated analogue, prepared in crude form and low yield from 2-carboxytetrachlorobenzenediazonium fluoroborate, and phenyltrimethylsilane did not, however, give any reaction even with aluminium chloride as catalyst.

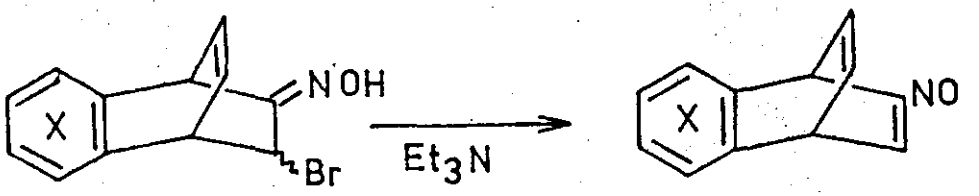


A third route devised to approach the nitrosobenzobarrelene proved to be successful. This was based on a recent synthesis of an unsaturated nitroso-compound.[21] 2-Chlorocyclohexanone oxime was dehydrochlorinated to give nitroso-cyclohexene which existed only temporarily in solution (scheme 11). Obviously this sequence can

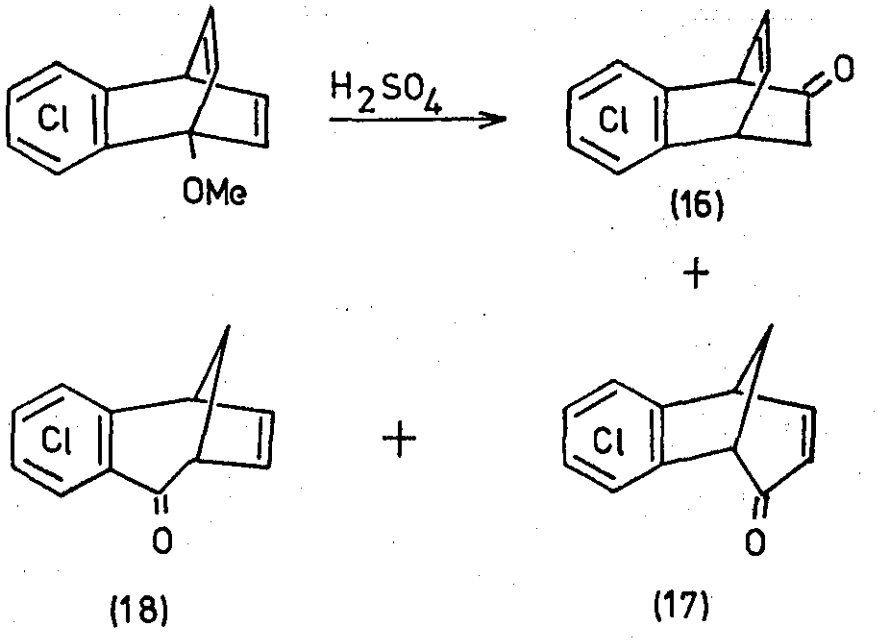


Scheme 11

be transposed to the benzobarrelene system and used to generate the postulated intermediate. The essential starting point in this synthesis



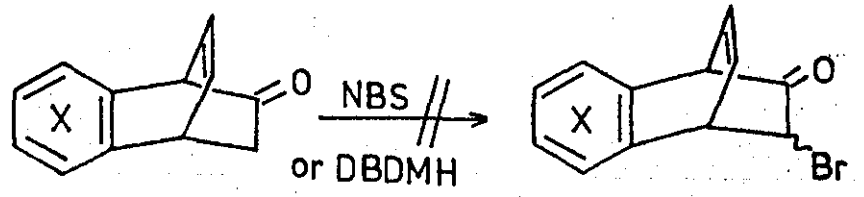
is an α-halobenzobarrelenone. Tetrahalobenzobarrelenones are readily available from acid catalysed rearrangements of bridgehead methoxybenzobarrelenes.[22] For instance, 5,6,7,8-tetrachloro-1-methoxybenzo-



Scheme 12

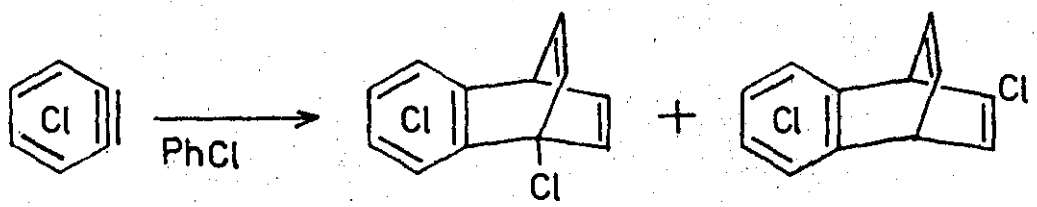
barrelene rearranges in conc. sulphuric acid to give mainly tetrachlorobenzobarrelenone (16) and small amounts of the other isomeric ketones (17) and (18) depending on conditions.[23] (Scheme 12). In

this way tetrabromobenzobarrelenone could be obtained in good yield. In relatively large scale reactions it was possible to isolate the desired product by crystallisation. It was subsequently discovered that tetrachlorobenzobarrelenone could be obtained free from side products by using chlorosulphonic acid as the catalyst rather than sulphuric acid. These rearrangements have been studied in detail by other workers in these laboratories.[22] It then merely remains to brominate the position adjacent to the carbonyl group to gain access to the bromobenzobarrelenone. However when tetrabromo or tetrachlorobenzobarrelenone was treated with



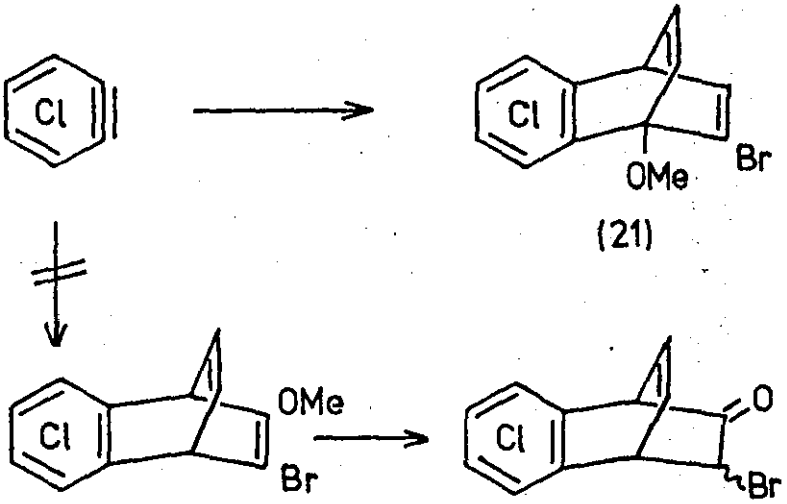
X = Cl, Br.

either N-bromosuccinimide or dimethyl dibromohydantoin the starting material was recovered essentially unchanged even after many hours of reaction. It was then decided that a more successful approach would be to start with a halogenated benzene derivative and add say, tetrachlorobenzyne to this. As benzyne is essentially an electrophilic reagent, the presence of halogen atoms in the diene, in this case a benzene derivative, would be expected to make the Diels-Alder reaction less favourable. A control reaction was therefore carried out between tetrachlorobenzyne and chlorobenzene. When 2-carboxy-tetrachlorobenzenediazonium chloride was decomposed in chlorobenzene the products obtained were pentachlorobenzene, formed by addition of HCl to tetrachlorobenzyne, and a mixture of bridgehead and non-bridgehead benzobarrelenes, (19) and (20).



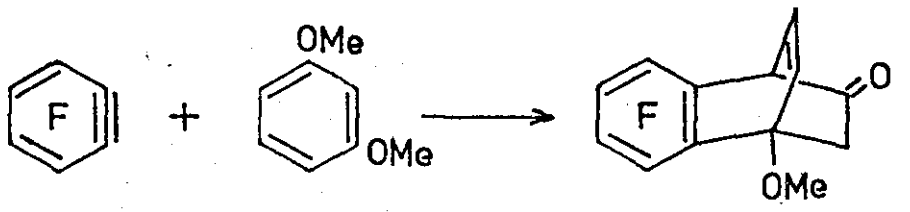
(19) (20)

Although the yield is lower than with typical alkylbenzenes like toluene, it is still appreciable. The two isomeric benzobarrelenes were not able to be separated but the ratio of the non-bridgehead to bridgehead is close to that for the toluene adducts, the methyl group and chlorine atom being of similar size. In order to introduce a carbonyl group into the product it is necessary to start with a methoxybenzene derivative, and the addition must occur in such a way that the methoxy group resides at a non-bridgehead position and the resultant enol-ether is hydrolysed to the carbonyl group. The methoxy group, however, has a strong directive influence towards the bridgehead position in reactions of tetrahaloarynes and methoxybenzene derivatives; [5a, 6, 24] thus when tetrachlorobenzyne was allowed to react with o-bromoanisole only the bridgehead adduct (21) was obtained (scheme 13). There was no bromo ketone. Obviously some other group was necessary to

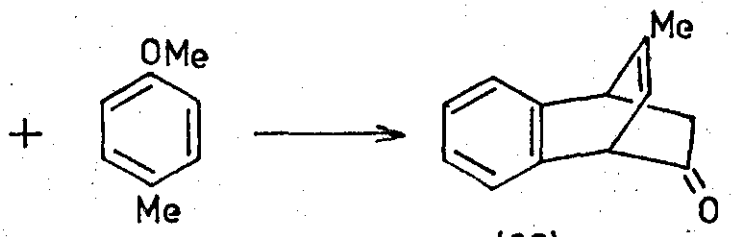


Scheme 13

direct the methoxy group away from the bridgehead position. Previous work in these laboratories has shown that m-dimethoxybenzene and p-methoxytoluene both react to give ketonic products in good yield.[24(22,23)]

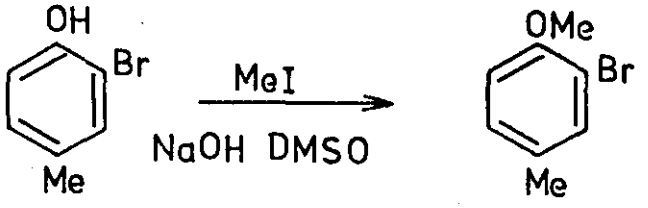


(22)

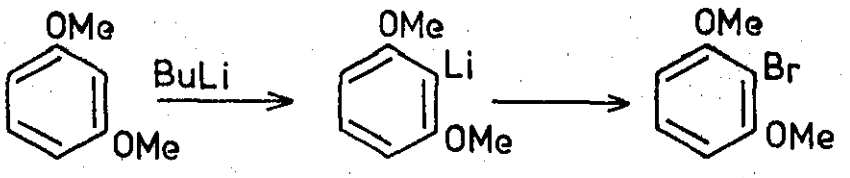


(23)

It was thus decided to prepare 2-bromo-4-methyl anisole and 2,6-dimethoxybromobenzene. The former was prepared by methylation of the commercially available phenol by the method of Gillies.[16a] 2,6-Dimethoxy



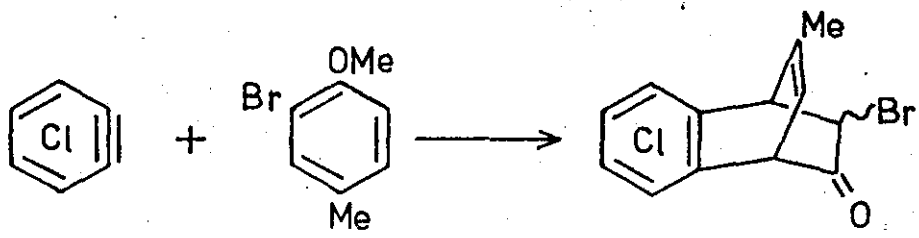
bromobenzene was prepared via an organometallic route starting from m-dimethoxybenzene (scheme 14). Treatment with n-butyl lithium gave 2,6-dimethoxyphenyl lithium[25] which underwent a halogen metal exchange



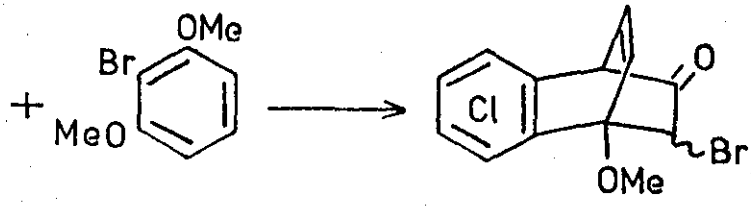
Scheme 14

with 1,2-dibromoethane[26] to give the product in 52% yield.

Both bromobenzene derivatives reacted successfully with tetrachlorobenzyne and gave the anticipated bromoketones, (24,25).

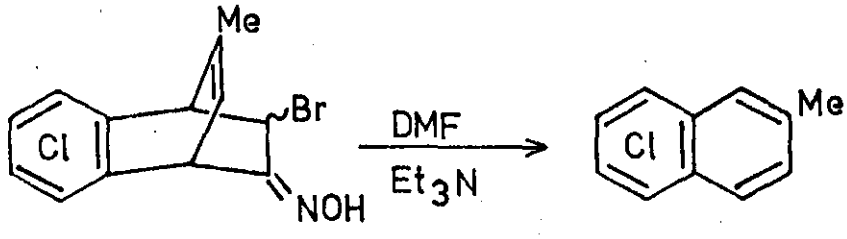


(24)



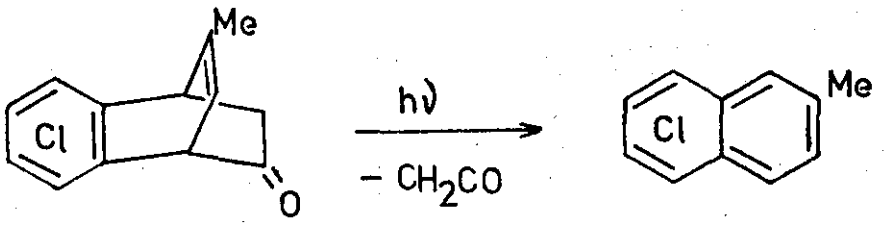
(25)

In each case the ^{1}H n.m.r. spectra indicated that there was only one epimer although the absolute stereochemistry was not established. Both bromoketones were converted into their respective oximes (26 and 28); the latter was not obtained analytically pure. When the compound (26) was heated at 90-100°C in dimethylformamide in the



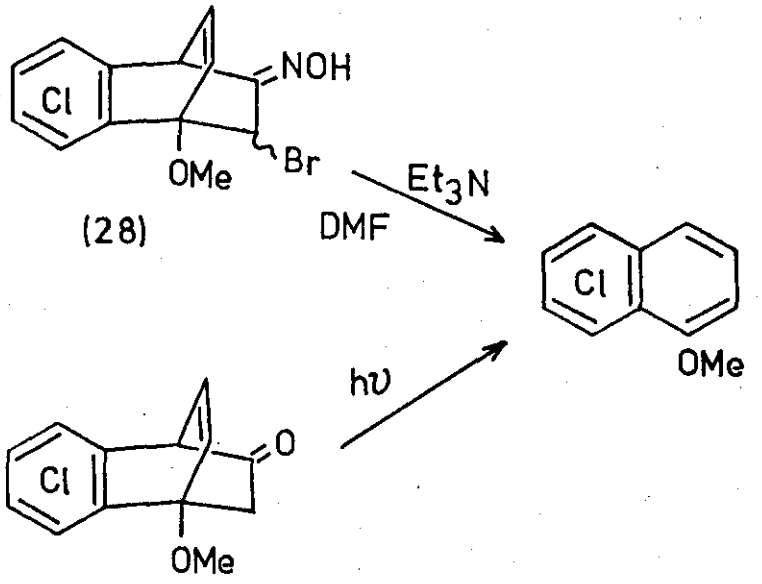
(26) (27)

presence of triethylamine for 3 hours, 2-methyl-5,6,7,8-tetrachloronaphthalene was obtained in 30% yield. The identity of the naphthalene was confirmed by reference to an authentic sample prepared by photolysis[27] of the benzobarrelenone (29). Similarly when the oxime (28) was

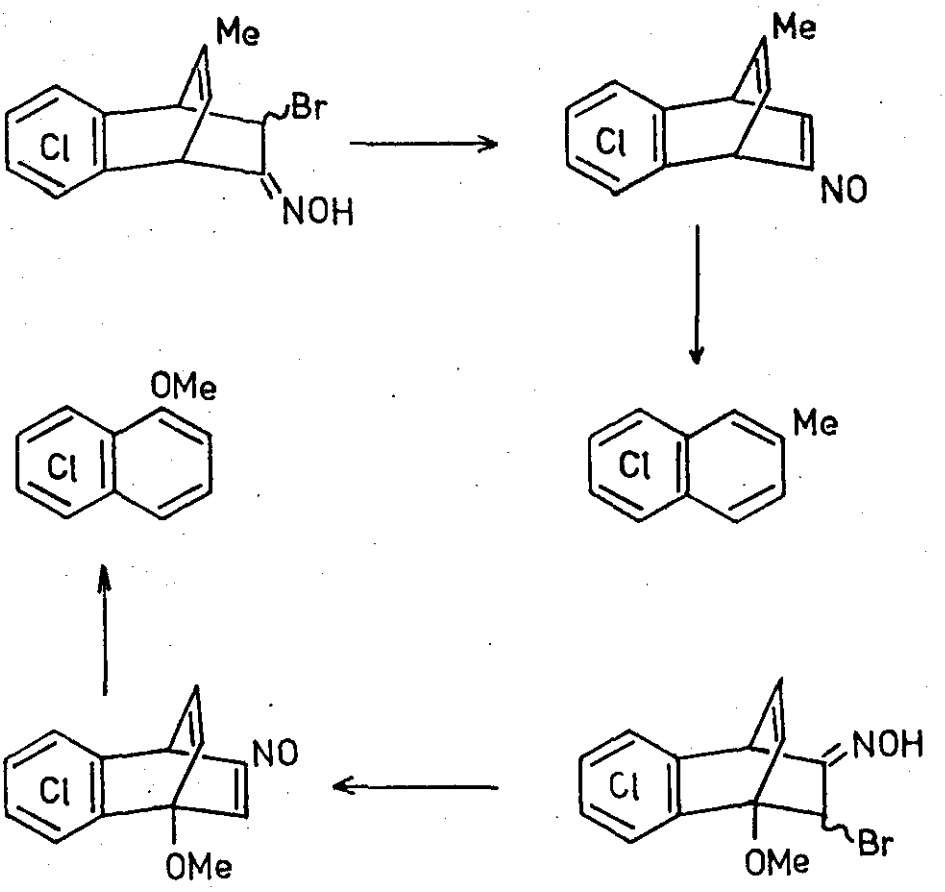


(29)

submitted to the same treatment for 16 hours 1-methoxy-5,6,7,8-tetrachloronaphthalene was obtained in up to 47% yield. An authentic sample was once again prepared by photolysis of the adduct of tetrachlorobenzyne and m-dimethoxybenzene. These results clearly point to the participation



of the nitrosobenzobarrelene and demonstrate the ease with which nitrosoacetylene is lost. Nitrosoacetylene itself has remained undetected; attempts to trap it with thebaine, a good diene for nitroso-compounds,[28] led only to the identification of thebaine hydrobromide. The driving force behind this reaction is undoubtedly the thermodynamic stability of the products, especially the naphthalene. Other workers in these laboratories[29] have noted the ready formation of naphthalenes when trying to prepare benzobarrelenes with electron withdrawing groups at



the non-bridgehead position.

Experimental

General:- All solvents used in organometallic reactions or in aryne reactions were dried by conventional means.

Analytical thin layer chromatography was carried out using silica gel (GF_{254} according to Stahl), for layers 0.25 mm.thick. Preparative layer chromatography was carried out using silica gel (PF_{254} according to Stahl). Column chromatography was carried out with silica* (ex.Fisons), and 'CAMAG' alumina (Brochmann activity 1).

Analytical gas chromatography was carried out using a Pye 104 series gas chromatograph using a hydrogen flame ionisation detector. The 5 ft. columns used were

A. 20% S.E. 30 on chromosorb W.

B. 10% PEG.A on brickdust.

C. 10% APIEZON L on chromosorb W.

Infra-red spectra were determined for potassium bromide discs in the case of solids or thin films in the case of liquids unless otherwise stated, on a Perkin-Elmer 257 spectrometer. Ultra-violet spectra were determined for solutions in ethanol, unless otherwise stated, with a Pye-Unicam SP 8000 spectrophotometer. ^{1}H Nuclear magnetic resonance spectra were determined at 60 MHz for approximately 20% w/v solutions using tetramethylsilane as an internal standard, with a Perkin-Elmer R 10 spectrometer. ^{1}H n.m.r. spectra at 100 MHz were recorded by courtesy of the S.R.C. through the P.C.M.U. Mass spectra were recorded on an A.E.I. M.S. 12 spectrometer. High resolution mass spectrometry was carried out on an A.E.I. M.S.9 at P.C.M.U. by courtesy of the S.R.C.

Melting points were determined on a Kofler block and are uncorrected. All compounds were colourless solids unless otherwise stated.

Isoamyl nitrite was stored over molecular sieve (4A) at -20°C. All diazonium salts were handled carefully with wooden applicators and filtered with porcelain funnels. All dilute acids were 2N.

*'Silica' refers to silica gel.

1. Preparation of Tetrachloroanthranilic acid

Ammonia solution (80 mls .880) was added to tetrachlorophthalic anhydride (114 gms 0.4 moles), and stirred vigorously with a glass rod for exactly 30 secs. The suspension was poured into ice cold sulphuric acid (80 mls.conc. H_2SO_4:1 litre crushed ice) and the bulky phthalamic acid which formed was filtered, washed with water and while still wet added to an alkaline solution of sodium hypobromite (32 mls. bromine : 120 gms. sodium hydroxide:1 litre iced water). This mixture was heated on a water bath at ca. 80°C for 1 hr. and filtered to remove any suspended solid. After cooling the red solution was acidified with conc. hydrochloric acid and the precipitated acid extracted into ether. The ethereal layer was dried over anhydrous magnesium sulphate and solvent removed to give crude tetrachloroanthranilic acid which on recrystallisation from aqueous methanol gave a pure product (70-85 gms, 64-77%) m.p. 184°C (lit.[30] 184°C) $\nu_{max.}$ 3510, 3400,(NH_2) 1690, (C=O) 1600 (NH_2) $cm.^{-1}$.

2. Preparation of Tetrabromoanthranilic acid

Tetrabromophthalic anhydride (35.6 gms.) was dissolved in warm N,N-dimethylformamide (160 mls). The solution was cooled by means of an ice salt mixture to 0°C and conc. ammonia (16 mls. .880) added, at a rate of one drop per second with vigorous stirring. In this way the temperature of the mixture rose to 20-25°C. The cooling bath was removed and the solution allowed to stir at room temperature. After 5-10 mins. a thick white precipitate formed and the mass became solid. The cooling bath was reapplied and the suspension diluted with dilute sulphuric acid (200 mls). The phthalamic acid was filtered and the damp solid added to sodium hydroxide solution (3 gms. NaOH 300 mls. H_2O). The mixture was tested for alkalinity, adding more sodium hydroxide if necessary. Sodium hypobromite solution (1 equ. 4 mls. Br_2:100 mls.ice water:

8 gms. NaOH) was added dropwise, with stirring, and stirring continued at room temperature for 75 mins, then at 60-70°C for a further 75 mins. The yellow solution was filtered to remove traces of suspended material and acidified with conc. hydrochloric acid. The cream solid liberated was filtered and recrystallised from aqueous ethanol to give tetrabromoanthranilic acid (20-25.5 gms. 58-73%) m.p. 204°C (lit.[31] 204-5°C) ν_{max} 3490, 3380 (NH_2), 1700 (C=O), 1600 (NH_2) $cm.^{-1}$

3. Preparation of 2-Carboxy-tetrachlorobenzenediazonium chloride

Dry hydrogen chloride gas was bubbled through a stirred solution of tetrachloroanthranilic acid (8.0 gms.) in tetrahydrofuran (120 mls.) overnight. The suspension of the hydrochloride, so formed, was cooled to below 0°C, and isoamyl nitrite (8 mls.) added dropwise with stirring, maintaining the temperature below 5°C. After a further 30 mins. the voluminous diazonium salt was filtered, washed with ether, and allowed to air dry. The yield was 7.5 gms. (78%).

CAUTION - When dry the diazonium salt is potentially explosive. Suitable precautions should be taken.

4. Preparation of 2-Carboxytetrachlorobenzene diazonium fluoroborate

Tetrachloroanthranilic acid (5.0 gms.) was dissolved in tetrahydrofuran (50 mls.) and fluoroboric acid (10 mls. 40% aqueous soln.) added. After standing for 15 mins. the solvent was removed, and replaced with diethyl ether (50 mls.) and the suspension cooled to 0°C. Isoamyl nitrite (2.5 mls.) was added dropwise, maintaining the temperature at 0°C, and stirring continued for 15 mins. The diazonium salt was filtered and washed with cold ether and allowed to dry in the atmosphere. The yield was 4.6 gms. (80%).

In a control reaction the fluoroborate salt (1.8 gms) was added to a mixture of anisole (20 mls.), carbon tetrachloride (40 mls.) and

pyridine (0.4 mls. 1 equ.) and warmed to ca. 50°C for 30 mins, followed by a short heating under reflux (10 mins.). The mixture was filtered, solvent removed, and the residue chromatographed on alumina (100 gms.). Elution with benzene-petrol (20:80) gave 1-methoxy-1,4-dihydro-5,6,7,8-tetrachloro-1,4-ethenonaphthalene (960 mgs. 62%). The i.r. spectrum was identical to that of an authentic sample.

2-Carboxytetrabromobenzenediazonium chloride and fluoroborate were prepared by identical procedures in 18% and 75% yields respectively. The hydrochloride gave tetrabromobenzyne by warming to 50°C in p-xylene for 30 mins. The product was isolated in 43% yield by elution of the residue, after removal of solvent, with light petroleum through an alumina column. The i.r. spectrum was identical to that of an authentic sample[7] of 5,6,7,8-tetrabromo-1,4-dihydro-2,10-dimethyl-1,4-etheno-naphthalene.

5. Preparation of 5,6,7,8-tetrabromo-2-methyl-1,4-dihydro-1,4-etheno-naphthalene

Tetrabromoanthranilic acid (4.56 gms. 0.01 moles) in an acetonitrile-toluene mixture (50 mls. MeCN:50 mls. toluene) was added concurrently with a solution of isoamyl nitrite (1.36 mls. 0.01 moles) in toluene (100 mls.) to toluene (100 mls.) maintained at 50°C. After addition, the solution was stirred at 50°C for 45 mins. and solvent removed. The residue was separated by preparative layer chromatography on silica (10 plates 1 metre x 20 cms. x 0.5 mm. eluent benzene-petrol 30:70) impregnated with 10% silver nitrate, to give in order of decreasing R_f:

a) A colourless oil (194 mgs. 4%) shown by i.r. to be 2,3,4,5-tetrabromo-3'-methylbutyl ether

b) A crystalline solid (1.07 gms. 22%) shown by comparison of i.r. and n.m.r. spectra to be 5,6,7,8-tetrabromo-2-methyl-1,4-dihydro-

-1,4-ethenonaphthalene.

c) A crystalline solid (445 mgs. 9%) shown by comparison of i.r. and n.m.r. spectra to be 5,6,7,8-tetrabromo-1-methyl-1,4-dihydro-1,4-ethenonaphthalene.

6. Reaction of 5,6,7,8-tetrabromo-2-methyl-1,4-dihydro-1,4--ethenonaphthalene with various nitrosating agents

a) Isoamyl nitrite

The benzobarrelene (500 mgs.) was dissolved in benzene (10 mls.) and isoamyl nitrite (1 ml.) added. After warming to 60°C glacial acetic acid (5 drops) was added and the solution stirred at this temperature for 16 hrs. A further identical amount of isoamyl nitrite and acetic acid was added and stirring continued. The starting material did not disappear (t.l.c.) until a total reaction time of 3 days had elapsed. The solution was washed with sodium bicarbonate solution and the organic phase separated, dried over magnesium sulphate and solvent removed to give a brown oil. Column chromatography on silica gave a pale cream solid (80 mgs. 17%) 5,6,7,8-tetrabromo-2-methylnaphthalene, the spectra of which were consistent with published values.[7,32] Attempts to elute further products from the column gave only tarry solids or unidentified oils.

b) Nitrosyl Chloride

The benzobarrelene (50 mgs.) was dissolved in carbon tetrachloride (30 mls.) Nitrosyl chloride (ca. 0.1 gms.) was added and the solution stirred at room temperature for 30 hrs. The solvent was concentrated to ca. 2 mls. and placed on a silica plate(20 cms. x 20 cms. x 0.75 mm.) A fast running band was isolated and shown by u.v. spectroscopy to be tetrabromo-2-methylnaphthalene (4 mgs. 8%).

c) Trifluoroacetylnitrite

The benzobarrelene (500 mgs.) was dissolved in dry carbon tetrachloride (10 mls.) and trifluoroacetylnitrite (200 mgs. 1 equ.) added. There was an instantaneous green coloration. The solvent was removed and the residual solid triturated with light petroleum. The insoluble material was filtered off and the filtrate separated by preparative layer chromatography on silica (5 plates 1 metre x 20 cms. x 0.5 mm. eluent benzene: petrol 50:50). A fast running band was isolated and shown by comparison of its i.r. and u.v. spectra to be 5,6,7,8-tetrabromo-2-methylnaphthalene (19 mgs. 4%). The petrol insoluble material showed virtually no absorption in the ^{1}H n.m.r. spectrum while attempts to isolate more components from the petrol soluble fraction by chromatography were unsuccessful.

7. Preparation of Trifluoroacetyl nitrite

Lead nitrate (66 gms. 0.2 moles), previously dried overnight at 100°C, was placed in a 250 ml. long-necked r.b. flask, the outlet of which was connected with p.v.c. tubing to a cold trap maintained at -25°C. The lead nitrate was heated vigorously with a bunsen and the nitrogen dioxide evolved collected in the trap. The nitrogen dioxide was allowed to liquify and nitric oxide was carefully bubbled in, maintaining the temperature at ca. 5°C, until the total volume had doubled. The cooling was removed and the dinitrogen trioxide so formed allowed to distil, with occasional warming, into a further cold trap maintained at -70°C. The tubing was removed and trifluoroacetic anhydride (20 mls. 29 gms.) was added from a dropping funnel. The deep blue mixture was kept at -20°C overnight. The colour changed from blue to yellow and was allowed to warm to room temperature. Distillation of the mixture at 55 mm. Hg. after oxides of nitrogen and starting material (b.p. 39°C @ 760 mm.) had been evolved,

gave trifluoroacetyl nitrite as a yellow liquid (16 gms. 45%) b.p. 36-7°C (lit.[33] 45°C @ 80 mm.).

8. Preparation of 5,6,7,8-tetrabromo-1-methoxy-1,4-dihydro-1,4--ethenonaphthalene

Tetrabromoanthranilic acid (4.56 gms.) in acetonitrile (100 mls.) was added concurrently with isoamylnitrite, (1.36 mls.) in anisole (100 mls.) to anisole (100 mls.) stirred at 80°C. The reaction mixture was stirred for a further 30 mins. at 50°C. Solvent was removed and the residue chromatographed on alumina (200 gms.). Elution with benzene-petrol (50:50) gave a white crystalline solid (2.6 gms. 52%) shown by comparison of i.r. and ^{1}H n.m.r. spectra with those of an authentic sample[32] to be 5,6,7,8-tetrabromo-1-methoxy-1,4-dihydro-1,4-etheno-naphthalene.

9. Preparation of 5,6,7,8-tetrabromo-1,4-dihydro-1,4-etheno-2-tetralone

The tetrabromobenzyne-anisole adduct (1.0 gms.) was shaken in conc. sulphuric acid (30 mls.) for 30 mins. when a clear brown solution was obtained. The solution was poured onto ice and the precipitate extracted into chloroform, dried over anhydrous magnesium sulphate, and solvent removed to give a pale brown solid. The product was separated by preparative layer chromatography (5 plates 1 metre x 20 cms. x 0.5 mm.) eluent diethyl ether-petrol 30:70) on silica to give 5,6,7,8-tetrabromo--1,4-dihydro-1,4-etheno-2-tetralone (603 mgs. 60%) identified by comparison of its i.r. spectrum with that of an authentic sample.

In a reaction using a larger quantity of the benzobarrelene (4.4 gms.) the crude product after removal of solvent was recrystallised from ethanol to give 2.8 gms. (64%) of the benzobarrelenone.

10. Preparation of 5,6,7,8-tetrachloro-1-methoxy-1,4-dihydro-1,4-etheno--naphthalene

2-Carboxy-tetrachlorobenzenediazonium chloride (5 gms) was added to

anisole (150 mls.) and stirred at ca. 50°C for 3 hrs. Solvent was removed and the residue chromatographed on alumina (300 gms.). Elution with light petroleum gave 171 mgs. of pentachlorobenzene m.p. 85-6°C (lit.[34] 86°C). Elution with benzene-petrol (50:50) gave 5,6,7,8-tetrachloro-1-methoxy-1,4-dihydro-1,4-ethenonaphthalene (3.14 gms. 63%) identified by comparison of its i.r. spectrum with that of an authentic sample.

11. Preparation of 5,6,7,8-tetrachloro-1,4-dihydro-1,4-etheno-2-tetralone

I: The tetrachlorobenzyne-anisole adduct (3 gms.) was shaken in conc. sulphuric acid and allowed to stand for 8 hrs. After pouring onto ice the precipitated solid was extracted into ether, dried over anhydrous magnesium sulphate and solvent removed to give a pale brown solid. The product was isolated by column chromatography on silica (150 gms.) using benzene as eluent. By taking fractions of 10 mls. and monitoring the separation by thin layer chromatography three fractions were obtained

a) 1.35 gms. of the benzobarrelenone

b) 281 mgs. of an unresolved mixture of (a) and (c)

c) 220 mgs. of the α-β unsaturated ketone (17).

The unresolved fraction was separated by preparative layer chromatography (2 plates 1 m x 20 cms. x 0.5 mm. eluent diethyl ether-petrol 50:50) on silica to give a combined yield of 5,6,7,8-tetrachloro-1,4-dihydro-1,4-etheno-2-tetralone of 1.51 gms. (53%) and 3,4-tetrachlorobenzo-2,5-methanosuber-6-enone (270 mgs. 9%).

II: The tetrachlorobenzyne-anisole adduct (1 gm) was added to chlorosulphonic acid in portions and stirred for 10 mins. The solution was then carefully poured onto crushed ice and the precipitated solid extracted into ether and dried over magnesium sulphate. Removal of solvent gave a white solid (650 mgs. 68%) shown by ^{1}H n.m.r. to be entirely the benzobarrelenone.

12. Reaction of 5,6,7,8-tetrabromo-1,4-dihydro-1,4-etheno-2-tetralone and phenyl magnesium bromide

Bromobenzene (1 gm. 0.0064 moles) was added dropwise to a mixture of anhydrous tetrahydrofuran (20 mls.) and magnesium turnings (200 mgs. 0.008 moles). The mixture was warmed to start the reaction and after complete addition was heated under reflux for 2 hrs. Tetrabromobenzobarrelenone (1 gm. 0.002 moles) in dry tetrahydrofuran (20 mls.) was added dropwise with stirring and the solution heated under reflux for 10 hrs. The solvent was removed and the residue chromatographed on alumina. Elution with benzene gave a white solid (450 mgs. 42%) shown by ^{1}H n.m.r. and mass spectrometry to be identical to an authentic sample of 5,6,7,8--tetrabromonaphthalene.[32]

13. Preparation of p-nitroso anisole

Phenol (47 gms. 0.5 ml.) was dissolved in sodium hydroxide solution (200 mls. H_2O:20 gms. NaOH) containing sodium nitrite (69 gms. 1 mole) and stirred at 0°C. Dilute hydrochloric acid (750 mls.) was added dropwise maintaining the temperature at 0°C and stirred for a further 30 mins. at this temperature. The mixture was allowed to warm to room temperature and the brown solid filtered off, washed neutral with water and allowed to dry in the atmosphere. The yield of p-nitroso phenol was 34.5 gms.(56%).

p-Nitrosophenol was dissolved in anhydrous methanol (200 mls.) and conc. sulphuric acid (0.28 mls.) added. The solution was then stirred at 50°C under nitrogen for 2 hrs. The methanol was removed and the brown residue extracted twice with n-pentane (300 mls.) gave a bright green solution which on cooling to -40°C deposited crystals of p-nitroso anisole (14.6 gms. 44%) m.p. ca. 20°C (lit.[14,15] 23°C)

τ 2.1 (d 2H), 2.98 (d 2H), 6.07 (s, 3H) J_o= 8 Hz.

$\nu_{max.}$ 2990, 2950, 2850, 1605, 1587, 1505, 1415, 1270, 1120, 840 $cm.^{-1}$

14. Preparation of tetramethylstannane

Magnesium turnings (51 gms) were stirred vigorously with di-n-butyl ether (600 mls. sodium dried) and methyl iodide (225 gms.) in an equal volume of dibutyl ether was added dropwise maintaining the temperature at ca. 50°C by using a cooling bath. In this way the Grignard reagent was prepared in 90 mins. Anhydrous stannic chloride (74 gms.) was added dropwise allowing the temperature to rise and after addition was complete the mixture was heated under reflux for 2 hrs. After standing overnight the mixture was stirred mechanically and a mixture of dibutylether and tetramethyl stannane b.p. 96-100°C was distilled off. Further distillation up a 12" vacuum Vigreux column gave tetramethylstannane b.p. 76-7°C (lit.[35] 78°C) 36.5 gms. (70%).

15. Preparation of Trimethyltin chloride

Mercuric chloride (24 gms.) was dissolved in absolute ethanol (100 mls.) and tetramethyl tin (16 gms.) added with stirring. After 2 mins. a heavy white precipitate of methyl mercuric chloride formed. Stirring was continued for 30 mins. and the mixture filtered. The filtrate was distilled at atmospheric pressure to give, after removal of solvent (b.p. 72°C), trimethyltin chloride (11.5 gms. 70%) b.p. 150-2°C (lit.[36] 152-4°C).

16. Preparation of phenyltrimethylstannane

Phenylmagnesium bromide (0.15 moles) was prepared in the usual way in diethyl ether (100 mls. anhydrous). Trimethyltin chloride (11 gms.) in dry ether (20 mls.) was then added dropwise maintaining a steady reflux and the solution then heated under reflux for 24 hrs. After neutralisation with water, the organic phase was separated, and dried over anhydrous magnesium sulphate. Removal of solvent gave a pale yellow

liquid which on distillation gave phenyltrimethylstannane (9.5 gms. 72%) b.p. 77-80°C @ 6 mms. (lit.[37] 203-8°C 760 mms).

17. Preparation of phenyltributylstannane

This was prepared in a similar way to that described above. Starting from phenylmagnesium bromide (0.1 moles), tributyltin chloride (20 gms.), and a reaction time of 2 hrs. phenyltributylstannane (13 gms. 59%) was obtained b.p. 119-21°C @ 0.2 mms. (lit.[37] 139°C 0.6 mms).

18. Preparation of o-nitrosoanisole

o-Bromoanisole (46.75 gms. 0.25 moles) was converted to its Grignard reagent in the usual way (Mg 7 gms ether 150 mls.). After formation of the reagent the solution was heated under reflux for 30 mins. Tributyltin chloride (65 gms. 0.2 moles) was added dropwise with stirring and the reaction mixture again heated under reflux for 2 hrs. The reaction was carefully quenched with dilute sulphuric acid (250 ml.s) and the organic layer separated, washed once with water and dried over anhydrous magnesium sulphate. Removal of solvent gave a yellow oil (71 gms.) which on distillation gave a clear oil boiling between 116 - 143°C at 0.2 mms. and was shown by ^{1}H n.m.r. to be a mixture of the required product and tributyltin chloride. The oil was diluted with diethyl ether and washed with saturated solution of potassium fluoride in ethanol. The insoluble tributyltin fluoride was filtered through celite and solvent removed from the filtrate to give a pale yellow oil, which on redistillation gave a fraction boiling at 117-130°C, again a mixture, and a pure sample of the product, (13.6 gms.) b.p. 141-3°C 0.2 mms., o-methoxyphenyl tributylstannane n_D^{24} - 1.5173

τ 2.62-3.40 (m, 4H), 6.25 (s,3H), 8.30-9.40 (m, 27H)

ν 3060, 3000, 2960, 2920, 2880, 2860, 1580, 1465, 1430, 1235, 755 cms.$^{-1}$

o-Methoxyphenyl-tributylstannane (13.6 gms.) was dissolved in dichloromethane (20 mls.) and cooled to -20°C. Nitrosyl chloride (3.0 gms.) in dichloromethane (10 mls.) was added dropwise, maintaining the temperature at -20°C. The solution rapidly turned green and stirring was continued for 30 mins. The mixture was then washed once with dilute sodium hydroxide, and once with water. The organic phase was dried over anhydrous magnesium sulphate and solvent removed to give a residue which on steam distillation gave o-nitrosoanisole (1.5 gms. 38%) as a white solid m.p. 103-5°C (ethanol) (lit.[15] 103°C.).

19. Preparation of p-nitroso-toluene

p-Methyl-phenylmagnesium bromide (0.25 moles), from p-bromo toluene (42.75 gms.) and magnesium (7 gms.), was heated under reflux for 60 mins. with tributyltin chloride (50 gms. 0.16 moles). The reaction was quenched with dilute sulphuric acid (200 mls.) and the organic phase worked up as described previously to give a pale yellow oil, which on distillation gave p-methylphenyltributylstannane (30 gms. 50%) b.p. 150-2°C @ 1 mm. n_D 1.5186.

τ 2.50 - 2.97 (ABq 4H J_{AB} 9 Hz), 7.70 (s, 3H)
8.20 - 9.30 (m, 27H)

ν 3065, 3035, 3010, 2960, 2925, 2825, 2855
1465, 1070, 790 cms.$^{-1}$

p-Methylphenyltributylstannane (19 gms. 0.05 moles) was treated with nitrosyl chloride (3.3 gms. 0.05 moles) at -20°C for 30 mins. The green solution was washed twice with water and dried over anhydrous magnesium sulphate. Removal of solvent gave a green oil which on steam distillation gave p-nitrosotoluene (1.5 gms. 25%) m.p. 46°C (lit.[15] 49°C).

20. Preparation of m-nitrosotoluene

m-Bromophenylmagnesium bromide (0.25 moles), prepared in the usual way, was heated under reflux with tributyltin chloride (50 gms. 0.16 moles) in diethyl ether. Work-up as previously described gave a yellow liquid which on distillation gave m-methylphenyltributylstannane (29.6 gms. 49%)

b.p. 153-6°C 0.3 mms. n_D^{22} 1.5168

τ 2.75-3.05 (m, 4H), 7.70 (s, 3H), 8.00-9.30 (m,27H)

ν_{max} 2960, 2920, 2850, 1590, 1460, 1880, 1100, 1070, 770, 700 cms.$^{-1}$

m-Methylphenyltributylstannane (19 gms. 0.05 moles) was treated with nitrosyl chloride (3.3 gms. 0.05 moles) as described for the para isomer. Identical work-up procedure gave m-nitrosotoluene (800 mgs. 14%) m.p. 56-8°C (lit.[15] 53-4°C.).

21. Preparation of nitrosomesitylene

2,4,6-Trimethylphenylmagnesium bromide (from bromomesitylene 20 gms. and magnesium 3 gms.) was heated under reflux with trimethyltin chloride (9.2 gms.) in ether for 30 hrs. Standard work-up procedure gave crude mesityltrimethylstannane (10.4 gms.)

The crude sample was treated with nitrosyl chloride (2.0 gms.) in dichloromethane at -20°C for 20 mins. in the usual way. Steam distillation of the residue, after removal of solvent, gave nitroso-mesitylene (1.2 gms.) m.p. 122°C (lit.[15] 120°C.).

22. Reaction of Tetrabromobenzyne and nitrosobenzene

Tetrabromoanthranilic acid (4.56 gms. 0.01 moles) in acetonitrile (170 mls.) was run concurrently with a solution of isoamylnitrite (1.36 mls. 0.01 moles) in acetonitrile (170 mls.) into a solution of nitrosobenzene (4.3 gms. 0.04 moles) in acetonitrile (50 mls.) maintained

at 50-55°C. Stirring was continued at this temperature for a further 45 mins. and solvent removed to give a brown residue, which was placed on an alumina column (100 gms.) Elution with benzene-light petroleum (50:50) gave in order of elution a) an unidentified oily material (30 mgs.) b) an orange oil (222 mgs.) shown by i.r. spectroscopy to be azoxybenzene c) unreacted nitrosobenzene (421 mgs.). Elution with benzene gave a pale yellow solid (1.27 gms. 25%) shown to be 1-hydroxy-6,7,8,9-tetrabromocarbazole m.p. 216-7°C (benzene-petrol).

τ 1.32-1.55 (d, 1H), 2.20-2.87 (m, 3H), -1.90 (s,1H exchangeable with D_2O)

$\nu_{max.}$ 3425, 1595, 1250, 765, 745, 720 cms.$^{-1}$

$\lambda_{max.}$ 222 (4.58), 250, (4.72), 260 (4.67), 272 (4.54), 295 (4.13), 304 (4.17), 339 (3.75), 352 (3.78) nms.

(found: C, 28.95; H, 1.1; N, 2.5% M [mass spectrometry] 499; $C_{12}H_5Br_4NO$ requires C, 28.9; H, 1.0; N, 2.8% M. 499).

A sample of the carbazole (250 mgs.) was stirred for 16 hrs. in a suspension of potassium hydroxide (100 mgs.) in dimethyl sulphoxide (40 mls.) containing methyl iodide (200 mgs.). The yellow solution was poured into water, and the precipitate filtered. Recrystallisation gave 1-methoxy-6,7,8,9-tetrabromocarbazole (105 mgs.41%) m.p. 170-172°C (benzene-methanol)

τ 1.20-1.43 (d, broad 1H), 2.43-2$\frac{1}{2}$90 (m, 3H), 5.90 (s, 3H).

$\nu_{max.}$ 1560, 1440, 1390, 1240, 740 cms.$^{-1}$

$\lambda_{max.}$ 224 (4.48), 253 (4.59), 263 (4.58), 272 (4.53), 297 (4.06), 304 (4.05), 347 (3.66), 360 (3.70) nms.

(found: C, 30.75; H, 1.5; N, 2.75%. M[mass spectrometry] 513]. $C_{13}H_7Br_4NO$ requires C, 30.45; H,1.4; N, 2.75% M 513.

23. Reaction of Tetrachlorobenzyne and nitrosobenzene

The reaction was performed as described for the tetrabromo analogue starting from tetrachloroanthranilic acid (2.75 gms. 0.01 moles), isoamyl nitrite (1.36 mls. 0.01 moles) and nitrosobenzene (4.3 gms. 0.04 moles).

Identical work-up procedure gave, after elution of azoxybenzene and unreacted nitrosobenzene, 1-hydroxy-6,7,8,9-tetrachlorocarbazole (647 mgs. 20%) m.p. 174-5°C (benzene-petrol).

τ (DMSO-d_6) 1.50-80 (d, 1H), 2.25-2.90(m, 3H)

$\nu_{max.}$ 3450, 1605, 1500, 1460, 1430, 1405, 1260, 800, 740, 720 cms.$^{-1}$

$\lambda_{max.}$ 220 (4.38), 248 (4.54), 255 (4.48), 265 (4.33), 302 (4.01), 337 (3.62), 350 (3.59) nms.

(found: C, 44.75; H, 1.65; N, 4.35% M[mass spectrometry] 321 $C_{12}H_5Cl_4NO$ requires C, 44.9; H, 1.55; N, 4.35% M 321)

24. Reaction of benzyne and nitrosobenzene

Identical reaction conditions and work-up, starting from anthranilic acid, gave, after removal of nitrosobenzene by-products, N-hydroxycarbazole (20 mgs. 1%) m.p. 219-20°C (benzene-petrol)

τ (DMSO-d_6) 1.70-2.00 (d, 2H), 2.30-3.00 (m, 6H)

$\nu_{max.}$ 3430, 3060, 1605, 1450, 1325, 1240, 750, 725 cms.$^{-1}$

$\lambda_{max.}$ 233 (4.65), 244 (4.41), 257 (4.33), 293 (4.26), 324 (3.65), 337 (3.61) nms.

(found: C, 79.15; H, 5.05; N, 7.75%; M[mass spectrometry] 181 $C_{12}H_9NO$ requires C, 78.65; H, 4.9; N, 7.6%; M 181)

Other reactions where the ratio of nitrosobenzene to benzyne was changed and benzenediazonium-2-carboxylate itself was used gave the same yield of N-hydroxycarbazole.

25. Reaction of tetrabromobenzyne and o-nitrosoanisole

Tetrabromobenzyne, generated in the usual way from tetrabromo anthranilic acid (0.75 gms. 0.0016 moles) and isoamyl nitrite (0.22 mls. 0.0016 moles) was allowed to react with o-nitrosoanisole (900 mgs. 0.0065 moles). Removal of solvent gave a brown residue which was placed on an alumina (100 gms.) column. Elution with benzene-petrol (50:50) gave a small amount of oily material. Elution with benzene gave 1-hydroxy-2-methoxy-6,7,8,9-tetrabromocarbazole (135 mgs. 16%) m.p. 198-201°C (benzene-petrol)

τ (DMSO-d_6) 1.70-1.95 (AXq J_o= 6.8 Hz, J_m = 2.7 Hz, 1H)
2.58-2.95 (m, 2H), 6.00 (s, 3H).

ν_{max} 3460, 1580, 1405, 1265, 1240, 1035, 780, 735 cms.$^{-1}$

λ_{max} 230 (4.70), 252 (4.78), 293 (4.07), 343 (3.81) nms

(found: C, 29.55; H, 1.3; N, 2.6%. M[mass spectrometry] 52%

$C_{13}H_7Br_4NO_2$ requires C, 29.5; H, 1.35; N, 2.65% M 52%)

26. Reaction of tetrabromobenzyne and p-nitrosoanisole

Tetrabromobenzyne, from tetrabromoanthranilic acid (1.14 gms. 0.0025 moles) and isoamyl nitrite (0.34 mls. 0.0025 moles), was allowed to react with p-nitrosoanisole (1.37 gms. 0.01 moles) in the usual manner. Removal of solvent gave a residue which was placed on an alumina column (100 gms) and eluted with benzene. A yellow solid (367 mgs.) was obtained which was separated by fractional crystallisation from benzene-petrol into a) bis(p-methoxy)azoxybenzene m.p. 114-8°C (lit.[34] 118-9°C) identified by i.r. and ^{1}H n.m.r. spectroscopy and b) 1-hydroxy-4-methoxy-6,7,8,9-tetrabromocarbazole (168 mgs. 13%) m.p. 237-8°C (benzene-petrol)

τ (DMSO-d_6) 2.00 (d, J_m= 2.7 Hz. 1H), 2.30-2.60 (d, J_o = 8.2 Hz 1H), 2.65-2.95 (q, J_o= 8.2 Hz, J_m= 2.7 Hz 1), - 1.1 (s, broad 1H).

$\nu_{max.}$ 3450, 1600, 1590, 1495, 1290, 1200, 840, 800, 725 cms.$^{-1}$

$\lambda_{max.}$ 216 (4.43), 246 (4.24), 256 (4.21), 266 (4.20), 277 (4.17), 311 (3.80), 365 (3.39) nms.

(found: C, 30.2; H, 1.2; N, 2.7%) M[mass spectrometry] 529.

$C_{13}H_7Br_4NO_2$ requires C, 29.5; H, 1.35; N, 2.65% M. 529.

27. Reaction of tetrabromobenzyne and p-nitrosotoluene

Tetrabromobenzyne, from tetrabromoanthranilic acid (1.14 gms. 0.0025 moles) and isoamylnitrite (0.34 mls. 0.0025 moles), was allowed to react with p-nitrosotoluene (1.2 gms. 0.01 moles). Removal of solvent gave a residue which was placed on a column of alumina (100 gms.). Elution with benzene gave a) p-azoxytoluene (370 mgs.) m.p. 68-9°C (lit.[34] 70°C) identified by i.r. and ^{1}H n.m.r. spectroscopy and b) 1-hydroxy-4-methyl-6,7,8,9-tetrabromocarbazole (301 mgs. 29%) m.p. 219-21°C (methanol)

τ (DMSO-d_6) 1.72 (s, broad 1H), 1.40-1.77 (ABq J_o= 8.9 Hz 2H)

$\nu_{max.}$ 3460, 1595, 1485, 1300, 1255, 1200, 1160, 800, 725 cms.$^{-1}$

λ_{max} 223 (4.63), 250 (4.76), 263 (4.72), 270 (4.60), 298 (4.21), 307 (4.23), 344 (3.78), 360 (3.80) nms.

(found: C, 31.7; H, 1.5; N, 2.7% M[mass spectrometry] 513

$C_{13}H_7Br_4NO$ requires C, 30.45; H, 1.4; N, 2.75% and

$C_{13}H_7{}^{79}Br_4NO$ requires M -16 492.7295 found 492.7305).

28. Reaction of Tetrabromobenzyne and m-nitrosotoluene

Tetrabromobenzyne, generated from tetrabromoanthranilic acid (1.14 gms. 0.0025 moles) and isoamyl nitrite (0.34 mls. 0.0025 moles) was allowed to react with m-nitrosotoluene (1.0 gms. 0.085 moles) in the usual fashion. Removal of solvent gave a brown residue which was placed on an alumina column (100 gms.) Elution with benzene gave a) unreacted m-nitrosotoluene and b) a mixture of the two isomeric N-hydroxycarbazoles (120 mgs. 9%) ($\nu_{max.}$ 3400 cms.$^{-1}$)

1-hydroxy-3-methyl-6,7,8,9-tetrabromocarbazole (τCH_3 7.50) and 1-hydroxy-5-methyl-6,7,8,9-tetrabromocarbazole (τCH_3 6.95). The ratio of the two was approximately 2:1 respectively; they were not separated.

29. Reaction of Tetrabromobenzyne and Nitrosomesitylene

The normal procedure was followed on a 0.0025 molar scale with nitrosomesitylene (0.5 gms. 0.0033 moles). Elution of silica column (100 gms.) with light petroleum gave a clear oil (56 mgs.) shown by i.r. spectroscopy to be 2,3,4,5-tetrabromophenyl-3'-methylbutylether. Further elution with benzene gave small amounts of yellow material which was not identified. No naphthalenes were detected.

30. Reaction of Tetrachlorobenzyne and nitrosomesitylene

2-Carboxy-tetrachlorophenyl-3,3'-dimethyl triazene (1.0 gms.) was heated under reflux in a solution of nitrosomesitylene (0.4 gms.) in tetrachloroethylene for 4 hrs. Removal of solvent gave a residue which was placed on an alumina column (100 gms.) Elution with benzene gave a red oil (300 mgs.) which was separated by preparative layer chromatography (2 1m. x 20 cms x 0.5 mm plates eluent benzene:petrol 50:50) on silica into 9 bands. All bands were checked by u.v. spectroscopy; no naphthalenes were detected.

31. Reaction of Tetrabromobenzyne and phenyl tributylstannane

Tetrabromobenzyne (0.0025 moles) was generated in the usual concurrent fashion and allowed to react with phenyltributylstannane (2.75 gms. 0.0075 moles) in acetonitrile (75 mls.) maintained at 50-60°C. The crude oil, after removal of solvent, was separated by preparative layer chromatography (5 1m x 20 cm. x 0.5 mm plates eluent light petroleum) on silica from which was isolated a brown oil (30 mgs.) which crystallised on standing and was shown by ^1H n.m.r. spectroscopy to be mainly tetrabromobenzobarrelene.

32. Reaction of Tetrachlorobenzyne with phenyltributylstannane

2-Carboxytetrachlorobenzenediazonium fluoroborate (2.0 gms.) was suspended in a solution of phenyltributylstannane (2.0 gms.) in dichloromethane (50 mls.) Pyridine (0.5 mls.) was added dropwise and after addition the mixture was heated under reflux for 15 mins. The suspended solid was filtered, and solvent removed to give an oily liquid. Excess starting material was distilled off under reduced pressure and the residue placed on an alumina column (200 gms.) Elution with light petroleum gave a brown oil (325 mgs.) shown by ^{1}H n.m.r. spectroscopy to be tetrachlorobenzobarrelene.

33. Reaction of tetrachlorobenzyne and phenyltrimethylstannane

The reaction was performed in the same way as the butyl compound starting from 2-carboxytetrachlorobenzenediazonium fluoroborate (3.0 gms.), pyridine (0.7 mls.), and phenyltrimethylstannane (3.0 gms.). Elution of the alumina column (200 gms.) as before gave a brown oil shown by ^{1}H n.m.r. spectroscopy to be crude tetrachlorobenzobarralene (572 mgs.).

34. Preparation of phenyltrimethylsilane

Trimethylsilyl chloride (22 gms.) was added dropwise to a stirred solution of phenylmagnesium bromide (from bromobenzene 60 gms. and magnesium 10 gms.) in diethyl ether under an atmosphere of dry nitrogen. A steady reflux was maintained and the solution heated under reflux for a further 4 hrs. after complete addition. Suspended magnesium salts were filtered through a celite pad and the filtrate quenched with saturated ammonium chloride solution. The organic layer was separated and dried over anhydrous magnesium sulphate. Removal of solvent gave an oil which on distillation gave phenyltrimethylsilane (25.5 gms. 86%) b.p. 170-4°C (lit. [38] 177°C).

35. Reaction of Tetrachlorobenzyne and phenyltrimethylsilane.

2-Carboxytetrachlorobenzenediazonium fluoroborate (3 gms.) was suspended in a solution of phenyltrimethylsilane (3 gms.) in dichloromethane (100 mls.). Pyridine (1.0 mls.) was added dropwise and reaction allowed to take place, and completed by heating under reflux for 15 mins. The solution was filtered and solvent removed from the filtrate. Excess starting material was distilled off under reduced pressure leaving a brown residue which was placed on an alumina column (300 gms.). Elution with light petroleum gave a free running oil (321 mgs.) shown to be mainly the non-bridgehead silane adduct.

This crude sample was dissolved in ether (50 mls.) and nitrosyl chloride (ca. 0.2 gms.) added. T.l.c. indicated there was no change after 2 days. Resublimed aluminium chloride (ca. 100 mgs.) was added and the solution was stirred for further 24 hrs. Again there was no substantial change.

36. Reaction of Tetrachlorobenzyne and chlorobenzene

2-Carboxytetrachlorobenzenediazonium chloride (3.7 gms.) was warmed to 60°C in chlorobenzene (100 mls.).When evolution of gas had ceased the solution was heated under reflux for 10 mins. After removal of solvent the residue was placed on a column of alumina (150 gms.) Elution with light petroleum gave a) pentachlorobenzene (500 mgs.) and b) a white solid (1.2 gms. 32%) shown by ^{1}H n.m.r. spectroscopy to be a mixture of bridgehead and non-bridgehead adducts (ratio 1:3.5). The two isomers did not separate on g.l.c. (column A 200°C) or by t.l.c. ($AgNO_3$ impregnated silica).

37. Preparation of 3-bromo-4-methoxytoluene

2-Bromo-4-methyl-phenol (18.7 gms. 0.1 moles) was stirred with a suspension of sodium hydroxide (16 gms. 0.4 moles) in dimethylsulphoxide

(100 mls.) containing methyl iodide (28.6 gms 0.2 moles) for 16 hrs. at room temperature. Water (ca. 200 mls.) was added and the solution extracted twice with equal volumes of carbon tetrachloride. The organic phase was dried over anhydrous magnesium sulphate which on removal of solvent gave a brown oil. Distillation gave 3-bromo-4-methoxytoluene (18.3 gms. 92%) b.p. 97-99°C at 3 mms. (lit.[40] 225-7°C 760 mms.).

38. Preparation of m-dimethoxybenzene

Resorcinol (55 gms. 0.5 moles) was dissolved in sodium hydroxide solution (80 gms. NaOH:500 mls. H_2O) and dimethyl sulphate (150 mls.) added dropwise with stirring, allowing the temperature to reach 60°C. A further quantity of sodium hydroxide (20 gms.) and dimethyl sulphate (50 mls.) was added to complete the reaction. After heating under reflux for 2 hrs. the liberated oil was extracted into ether, washed with dilute sulphuric acid and then water. The organic phase was dried over anhydrous magnesium sulphate and solvent removed to give a brown oil which on distillation gave m-dimethoxybenzene (43.5 gms. 63%) b.p. 64°C 2 mms. (lit.[34] 216-7°C).

39. Preparation of 2,6-dimethoxybromobenzene

m-Dimethoxybenzene (13.8 gms. 0.1 moles) was dissolved in dry ether (200 mls.) and the system flushed with dry nitrogen. n-Butyl-lithium (50 mls. 2.3 M in hexane) was added by means of a syringe introduced through a septum and the solution allowed to stand at room temperature for ca. 30 hrs. when 2,6-dimethoxyphenyl-lithium separated as a white crystalline solid. 1,2-Dibromoethane (25 gms.) was added dropwise with stirring. There was a steady evolution of gas and the solution was allowed to stand for 24 hrs. The mixture was then filtered and the filtrate reduced in volume resulting in the crystallisation of 2,6-dimethoxybromobenzene (11.3 gms. 52%) m.p. 92-3°C (light petroleum) (lit.[39] m.p. 91-2°C) M [mass spectrometry] 216.

40. Reaction of Tetrachlorobenzyne and o-bromoanisole

2-Carboxytetrachlorobenzenediazonium chloride (1.5 gms.) was decomposed in a solution of o-bromoanisole (1.5 gms.) in carbon tetrachloride (50 mls.) by warming to 50-60°C. The reaction was completed by heating under reflux for 10 mins. After removal of solvent the residue was place on a silica column (200 gms.) Elution with light petroleum gave pentachlorobenzene; with benzene-petrol (50:50) unreacted o-bromoanisole was obtained; and finally elution with benzene gave 1-methoxy-2-bromo-5,6,7,8-tetrachloro-1,4-dihydro-1,4-ethenonaphthalene (520 mgs. 28%) m.p. 152-3°C (Ethanol) τ 2.67-3.20 (m, 3H), 3.56-3.85 (tr. of d. 1H) 6.20 (s, 3H).

$\nu_{max.}$ 3100, 3020, 2950, 2850, 1595, 1470, 1435, 1300, 1250, 1110, 1040, 700 cms.$^{-1}$

(found: C, 38.5; H, 1.8%. M[mass spectrometry] 401

$C_{13}H_7BrCl_4O$ requires C, 38.9; H, 1.75% M 401)

41. Reaction of Tetrachlorobenzyne and 3-bromo-4-methoxytoluene

2-Carboxytetrachlorobenzenediazonium chloride (4 gms.) was allowed to decompose in a solution of 3-bromo-4-methoxy toluene (4 gms.) in carbon tetrachloride (100 mls.) heated under reflux for 20 mins. Solvent was removed and the residual oil placed on a column of silica (300 gms.). Elution with light petroleum gave pentachlorobenzene (560 mgs.). Elution with petrol-benzene (50:50) gave unreacted starting material (2.6 gms.) and elution with benzene gave 10-methyl-3-bromo-1,4-etheno-5,6,7,8-tetrachlorotetral-2-one (1.36 gms. 27%) m.p. 172-5°C(ethanol)

τ ($CDCl_3$) 3.60-3.90 (m, 1H), 5.03-5.21 (d, J = 6.8 Hz), 5.23-5.39 (ABq J_{AB} = 3.4 Hz, $J_{allylic}$ = 2.7 Hz 1H), 5.63-5.85 (d, J = 3.4 Hz 1H)

ν_{max} 3080, 3020, 2980, 2950, 2920, 2860, 1745, 1380, 1090, 1030, 780, 770, 685, 675 cms.$^{-1}$

(found: C, 38.8; H, 1.75%. M [mass spectrometry] 280 (M-CHBrCO)

$C_{13}H_7BrCl_4O$ requires C, 38.90; H, 1.75% M 401)

The bromoketone (24; 400 mgs.) was dissolved in a solution of hydroxylamine hydrochloride (200 mgs.) in pyridine (25 mls.) and heated at 80°C for 2 hrs. The solution was poured into ice-water and the precipitated solid filtered and dried to give 10-methyl-3-bromo-1,4-etheno-5,6,7,8-tetrachlorotetral-3-one oxime (330 mgs. 79%)m.p. 202-3°C (benzene-methanol)

(found: C, 37.65; H, 2.0; N, 3.3% M [mass spectrometry] 416

$C_{13}H_8BrCl_4NO$ requires C, 37.55; H, 1.5; N, 3.35% M 416.)

42. Dehydrobromination of the 2-bromo-4-methyl-tetrachlorobenzobarrelenone oxime

The oxime (26; 300 mgs.) was heated in a solution of triethylamine (1 ml.) in dimethyl formamide (20 mls.) at ca. 100°C for 3 hrs. The solution was then reduced to a volume of ca. 5 mls. and placed on a silica plate(1 m x 20 cms. x 0.5 mms.) and eluted with benzene. Two bands were isolated; the lower R_f band gave unreacted starting material (99 mgs.) and the fast running band gave 2-methyl-5,6,7,8-tetrachloro-naphthalene (65 mgs. 30% conversion 38%) m.p. 125-7°C. The compound had identical ^1H n.m.r. and i.r. spectra to an authentic sample.

An authentic sample was prepared by irradiation of tetrachloro-4-methylbenzobarrelenone (500 mgs.) in ether (300 mls.) using a 'Hanovia' 500 W medium pressure lamp (external source) for 7 hrs. in an atmosphere of nitrogen. The reaction was worked up by column chromatography (alumina 50 gms.) Elution with light petroleum gave 2-methyl-5,6,7,8-tetrachloronaphthalene (146 mgs. 43%) m.p. 125-7°C (ethanol)

τ ($CDCl_3$) 1.85-1.98 (d, J_o= 8.9 Hz 1H), 2.03-2.08 (m, 1H),

2.46-2.68 (q, J_o= 8.9 Hz J_m= 1.8 Hz 1H).

$\nu_{max.}$ 1630, 1560, 1490, 1320, 1310, 1300, 1260, 810 cms.$^{-1}$

$\lambda_{max.}$ 240 (5.01), 277 (3.69), 288 (3.85), 298 (3.90), 307 (3.80) nms.

(found: C, 47.4; H, 2.25%. M [mass spectrometry] 280

$C_{11}H_6Cl_4$ requires C, 47.15; H, 2.15% M 280).

43. Reaction of Tetrachlorobenzyne and 2,6-dimethoxy-bromobenzene

2-Carboxytetrachlorobenzenediazonium chloride (2.5 gms. 0.0077 moles) was decomposed in a solution of 2,6-dimethoxybromobenzene (1.8 gms. 0.0083 moles) in carbon tetrachloride (50 mls.) by heating under reflux for 30 mins. Solvent was removed and the residue placed on a silica column (250 gms.) Elution with light petroleum gave pentachlorobenzene (120 mgs.); elution with benzene gave a) recovered starting material (620 mgs.) and b) 1-methoxy-2-bromo-1,4-etheno-5,6,7,8-tetrachloro-tetral-3-one (1.36 gms. 42%) m.p. 232-4°C (benzene)

τ ($CDCl_3$ 100 MHz) 2.96-3.29 (m, 2H), 4.84-4.98 (d.d J_{vic} = 6 Hz $J_{allylic}$ = 2 Hz 1H), 5.56 (s, 1H), 6.30 (s, 3H)

$\nu_{max.}$ 3080, 2960, 2940, 2850, 1748, 1620, 780, 715, 700, 680 cms.$^{-1}$

(found: C, 37.45; H, 1.65% M [mass spectrometry] 296 (M-CHBrCO)

$C_{13}H_7BrCl_4O_2$ requires C, 37.4; H, 1.7% M 417)

44. Dehydrobromination of 1-methoxy-2-bromo-tetrachlorobenzobarrelenone oxime

The bromobenzobarrelenone (250 mgs.) was warmed in a solution of hydroxylamine hydrochloride (200 mgs.) in pyridine (25 mls.) at 80°C for 60 mins. The solution was poured into ice-water (50 mls.) and the precipitated solid filtered and dried. The crude oxime was dissolved in dimethylformamide containing triethylamine (0.5 mls.) and thebaine (200 mgs.), and the solution heated at ca. 100°C for 16 hrs. On cooling a crystalline solid formed which was filtered and shown by i.r. spectroscopy to be thebaine hydrobromide. Excess solvent was distilled off from the filtrate, under reduced pressure, and the residue chromatographed on alumina. Elution with benzene gave a white solid

(84 mgs.) shown by comparison of i.r. and ^{1}H n.m.r. spectra to be 1-methoxy-5,6,7,8-tetrachloronaphthalene.

45. Reaction of Tetrachlorobenzyne and m-dimethoxybenzene

a) 2-Carboxytetrachlorobenzenediazonium chloride (11.0 gms.) was allowed to stand in a solution of m-dimethoxybenzene (6.0 gms.) in carbon tetrachloride (60 mls.) for 2 days. The red crystalline solid was filtered and washed with benzene to give 4-(2'-carboxytetrachlorophenylazo)-1,3-dimethoxybenzene (14.1 gms. 97%) m.p. 218-21°C (ethanol)

τ 2.25-2.45 (d, J = 8.9 Hz 1H), 3.15-3.50 (m, 2H), 6.03 (s, 3H), 6.10 (s, 3H).

ν_{max} 3250-2300 (broad), 1705, 1600, 1580, 1290, 1260, 1235, 1120, 1030, 840, 800 cms.$^{-1}$

$\lambda_{max.}$ 209 (4.34), 385 (4.11) nms.

(found: C, 42.5; H, 2.3; N, 6.7% M [mass spectrometry] 424

$C_{15}H_{10}Cl_4N_2O_4$ requires C, 42.4; H, 2.4; N, 6.6% M 424)

b) 2-Carboxytetrachlorobenzenediazonium chloride (3 gms.) was decomposed in a solution of m-dimethoxybenzene (3 gms.) in carbon tetrachloride (100 mls.) by addition of pyridine (1 ml.) and heating under reflux for 30 mins. The mixture was filtered and solvent removed from the filtrate to give a red oil which was placed on a column of silica (300 gms.) Elution with benzene-petrol (50:50) gave pentachlorobenzene (120 mgs.); elution with benzene gave a brown oil consisting of mainly starting material; and elution with ether-benzene (10:90) gave a brown solid which on treatment with activated charcoal and crystallisation from methanol-benzene gave 1-methoxy-1,4-etheno-5,6,7,8-tetrachlorotetral-3-one (442 mgs. 12%) m.p. 146-8°C (methanol-benzene)

τ ($CDCl_3$) 2.95-3.50 (m, 2H), 4.88-5.13 (m, 1H), 6.35 (s, 3H), 7.25-7.90 (ABq J_{AB} = 17.7 Hz).

$\nu_{max.}$ 3005, 2980, 2960, 2930, 1750, 1620, 1370, 1270, 1215, 1130, 1010, 710, 690 cms.$^{-1}$

(found: C, 46.4; H, 2.1% M (mass spectrometry) 296 (M - CH_2CO) $C_{13}H_8Cl_4O_2$ requires C, 46.2; H, 2.4% M 338).

46. Preparation of 1-methoxy-5,6,7,8-tetrachloronaphthalene

1-Methoxy-tetrachlorobenzobarrelen-3-one(500 mgs.) was photolysed in ether (50 mls.) for 16 hrs. using a 'Hanovia' medium pressure lamp. Solvent was removed to give a solid; elution with light petroleum from a short column of silica (50 gms.) gave 1-methoxy-5,6,7,8-tetrachloro naphthalene (186 mgs 42%) m.p. 134-6°C (Et OH)

τ ($CDCl_3$) 2.00-2.20 (dd. J_{4-2} = 2 Hz, J_{4-3} = 8.2 Hz 1H), 2.32-2.67 (t, $J_{2-3} = J_{3-4}$ = 8.2 Hz 1H), 2.85-3.15 (dd. J_{2-3} = 8.2 Hz J_{2-4} = 2 Hz 1H), 6.07 (s, 3H)

$\nu_{max.}$ 2940, 2850, 1615, 1545, 1315, 1285, 1260, 1020, 790, 735 cms.$^{-1}$

$\lambda_{max.}$ 228 (4.63), 252 (4.61), 307 (3.70), 320 (3.80), 331 (3.79), 345 (3.65).

(found: C, 44.7; H, 2.1% M [mass spectrometry] 296

$C_{11}H_6Cl_4O$ requires C, 44.6; H, 2.05% M 296)

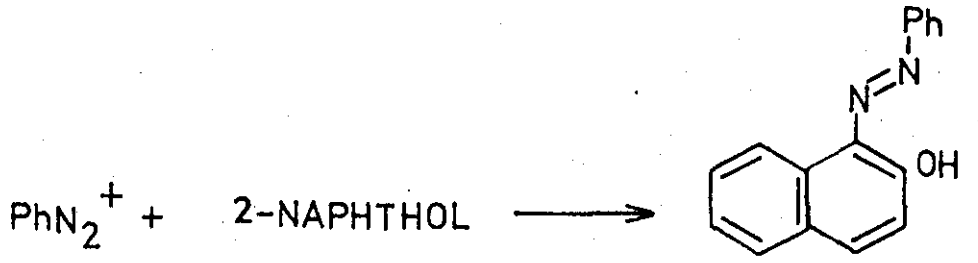
CHAPTER 2

THE FORMATION OF ARYNES FROM AROMATIC DIAZONIUM SALTS

Introduction

Since the initial isolation of crystalline diazonium salts by Griess in 1858, these compounds have occupied an important position in the development of organic chemistry from both theoretical and practical viewpoints. The discovery of the azo-dyes in the late nineteenth century initiated a considerable increase in the study of their chemistry and by the turn of the century a vast number of reactions had been discovered. It was not until the development of the electronic theories of organic chemistry that the apparently unrelated multitude of different reactions could be explained on a rational basis. It was then realised that these reactions fell broadly into four different classes.[41]

Some reactions occurred with an overall retention of nitrogen. Although other examples are known, by far the most common reactions are those known as diazo-coupling reactions. For instance coupling benzenediazonium salts with 2-naphthol gives the azo-dye (29).

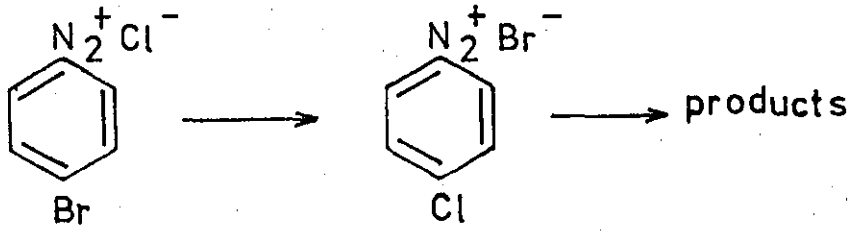


(29)

Coupling reactions occur with a wide variety of reagents at carbon, nitrogen, oxygen, sulphur, and even phosphorus atoms.[41] An example of coupling with nitrogen is afforded by the reaction of dimethylamine to give 1-aryl-3,3-dimethyl triazenes (30).

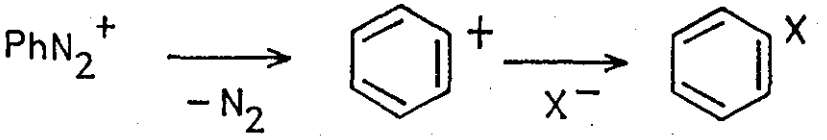
(30)

A second category of reaction concerns the strongly activating effect of the diazonium function towards nucleophilic substitution. p-Bromobenzenediazonium chloride for instance rearranges to p-chlorobenzenediazonium bromide.[42] Reactions of this kind are common when a good



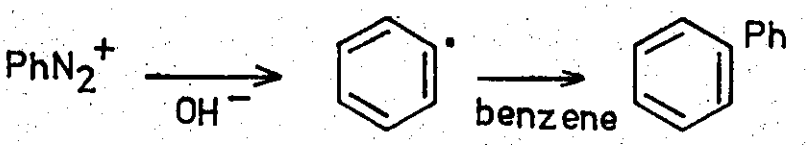
leaving group is present in the aromatic ring.

Other reactions with simple nucleophiles are known to proceed via a heterolytic loss of nitrogen to aryl cations (31) as first postulated by Waters[43] in 1942. Typical reactions of this type include the

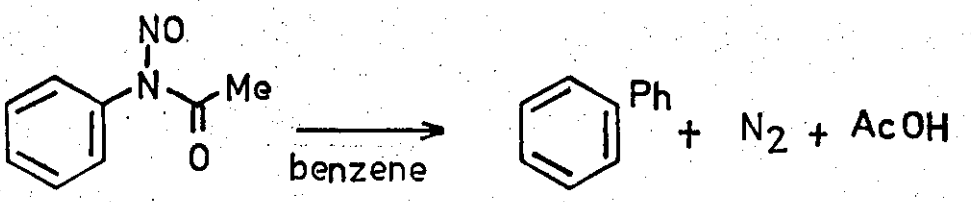


(31)

hydrolyses of diazonium salts to give phenols. A fourth series of reactions involves the homolytic loss of nitrogen to give aryl radicals. In the well known Gomberg reaction[44] aryl radicals are formed which then react with arenes to give biaryls. It is at this stage timely to mention the

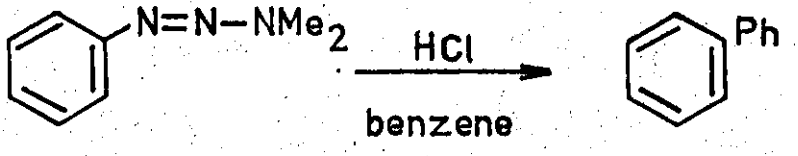


role of N-nitrosoacylanilides in the formation of aryl radicals. N-Nitrosoacetanilide was found by Bamberger[45] to decompose at room temperature, in benzene, to give biphenyl and acetic acid (Scheme 15).



Scheme 15

Similarly Hey[46] discovered that 1-aryl-3,3-dialkyltriazenes decompose in the presence of acid to give biaryls, again via aryl radicals, (Scheme 16). The triazenes are evidently converted to the diazonium

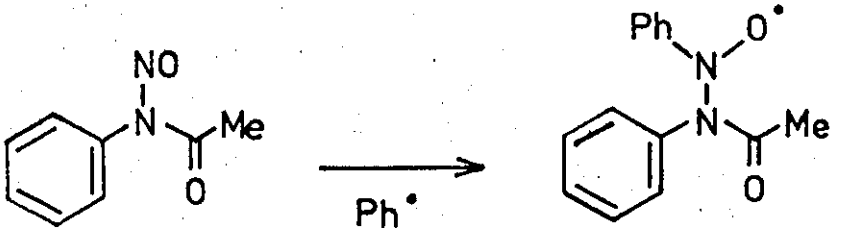


Scheme 16

salts which then proceed as in the Gomberg reaction to aryl radicals; the other intimate details of these mechanisms were not however finally established until recently.[47] It was Huisgen[48] who originally showed that N-nitrosoacetanilide isomerises in the rate determining step to the diazoacetate (32). It was then assumed that this species decomposed homolytically to phenyl radicals, nitrogen and acetoxyl radicals;

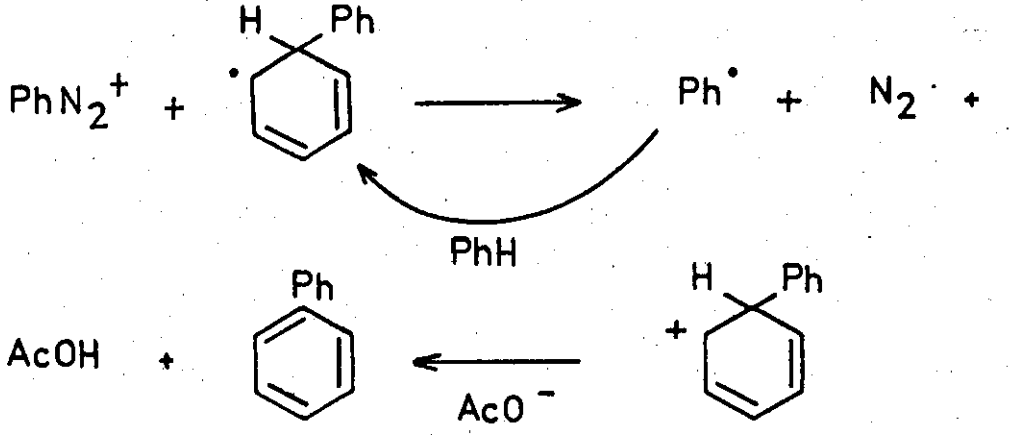
however, this was untenable for a number of reasons.[47] Based on the discovery[49] that the diazo-acetate is in equilibrium with the arene-diazonium acetate ion-pair Ruchardt[50] proposed a mechanism to account for the products (Scheme 17).

The chain carrier in this sequence is the stable nitroxide radical (33) which has been identified by e.s.r. spectroscopy as a σ-radical. In some solvents the chain carrier is the (N-phenylacetamido)-phenyl nitroxide radical (34) produced by N-nitrosoacetanilide scavenging a phenyl radical.[51]

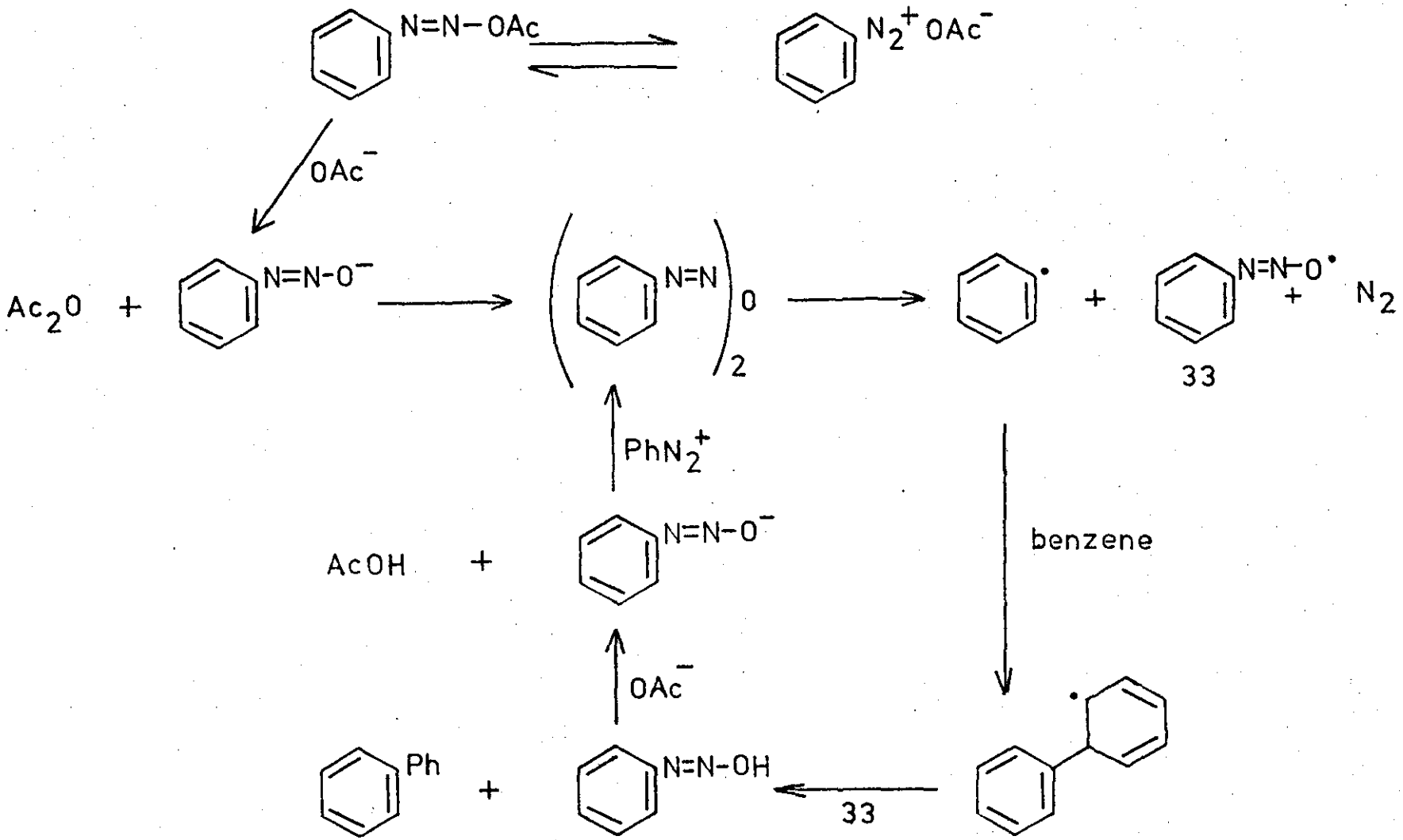


(34)

The mechanism of the Gomberg[52] reaction is essentially the same except that the initial covalent intermediate is the diazohydroxide. In this case, of course, there is no possibility for the participation of the (N-phenylacetamido)phenyl nitroxide. In both of the mechanisms it is likely that once the chain is initiated it is continued by a redox reaction involving the diazonium cation[51] (Scheme 18).

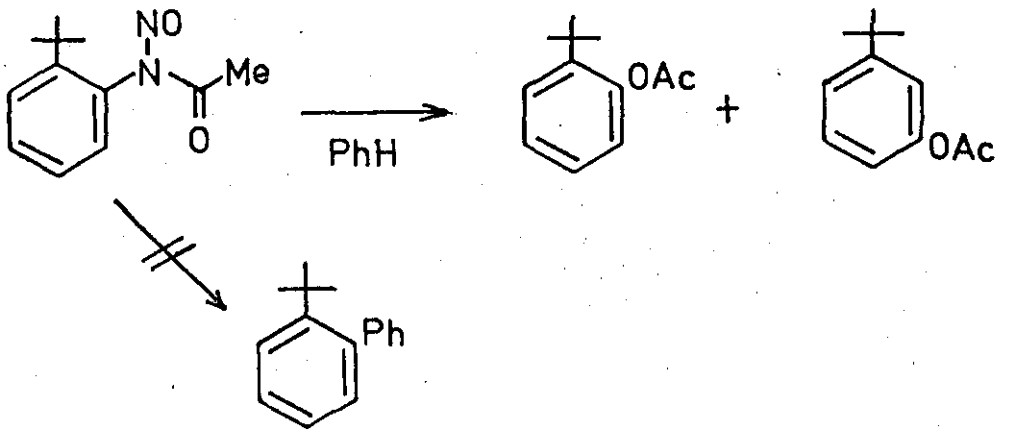


Scheme 18


N=N-OAc
N_2^+ OAc^-
OAc^-
Ac_2O +
N=N-O⁻
N=N
0
2
33
N_2
PhN_2^+
AcOH +
benzene
OAc^-
Ph +
N=N-OH
33

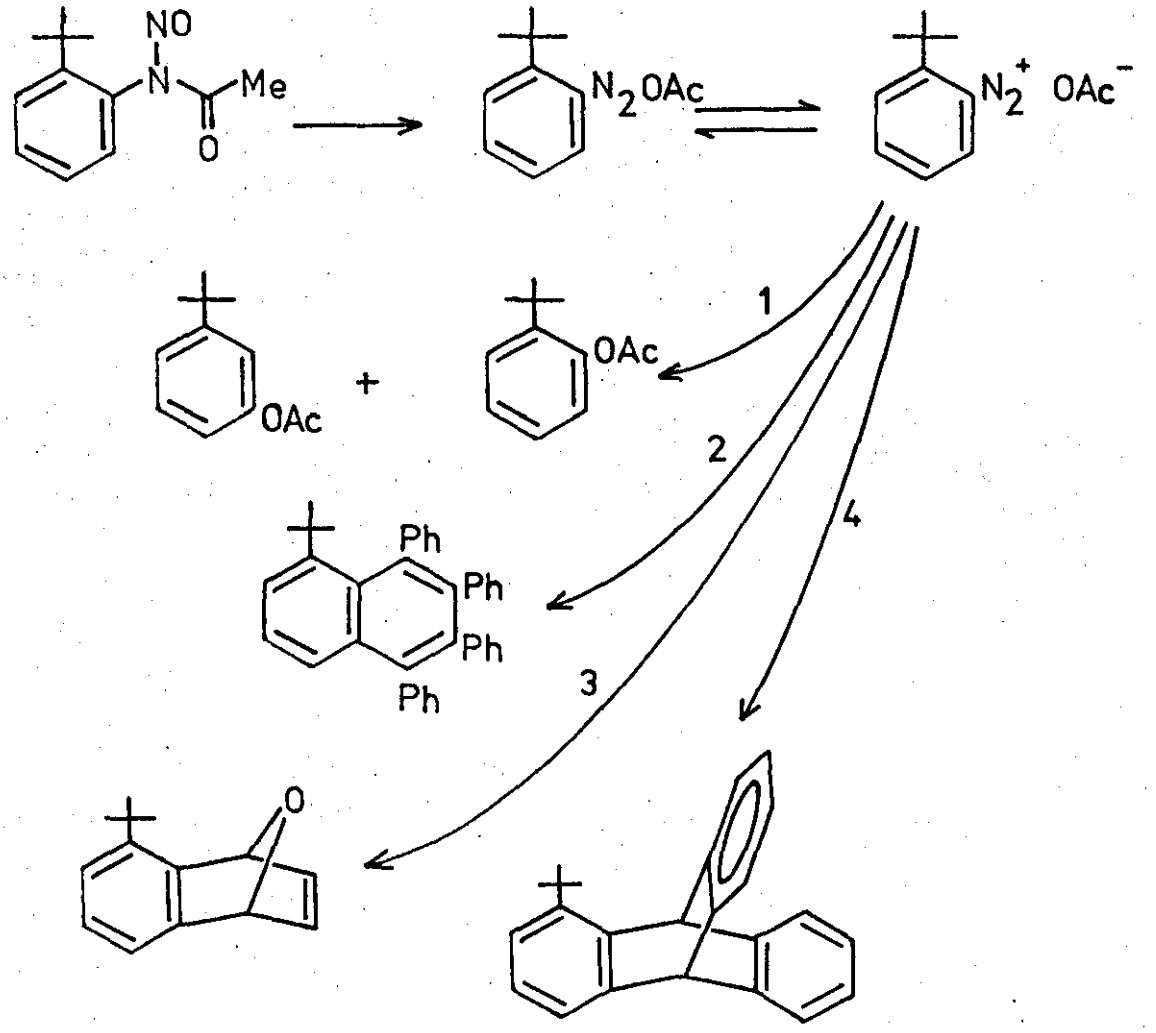
Scheme 17

Although these radical mechanisms have had great success, especially in recent years, in explaining the behaviour of diazonium salts and related compounds with a wide variety of reagents, there have still been several observations that could not satisfactorily be accounted for. In 1954 Hey and Cadogan observed that o-t-butyl-N-nitrosoacetanilide did not form the anticipated biphenyl when allowed to decompose in benzene.[53] The products obtained were later shown by Cadogan and Hibbert to be a mixture of o- and m-t-butylacetates[54] (Scheme 19).



Scheme 19

The somewhat startling explanation for these results was the idea of the intermediacy of t-butyl benzyne. Support for this came by performing the reactions in the presence of aryne traps such as furan, anthracene and tetracyclone. In all cases aryne adducts were obtained.[55] It was postulated that the N-nitrosoacetanilide rearranges to the diazonium acetate which then collapses to t-butyl benzyne (Scheme 20). Further confirmation of this came when Franck and Yanagi isolated aryne adducts from 2,5-di-t-butyldiazonium salts themselves.[56]



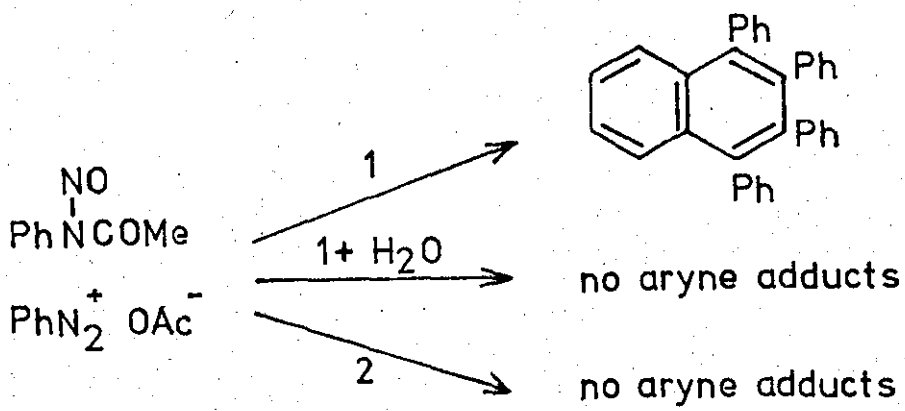
1 AcOH 2 tetraphenyl cyclopentadienone

3 furan 4 anthracene

Scheme 20

There was then speculation as to whether other N-nitrosoacylanilides decomposed via arynes. Cadogan showed that N-nitrosoacetanilide decomposed in the presence of anthracene, 1,3-diphenylisobenzofuran, and tetracyclone to give the corresponding aryne adducts.[57] Similarly Ruchardt and Tan showed that benzenediazonium chloride or fluoroborate decomposes in the presence of acetate ion and tetracyclone or anthracene to give aryne adducts in fair yields.[58] However, in both cases two confusing observations were recorded. No aryne adducts were formed in the presence of furan or in

the presence of water (Scheme 21).



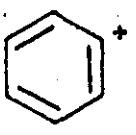
1 tetraphenyl cyclopentadienone 2 furan

Scheme 21

The only product obtained with furan was the 'normal' radical product 2-phenylfuran. The suppression of aryne formation by furan and water, initiated interest in the mechanisms of formation of arynes, indeed as to whether arynes were involved at all.[57]

Discussion

The abstraction of hydrogen atoms from the aromatic nucleus, formed the basis of preparation of arynes in earlier years. The essential requirement was the presence of strongly basic reagents to remove the weakly acidic hydrogen; typical conditions involving sodamide in liquid ammonia or 'lithium amides' in diethyl ether. The abstraction of hydrogen atoms from aromatic diazonium salts is thus remarkable in that the base involved is the carboxylate ion, which is not generally regarded as a strong base. Two points become apparent in this context in that the diazonium function has a considerable activating effect on the ortho hydrogens and the carboxylate counter ion is unsolvated in aprotic solvents. In aqueous systems the acetate ion, for example, is highly solvated and is consequently regarded as a weak base. The mild conditions under which the reaction occurs and the wide availability of diazonium salts would appear to provide a new synthetic route of general utility were it not for the existence of some disturbing observations. The suppression of aryne adducts in the presence of furan initially led to doubts as to whether benzyne itself was involved and prompted the suggestion that 'arynoid' intermediates such as (35) and (36) were involved.[57] These doubts however have now been removed as competition reactions carried out



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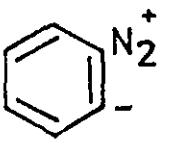


(36)

with 9,10-dimethoxyanthracene and anthracene[55] or analysis of A and B ring products[59] from 1,4-dimethoxyanthracene give identical product ratios to those obtained from authentic arynes. o-Tert-butyl-N-nitroso-

acetanilide however does give aryne adducts in the presence of furan and is also unaffected by traces of water, which suppresses aryne formation from N-nitrosoacetanilide itself, or benzenediazonium salts. Clearly the situation is complex and some clarification is necessary before the full scope of the reaction can be realised. The 'inhibiting' properties of water were first recognised by Cadogan who showed that aryne adducts could not be obtained by the established aprotic diazotisation with alkyl nitrite because water was produced *in situ*.[60] (Scheme 22). It was further established that if acetic anhydride was used instead of acetic acid

$$AmONO + CH_3CO_2H \longrightarrow NO^+ + AmOH + OAc^-$$

$$\downarrow PhNH_2$$

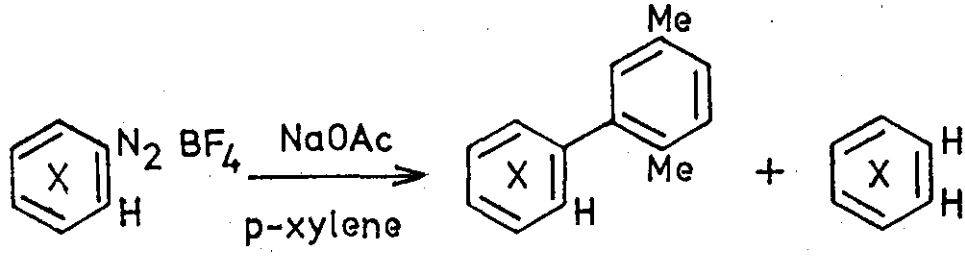
$$PhN_2^+ + {}^-OAc + AmOH + H_2O$$

Scheme 22

aryne products could be obtained, the principle being that the use of acetic anhydride avoids the formation of water. The full scope and mechanism of this reaction has recently been discussed.[61]

It thus appeared to us that this method of generating arynes would lend itself readily to the case of the tetrahalogenoarynes since the lone aromatic proton is made more acidic by the strong inductive effects of the halogen atoms. This would be particularly useful for the formation of tetrafluorobenzyne as a convenient non-organometallic method of preparation is not available. Although tetrafluoroanthranilic acid is known to proceed to tetrafluorobenzyne,[62] experience in these laboratories has shown that this precursor is inefficiently prepared and does not give acceptable yields of adducts.[63] It was our intention to prepare the tetrahalogenoanilines and attempt to generate the

corresponding tetrahaloarynes from the respective diazonium salts. The competition data of tetrahaloarynes for benzene and p-xylene is available[32] and thus the intermediacy of tetrahaloaryne could have been established. Tetrafluoro and tetrachloroaniline were prepared by reduction of the corresponding nitro compounds while tetrabromo and again tetrachloroaniline were prepared by decarboxylation of the anthranilic acids. The diazonium fluoroborates were prepared and allowed to decompose in p-xylene containing anhydrous sodium acetate at ca. 100°C. In all cases the main product obtained was the tetrahalogenobiphenyl. (Scheme 23).



X = F 15 %

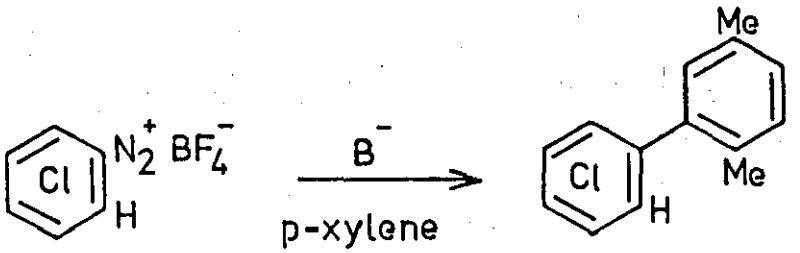
Cl 58% 10% (37)

Br 32% 12% (38)

Scheme 23

No aryne adducts were found. As all the starting materials were carefully dried beforehand to avoid suppression of aryne products it can be concluded that only the radical pathway is occurring. This is confirmed by the isolation of the tetrahalogenobenzenes (37,38) which would be absent if the biaryls were formed by an electrophilic process. The failure to generate the aryne in this case prompts three explanations. Either acetate ion is not a sufficiently strong base to remove the ortho proton, p-xylene is particularly prone to radical attack, or the chlorine atoms are preferentially directing the reaction along a radical pathway.

Reactions of tetrachlorobenzenediazonium fluoroborate with p-xylene

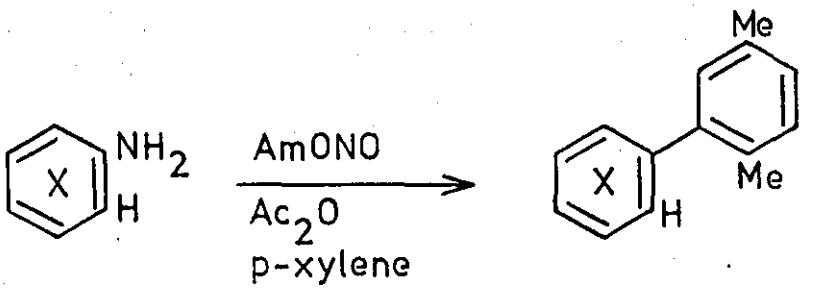


(39)

B^- = OMe 53%

= pyridine 39%

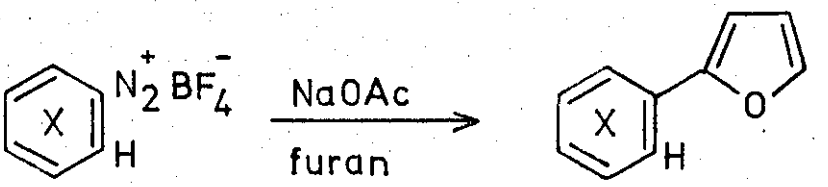
in the presence of sodium methoxide or pyridine again gave only the radical-derived product, the biphenyl (39). Identical results were also observed by the method of aprotic diazotisation. When tetrafluoro- and tetrachloro-aniline were diazotised and decomposed in the presence of iso-amyl nitrite, acetic anhydride and p-xylene the halogenated biphenyls (39) and (40) were obtained in 51% and 23% yields respectively.



X = Cl (39) 51%

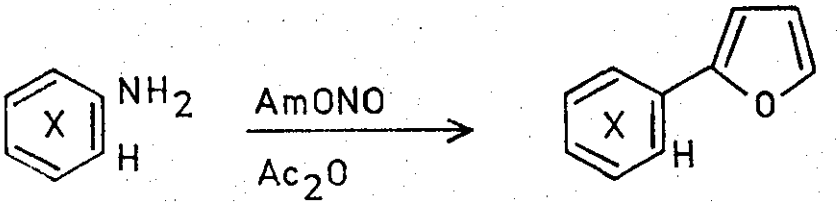
= F (40) 23%

In the presence of furan tetrahalogenobenzenediazonium salts react to give 2-tetrahalophenylfurans. Better yields of the furans are obtained by the method of aprotic diazotisation. The azo-coupling reaction also appears to be present, especially noticeable in the case



X = F < 5%

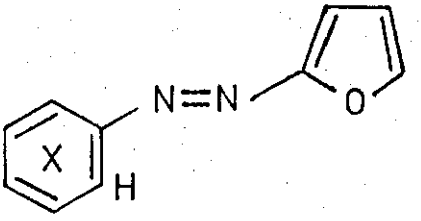
= Cl 12%



X = F 13%

X = Cl 39%

of the aprotic diazotisations as red compounds, presumably corresponding to (41) and (42) were both isolated in crude form.

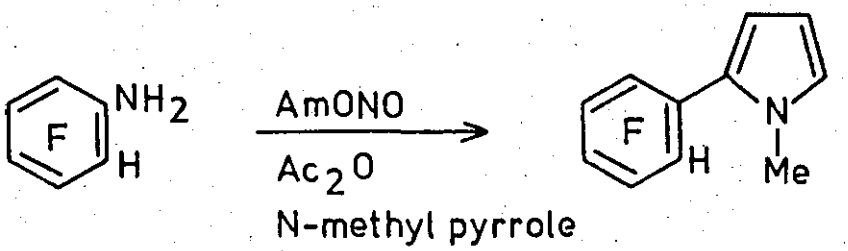


X = F (41)

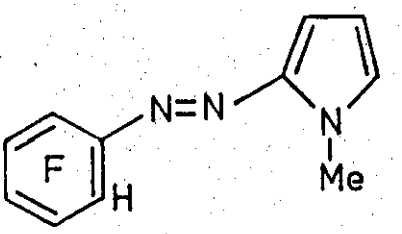
= Cl (42)

Other workers in these laboratories have examined this reaction in the presence of N-methylpyrrole[22] and obtained the phenylated compound (43) and also the azo-coupled product (44). Thus as far as reactions in furan are concerned the tetrahalogenoanilines behave in the same way as aniline itself.

It is now considered, "that the sequence of radical and ionic reactions leading to phenylated products is dominant in the case of furan; e.g. the chain sequence, if fast, would consume the precursory diazonium cation in successful competition with its conversion to benzyne."[59a]



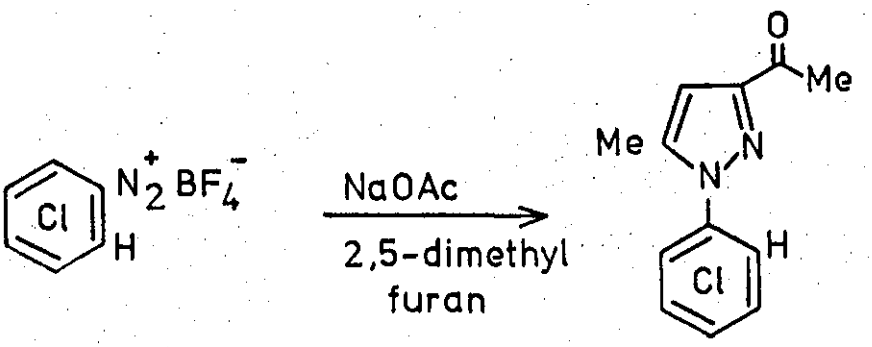
(43)



(44)

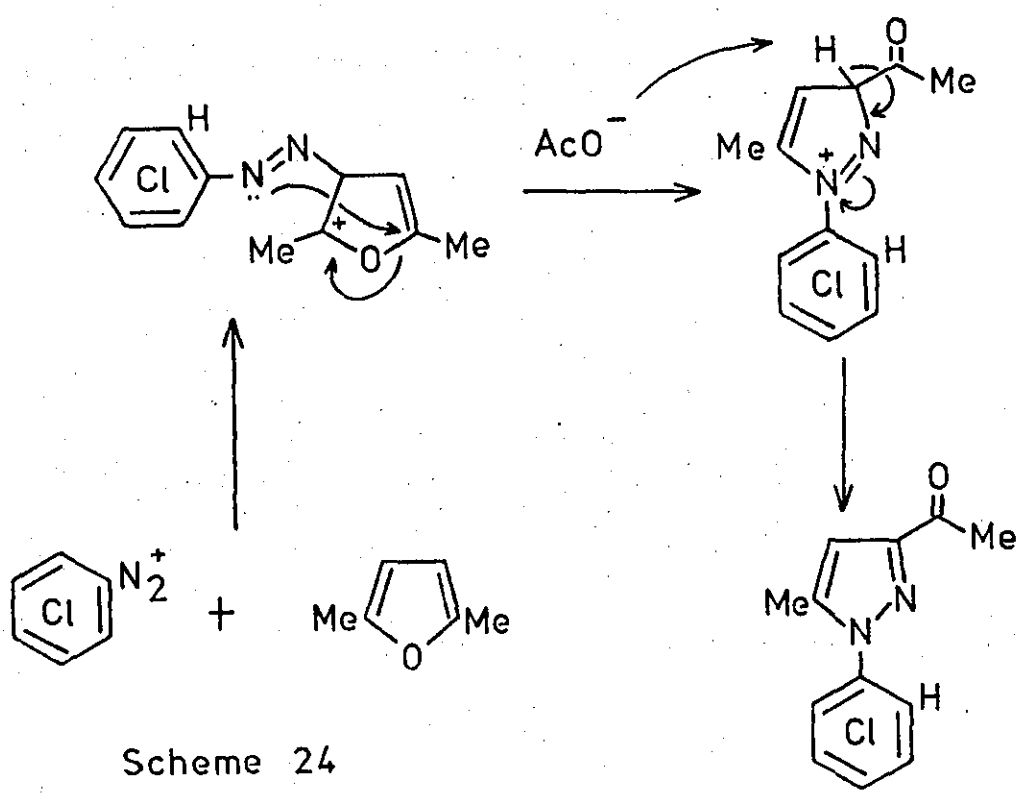
The suppression of aryne formation in furan is then merely a consequence of the much more favourable radical pathway operating. The presence of diazo-coupled products would indicate that the benzene diazonium ion may also be removed by a fast coupling reaction in addition to a redox reaction to form radicals.

It is possible to reduce the ease of radical substitution in the furan system by blocking the 2- and 5-positions. This was observed when tetrachlorobenzenediazonium fluoroborate was reacted with 2,5-dimethyl furan. The product obtained was the pyrazole (45).



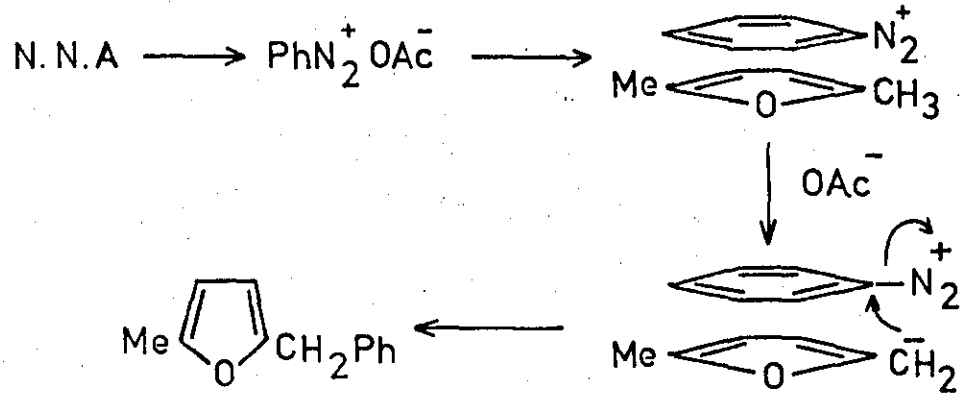
(45)

This is not derived from a radical reaction but probably by a coupling process as depicted in Scheme 24. This formation of pyrazoles has been observed by Eastman and Detert[65] and indeed Cadogan has isolated similar compounds from decompositions of some N-nitrosoacylanilides in 2,5-dimethylfuran[66]



Scheme 24

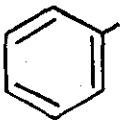
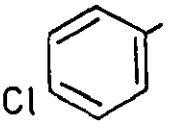
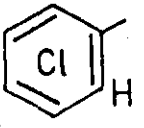
This is in contrast to the proposed charge transfer complex formed by benzenediazonium acetate and 2,5-dimethyl furan leading to 2-methyl-5-benzyl furan[66] Scheme 25.



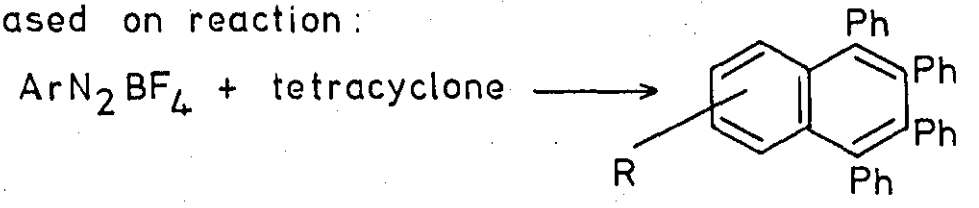
Scheme 25

Although benzenediazonium salts are known to give benzyne adducts with tetracyclone, tetrachlorobenzenediazonium fluoroborate did not react at all, the only products obtained were substitution products from the

p-xylene used in the latter stages of the reaction. These results lead us to conclude that tetrahalogenobenzene diazonium salts do not decompose to arynes and that it is the halogens that are in some way directing the reaction away from aryne formation. This is borne out by a series of experiments with other diazonium salts. The introduction of one chlorine atom in the para position gives a considerably reduced yield of aryne

Diazonium fluoroborate	% Aryne adduct
	40 †
	5
	0

Based on reaction:

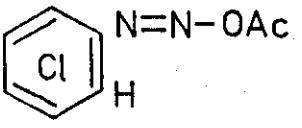


† 70% based on tetracyclone

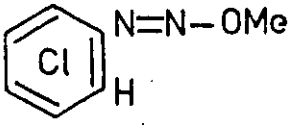
adduct. Similar trends have been observed by Cadogan in decompositions of various N-nitrosoacetanilides.[59a]

In these reactions it can be seen that when aryne formation is suppressed, the products found are those derived from attack at the terminal nitrogen atom i.e. either coupling or radical reactions occur.

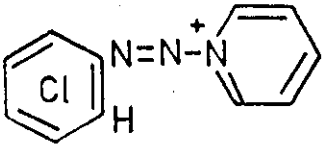
Whatever the main mechanism for the production of free radicals in these reactions initiation must occur by the formation of a covalent diazo species. It is known that diazonium salts with electron withdrawing groups in the ring are more powerful diazo-coupling agents; 2,4,6-trinitrobenzenediazonium ion, for instance couples with mesitylene,[67] normally an unreactive coupling agent. This increased coupling power is brought about by an increase in the electrophilicity of the diazonium function. Thus in the reactions of tetrachlorobenzenediazonium salts, although the lone proton is more acidic, the diazonium function has a considerably increased propensity for diazo coupling. It is thus likely that intermediates of the type (46-48) are formed. The base is thus



(46)

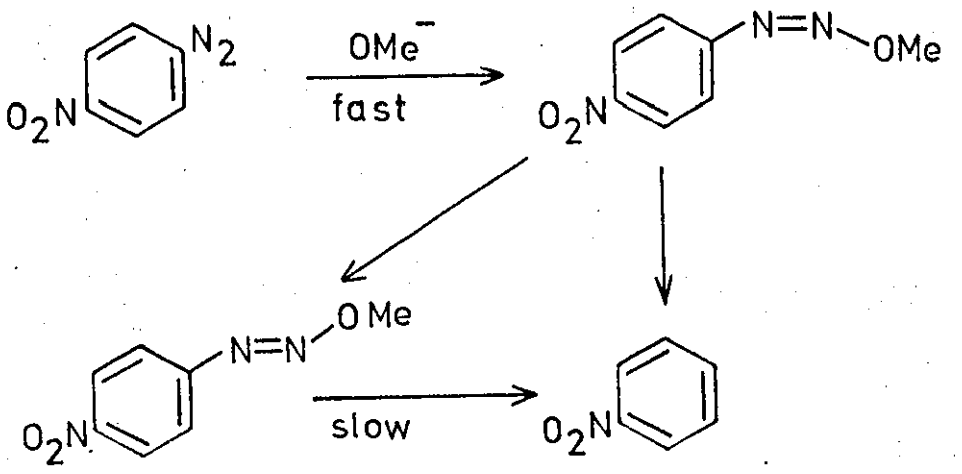


(47)



(48)

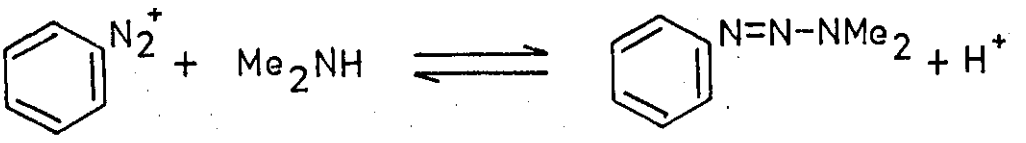
removed from the reaction and the resultant azo linkage has none of the activating effects of the diazonium group. All these intermediates are known to lead to aryl radicals. The diazoacetate forms part of the established breakdown of N-nitrosoacetanilide as previously mentioned. Diazo-ethers have not been examined in great detail and would appear to be in the main unstable species[41] although some stable compounds are known. Bunnett has shown that in the reaction of the p-nitrobenzene-diazonium ion with methoxide ion, the initial step is the fast formation of the cis azo-ether which may either proceed to phenyl radicals or isomerise to the trans azo-ether[68] which was isolated in the reaction (Scheme 26). In a reaction of tetrachlorobenzenediazonium fluoroborate



Scheme 26

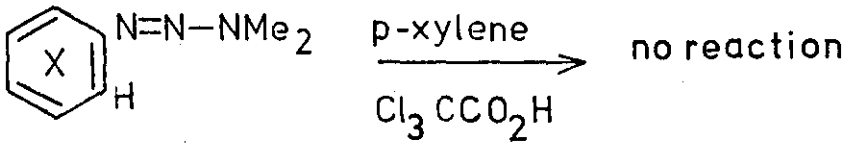
and sodium methoxide in methanol tetrachlorobenzene was obtained indicating the ready formation of radicals,and by implication attack at nitrogen. Abramovitch has demonstrated the capture of the diazonium ion by pyridine to form the intermediate (48).[69]

In addition to the increased rates of diazo coupling produced by electron withdrawing groups, it may also be noticed that the coupled products are thermodynamically more stable. The stability of **p**-nitro-benzenediazo-methylether compared with the parent diazo-ether has already been mentioned. A further example of this is found in the 3,3-dialkyl triazenes, formed by coupling of arenediazonium ion and dimethylamine.



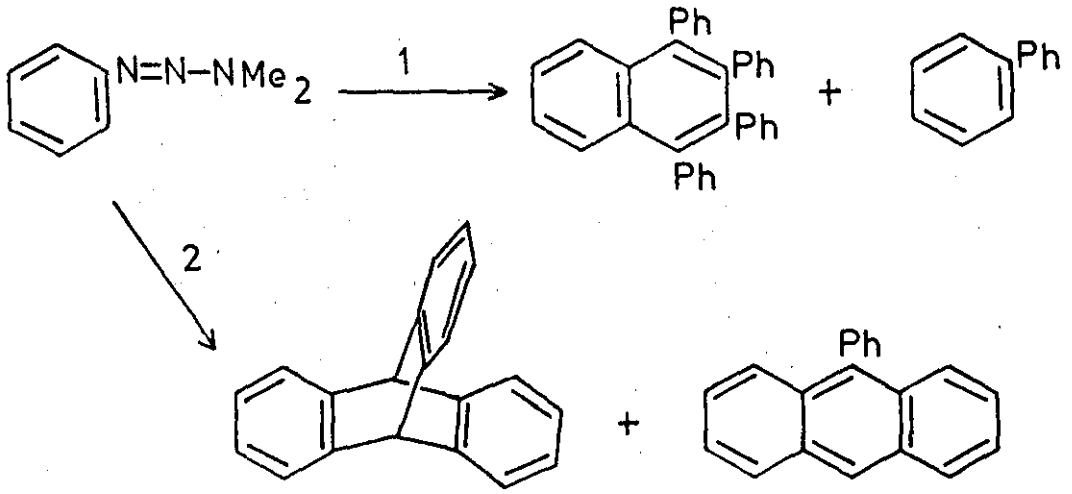
These triazenes may be regarded as stable sources of the diazonium ion since they can be converted in the presence of acid to the original

diazonium ion. Thus Hey discovered that they are potential sources of aryl radicals and showed that upon heating in aromatic solvents in the presence of acetic or hydrochloric acid, biaryls may be formed in much the same way as N-nitrosoacylanilides, or diazonium salts in the Gomberg reaction.[46] In the light of this research it would seem that these triazenes may also be potential aryne precursors. We have prepared the halogenated triazenes (49 X = F, Cl) and found that when they were



(49)

heated under reflux in p-xylene containing trichloroacetic acid they were recovered quantitatively even after many hours of attempted reaction. They thus possess considerable stability. In contrast when the triazene



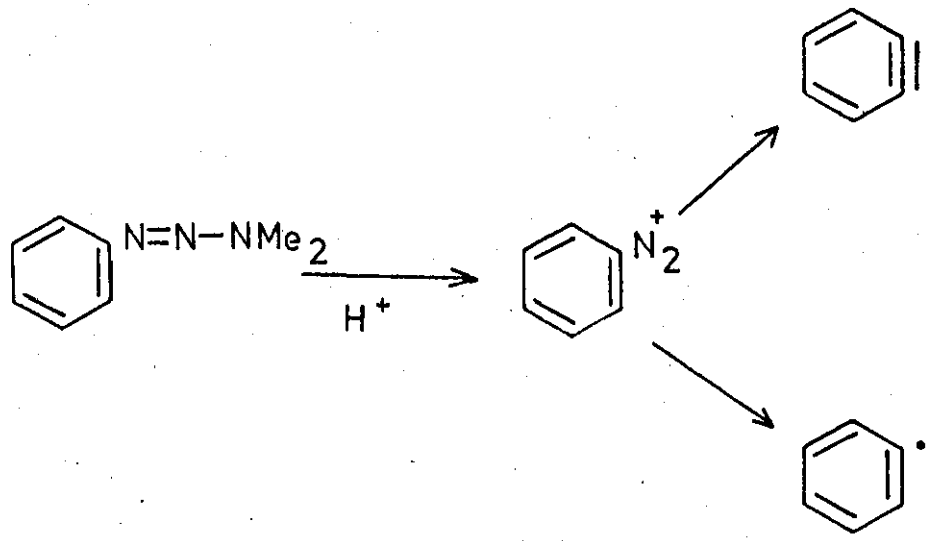
1 tetraphenyl cyclopentadienone

2 anthracene

Scheme 27

(49 X = H) was heated under reflux in benzene, containing tetracyclone,

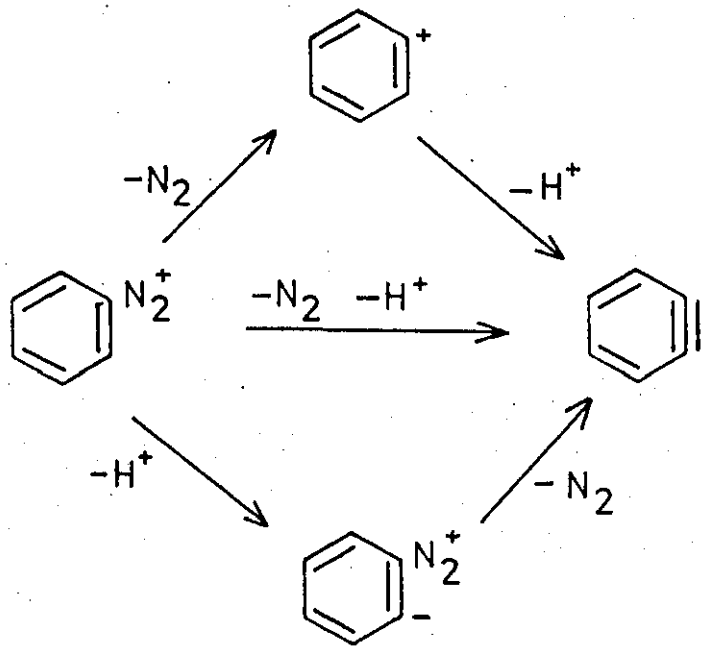
sodium trichloroacetate, and trichloroacetic acid, tetraphenyl naphthalene and biphenyl were obtained, in 35% and 18% yields respectively. Similarly when heated in 1,2-dichloroethane containing anthracene, trichloroacetic acid, and sodium trichloroacetate; triptycene and 9-phenyl anthracene were isolated in 15% and 31% yields (Scheme 27). In this case the triazene is converted to the diazonium ion which then proceeds to both benzyne and phenyl radicals (Scheme 28).



Scheme 28

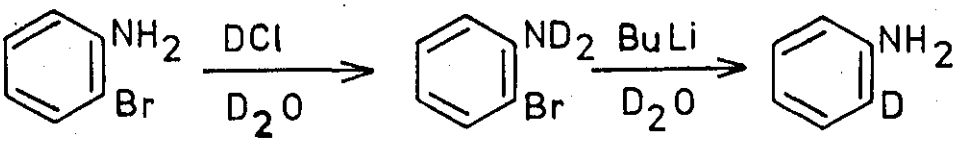
We then decided to determine the exact mode of breakdown of the diazonium ion to benzyne.[64] There are three possibilities, a concerted elimination of $H^{\oplus}$ and N_2, prior loss of N_2 or prior loss of $H^{\oplus}$ (Scheme 29).

All three mechanisms have been suggested in various circumstances but no evidence has ever been presented.[47, 56a, 58] We proposed to approach the problem by preparing a suitably deuteriated aniline and then to examine the deuterium contents of the products. o-Deuterio-aniline



Scheme 29

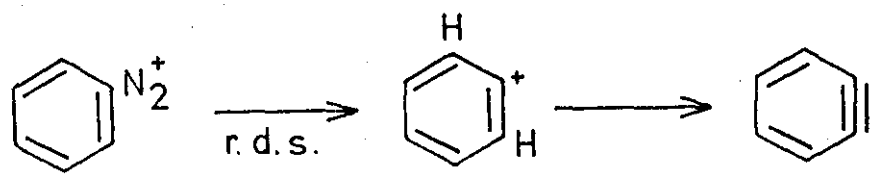
was prepared by the method of Heaney, Sketchley and Mason[70] from o-bromoaniline by lithiation and quenching with D_2O. The o-deuterioaniline



thus prepared contained 81% deuterium, determined as o-deuterioacetanilide. The most suitable system for the experiment was found to be anthracene in 1,2-dichloroethane using potassium acetate as the base to form the aryne. In this way it was found possible to monitor the radical pathway as 9-phenyl anthracene and the aryne pathway as triptycene. The levels of deuterium found in the products are listed in the table.

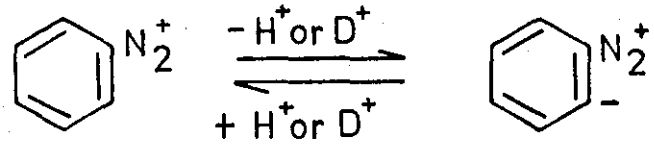
Compound	% deuterium
Acetanilide	81% $^2H_1$
Triptycene	18% $^2H_1$
9-phenylanthracene	36% $^2H_1$, 7% $^2H_2$
Acetanilide	42% $^2H_1$
4-hydroxyazobenzene	41% $^2H_1$

The most important point about these results is the significant amount of 'washing out' of deuterium. This immediately rules out a concerted elimination as the bond breaking would be controlled by a kinetic isotope effect and would have resulted in a retention of considerably more than one half of the deuterium content. If the formation of a phenyl cation was the initial step than the rupture of the C-H bond would not occur in the rate determining step and the deuterium loss would approximate to the statistical value of 50%. The deuterium content of the radical



equal probability
of loss of H^+

product, 9-phenylanthracene, does approach a ca. 50% loss. However the presence of a small amount of the di-deuterated product is hard to rationalise. The situation becomes clear when one examines a primary loss of H^+ to give the betaine (36). If this occurs then deuterium will



(36)

be lost and if there is an equilibrium, will be replaced by hydrogen. Also it is possible to lose hydrogen ion and be replaced by deuterium. This explains the origin of the di-deuterated species found in the reaction. At equilibrium there will be a 'common pool' of deuterium and the deuterium content of the aryne product should be approximately one half of that found in the radical product. This is indeed the case

(18% against 42%) and if the dideuteriated species shows any preference to go to phenyl radicals the agreement is even more striking. It is likely, however, that the fact that the aryne product, triptycene, contains exactly one half D_1 of the 9-phenylanthracene is merely coincidence. If this mechanism is tenable then it is theoretically possible to wash deuterium into the product starting with a non-deuterated sample. It was found however that only ca. 1% could be washed in when unlabelled benzenediazonium chloride was decomposed under the similar conditions in the presence of O-deuterioacetic acid. Why this is so is not clearly understood. An alternative way of establishing that the betaine can be protonated is to vary the acid concentration and examine the effect on the ratios of 9-phenylanthracene to triptycene. An increase in the acid concentration would move the equilibrium from the betaine (36) to the diazonium ion. If benzyne is formed solely from the betaine and radicals from the diazonium ion (initially), then this shift of equilibrium would produce an increase in the yield of radical product. A series of control reactions was performed in which benzenediazonium chloride was decomposed in a solution of anthracene in 1,2-dichloroethane containing potassium acetate and varying amounts of acetic acid. From the table

No.equivs. of HoAc	0	1	2	4
Ratio of 9-phenylanthracene/triptycene	1.3	2.6	2.9	3.8

and the graph (fig. 1) it can be seen that the radical product increases as the acid concentration is raised. Benzyne is thus formed from benzene diazonium ion by an Elcb mechanism. The mechanism of the whole reaction is outlined in Scheme 30.

It follows from the scheme that if hydrogen ion is removed from the

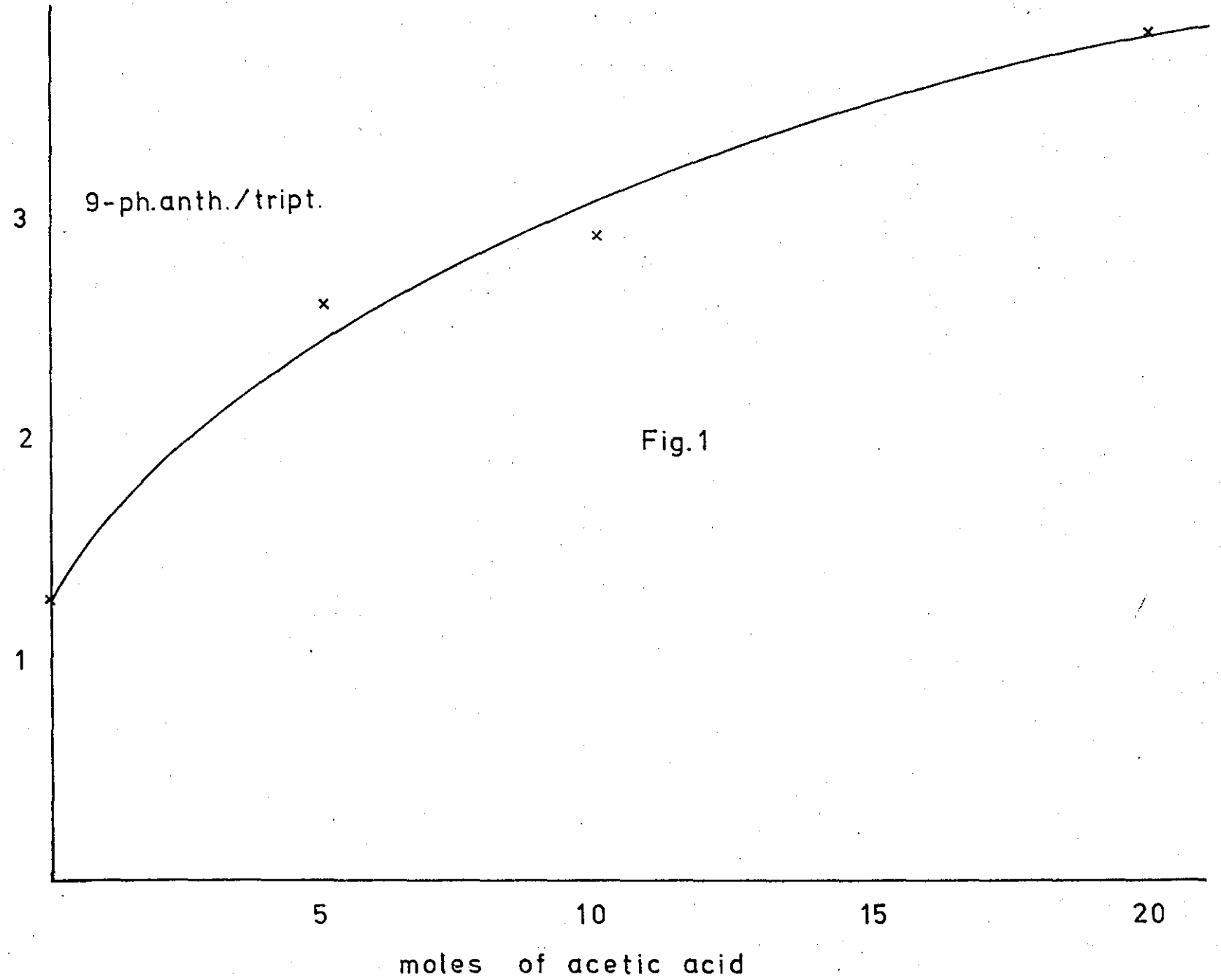
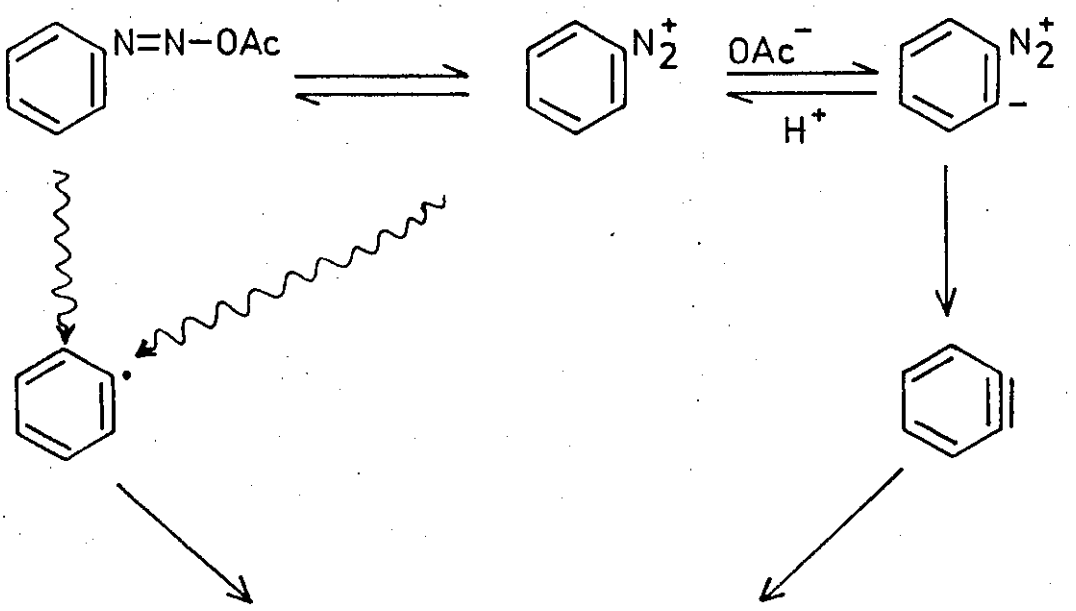


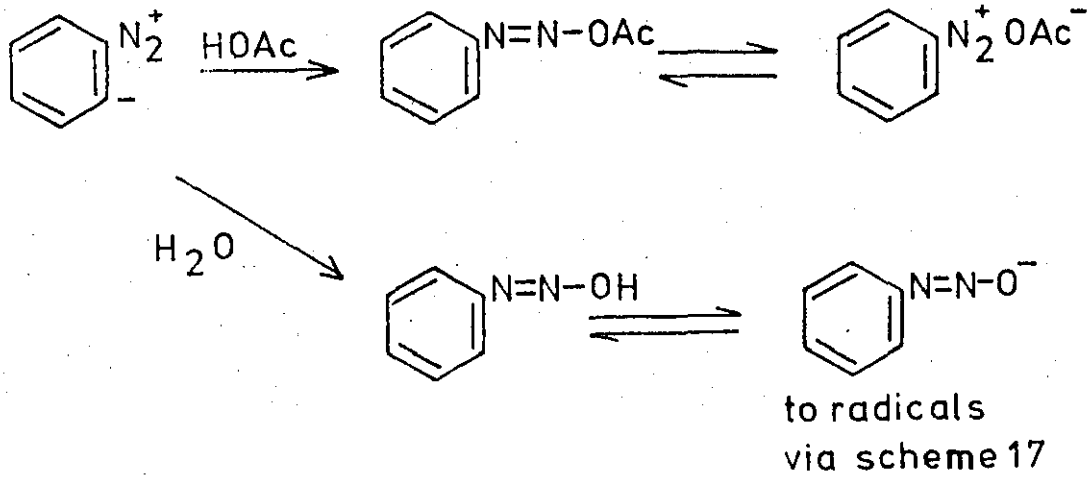
Fig. 1



Scheme 30

system than aryne adducts will be favoured. This may be achieved by using an anion of an insoluble acid as the base such as p-chlorobenzoate. Cadogan has remarked on the increased yields of aryne products obtained when p-chlorobenzoate is used as the counter ion particularly in an aprotic solvent such as carbon tetrachloride.[71]

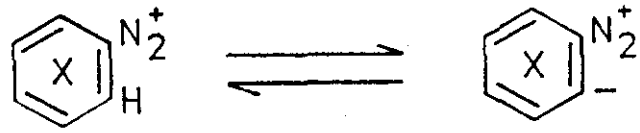
p-Chlorobenzoic acid is found to crystallise from solution when N-nitroso-p-chlorobenzanilides are decomposed. The scheme also offers an explanation for the apparently anomalous effect of water. If the source of H^+ in the reaction is acetic acid then the betaine will be protonated to give the diazo-acetate (Scheme 31). This can still lead to aryne products however, as the diazonium ion is still in equilibrium with the diazoacetate although the equilibrium has been moved in favour of the diazo-acetate. If the source of H^+ is from water however, the betaine can be removed as the diazohydroxide. The difference here is that the diazohydroxide cleaves spontaneously at the O-H bond[41] and not at the N-O bond as in the previous case. Thus the diazonium ion,



Scheme 31

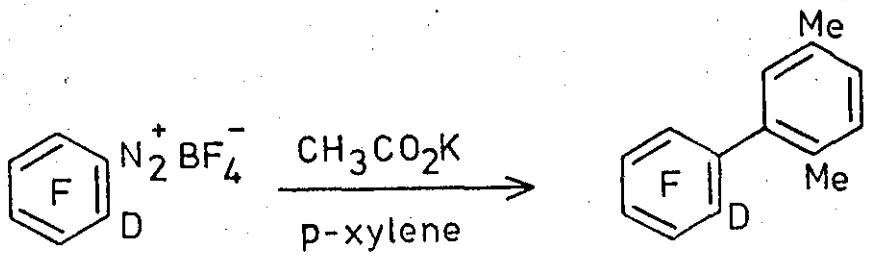
which is the precursor for the betaine, and hence benzyne, cannot be regenerated and further the diazotate anion is a direct precursor for the formation of phenyl radicals. It is thus not surprising that the presence of water inhibits the formation of aryne adducts.

The existence of the betaine, the 'arynoid' originally suggested by Cadogan as an alternative to benzyne in these reactions, provokes one further consideration in the case of the halogenated diazonium salts. It is possible that the comparable intermediate (50) is being formed but does not continue to tetrahalobenzyne. We tested this



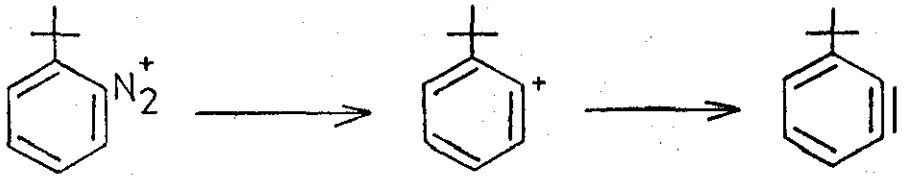
(50)

possibility by decomposing 2-deuterio-tetrafluorobenzenediazonium fluoroborate in p-xylene containing potassium acetate. The biphenyl formed was shown to have the same deuterium content as the starting material. Thus the betaine (50) is not formed and attack by nucleophile on the tetrahalogenobenzenediazonium ion occurs exclusively at nitrogen.



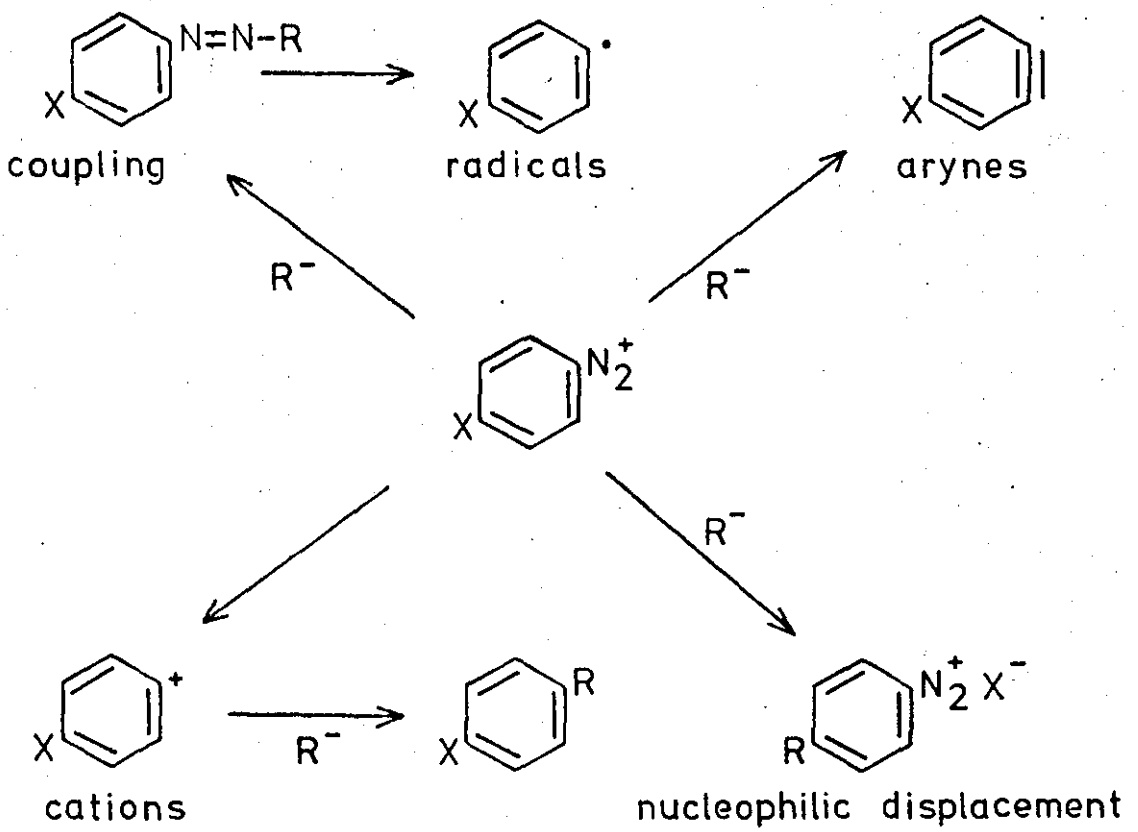
complete retention

The case of the o-t-butylbenzenediazonium ion remains anomalous. The fact that water and furan have no effect on aryne formation argues strongly against the mechanism just described. In this case the aryne is undoubtedly formed by an El mechanism involving the aryl cation. The cation is protected from the usual nucleophilic reactions by the



bulky t-butyl group adjacent to it.[55]

In conclusion it may be said with some justification that in reactions of nucleophiles with diazonium salts the complete range of possibilities is displayed. Reaction at the terminal nitrogen leads to coupling and radical products, reaction at the diazonium ring carbon involves phenyl cations and reaction at any other (usually para) ring carbon leads to nucleophilic displacement. In this context, reaction at the ortho hydrogen to give arynes merely constitutes a newly discovered pathway to add to the already known modes of decomposition of arenediazonium ions.


N=N-R
X
coupling
radicals
arynes
R⁻
R⁻
N₂⁺
R⁻
cations
R⁻
R
N₂⁺ X⁻
nucleophilic displacement

Experimental

General The general details were as described in chapter 1. All diazonium salts were handled with wooden applicator sticks and dried over phosphoric oxide *in vacuo*.

p-Xylene was dried over sodium wire; carbon tetrachloride and 1,2-dichloroethane were distilled and kept over molecular sieve (4A); benzene was dried over sodium wire and distilled from lithium aluminium hydride in reactions with diazonium salts or triazenes.

n-Butyl lithium was obtained in hexane solution and was approximately 2.5M.

Potassium acetate was dried at 100°C before use.

1. Preparation of Tetrafluoroaniline

2,3,4,5-Tetrafluoronitrobenzene (20 gms.) was stirred at 80°C with finely granulated tin (17 gms.) and conc. hydrochloric acid (42 mls.) added dropwise, maintaining the temperature at 80°C by occasional cooling. Stirring was continued for 5 hrs. and the mixture was made alkaline by addition of sodium hydroxide. Steam distillation gave a pale yellow oil which was extracted into ether and dried over anhydrous magnesium sulphate. Removal of solvent gave a yellow oil which on distillation gave 2,3,4,5-tetrafluoroaniline as a colourless liquid (b.p. 72°C @ 20 mms.) which crystallised to colourless needles (9.7 gms. 59% lit. m.p. 27°C.[72])

2. Preparation of Tetrachloroaniline

I. 2,3,4,5-Tetrachloronitrobenzene (13 gms. 0.05 moles) was added to a mixture of iron powder (16 gms) and industrial alcohol (30 mls.) The mixture was warmed until the organic solid was in solution. Conc. hydrochloric acid (2 ml.s) was added and the mixture heated under reflux for 60 mins. The mixture was made alkaline by the addition of aqueous sodium

hydroxide and filtered while still hot. The residue was washed once with warm benzene and the organic phases combined. Removal of solvent gave a brown solid which on recrystallisation from methanol gave tetrachloroaniline (9.4 gms. 81%) m.p. 119-21°C (lit. 118-20°C[73]).

II. Tetrachloroanthranilic acid (1 gm.) was dissolved in conc. sulphuric acid (30 mls.) and maintained at 150°C for 3 hrs. After cooling to room temperature the solution was quenched in ice (200 mls.) and the precipitated solid extracted into ether. Most of the aqueous phase was separated and the remaining interfacial suspension of the amine salt neutralised with sodium hydroxide solution until the liquid phases were clear. The ether layer was dried over magnesium sulphate and solvent removed to give 2,3,4,5-tetrachloroaniline (573 mgs. 68%) m.p. 120-1°C (from methanol).

3. Preparation of 2,3,4,5-tetrabromoaniline

Starting from tetrabromoanthranilic acid (2 gms) and using the method previously described at a temperature of 200°C, 2,3,4,5-tetrabromoaniline was obtained as a tan powder (1.1 gms. 61%). A sample was dissolved in methanol, filtered through activated charcoal and allowed to crystallise. The aniline was thus obtained as a white crystalline solid (m.p. 148°C lit. 123°C,[74] 148-50°C,[75]) M[mass spectrometry] 409

$\nu_{max.}$ 3460, 3360, 1605 cms.$^{-1}$

4. Preparation of 2,3,4,5-Tetrafluorobenzenediazonium fluoroborate

2,3,4,5-Tetrafluoroaniline (10 gms.) was dissolved in a solution of fluoroboric acid (15 mls. 40% soln.) in tetrahydrofuran (100 mls.) The solvent was removed and replaced by diethyl ether (100 mls.) The solution was cooled to 0°C and isoamyl nitrite (9 mls.) added dropwise with stirring. After 20 mins. the voluminous diazonium salt was filtered, washed with ether, and dried in a vacuum desiccator. The final yield was 12.8 gms. (80%).

5. Preparation of 2,3,4,5-tetrachlorobenzenediazonium fluoroborate

2,3,4,5-Tetrachloroaniline (2.3 gms.) was dissolved in tetrahydrofuran (20 mls.) containing fluoroboric acid (4.2 gms.). The solution was cooled to below 5°C and isoamyl nitrite (3 mls.) added dropwise with stirring. After 20 mins. the mixture was diluted with ether and the diazonium salt filtered, washed with ether and dried in a vacuum desiccator to give 2.5 gms. of the diazonium salt.

6. Preparation of 2,3,4,5-tetrabromobenzenediazonium fluoroborate

Using the procedure described above the diazonium salt was obtained as a pale pink solid in 35% yield. The solid did not crystallise until the addition of ether.

7. Reaction of 2,3,4,5-Tetrafluorobenzenediazonium fluoroborate and p-xylene

2,3,4,5-Tetrafluorobenzenediazonium fluoroborate (1.3 gms. 0.005 moles) was stirred at ca. 100°C in a mixture of anhydrous sodium acetate (400 mg. 0.005 moles) and dry p-xylene (100 mls.) for 5 hrs. The reaction mixture was filtered and solvent removed to give a brown residue. Preparative layer chromatography on silica (7 x 1 metre x 20 cm x 0.5 mm:eluent light petroleum) gave 2,3,4,5-tetrafluoro-2',5'-dimethyl biphenyl (17.8 mgms. 15%) m.p. 59-60°C (ethanol)

τ 2.85-3.40 (m, 4H), 7.69 (s, 3H), 7.88 (s, 3H).

$\nu_{max.}$ 3030, 2940, 1630, 1550-1450, 1365, 1200, 1135, 1080 1040, 1020, 920, 815, 800, 710 cms.$^{-1}$

$\lambda_{max.}$ 212 (4.33) nms.

(found: C, 66.4; H, 4.05% M [mass spectrometry] 254

$C_{14}H_{10}F_4$ requires C, 66.2; H, 3.95% M 254)

8. Reaction of 2,3,4,5-Tetrachlorobenzenediazonium fluoroborate and p-xylene

The diazonium salt (2.0 gms.) was stirred in dry p-xylene (100 mls.)

containing anhydrous sodium acetate (600 mgs.) for 16 hrs. and maintained at ca. 100°C. The mixture was filtered and solvent removed to give a brown oil. Preparative layer chromatography on silica (8 x 1 metre x 20 cms. x 0.75 mms:eluent light petroleum) gave two bands.

a) R_f 0.9 gave a white crystalline solid shown by ^1H n.m.r. and gas chromatography to be tetrachlorobenzene (131 mgs. 10%) m.p. 43-6°C (methanol)(lit. m.p. 46-7°C.[76])

b) R_f 0.6 gave a clear oil (1.12 gms. 58%) which crystallised on standing to afford 2,3,4,5-tetrachloro-2',5'-dimethyl biphenyl m.p. 54-5°C (ethanol)

τ 2.65-2.90 (m, 3H), 7.70 (s, 3H), 7.97 (s, 3H)

$\nu_{max.}$ 3030, 2930, 1630, 1600, 1420, 1400, 1350, 1175, 870, 840, 820, 800, 715, 700

$\lambda_{max.}$ 218 (4.42) nms.

(found: C, 52.5; H, 3.15% M [mass spectrometry] 320.

$C_{14}H_{10}Cl_4$ requires C, 52.55; H, 3.15% M 320)

9. Reaction of 2,3,4,5-Tetrabromobenzenediazonium fluoroborate and p-xylene

The diazonium salt (900 mgs.) was stirred in p-xylene (50 mls.) containing anhydrous sodium acetate (200 mgs.) for 48 hrs. and maintained at ca. 100°C. Work up as described for the chlorinated analogue gave :

a) At R_f 0.9 a white solid identified at 1,2,3,4-tetrabromobenzene (81 mgs. 12%) m.p. 59-60°C (ethanol)(lit. m.p. 62-3°C.[75])

τ 2.60 (s).

(found: C, 18.2; H, 0.5% M [mass spectrometry]389.6905

$C_6H_2Br_4$ requires C, 18.3; H, 0.5%. $C_6H_2{}^{79}Br_4$ requires M 389.6892)

b) At R_f 0.7, a clear oil which crystallised on standing to give 2,3,4,5-tetrabromo-2',5'-dimethyl biphenyl (276 mgs. 32%)

m.p. 54-6°C (methanol)

τ 2.53 (s, 1H), 2.85-2.93 (d, 2H), 7.70 (s, 3H), 7.97 (s, 3H).

$\nu_{max.}$ 3020, 2930, 1510, 1390, 1330, 1165, 1030, 875, 810, 760, 700

λ_{max} 218 (4.77) nms.

(found: C, 33.8; H, 2.1% M [mass spectrometry] 498

$C_{14}H_{10}Br_4$ requires C, 33.7; H, 2.0% M 498)

10. Reactions of Tetrachlorobenzenediazonium fluoroborate and p-xylene using pyridine and sodium methoxide

The reactions were performed in exactly the same way as with sodium acetate, using the diazonium salt (1 gm.), p-xylene (150 mls.), and pyridine (0.5 mls.) or sodium methoxide (166 mgs.). The yields of 2,3,4,5-tetrachloro-2',5'-dimethyl biphenyl obtained were 39% and 53% respectively.

11. Aprotic diazotisation of Tetrafluoroaniline in p-xylene

2,3,4,5-Tetrafluoroaniline (830 mgs. 0.005 moles) was dissolved in a mixture of acetic anhydride (1.55 gms. 0.015 moles) and p-xylene (150 mls.) Isoamyl nitrite (1 ml. 0.075 moles) was added and the mixture heated with stirring at ca. 100°C for 24 hrs. Removal of solvents gave a red oil which was placed on a column of alumina (100 gms.). Elution with light petroleum gave a clear oil which crystallised on standing, and was shown by t.l.c. and ^{1}H n.m.r. to be 2,3,4,5-tetrafluoro-2',5'-dimethyl biphenyl (310 mgs. 23%)

12. Aprotic diazotisation of 2,3,4,5-tetrachloroaniline in p-xylene

Using an identical procedure as in the fluoro analogue and the same molar scale, 2,3,4,5-tetrachloro-2',5'-dimethyl biphenyl was obtained (491 mgs. 30%)

13. Aprotic diazotisation of 2,3,4,5-tetrafluoroaniline in furan

2,3,4,5-Tetrafluoroaniline (5.0 gms.) was dissolved in furan (100 mls.) containing acetic anhydride (9.0 gms.). Isoamyl nitrite (6.0 mls.) was added and the solution heated under reflux for 3 hrs. The solvent was removed and the residue chromatographed on silica (500 gms.). Elution with light petroleum gave 2-(2',3',4',5'-tetrafluorophenyl)furan (840 mgs. 13%) m.p. 54-5°C (MeOH).

τ 2.35-2.85 (m, 1H), 2.45-2.55 (d, 1H J_{5-4} = 1.55 Hz), 3.05 - 3.22 (t, 1H $J_{3-4} = J_{3.2F}$ = 3.40 Hz), 3.40-3.55 (q, 1H J_{4-5} = 1.55 Hz, J_{4-3} = 3.4 Hz)

$\nu_{max.}$ 1620, 1550-1450, 1380, 1230, 1080, 1000, 890, 860, 820, 810, 740, 710 cms.$^{-1}$

$\lambda_{max.}$ 215 (4.04), 275 (4.28) nms.

(found: C, 55.35; H, 1.75% M [mass spectrometry] 216

$C_{10}H_4F_4O$ requires C, 55.5; H, 1.85% M 216)

Further elution with benzene gave an orange red oil (972 mgs.) the ^{1}H n.m.r. spectrum of which was similar to the first fraction, presumably an azo-coupled product.

14. Aprotic diazotisation of 2,3,4,5-tetrachloroaniline in furan

By an identical procedure to that described for the fluoro analogue using tetrachloroaniline (2.3 gms.), acetic anhydride (3.1 gms.) and isoamyl nitrite (2 mls.) was obtained:

a) 2,(2',3',4',5'-tetrachlorophenyl)furan (1.1 gms. 39%) m.p. 90-2°C (methanol)

τ 2.23 (s, 1H), 2.50-2.60 (d, 1H J_{5-4} = 1.55 Hz), 2.75-2.95 (d, 1H J_{3-4} = 3.75 Hz.), 3.50-3.65 (q, 1H J_{4-3} = 3.75 Hz, J_{4-5} = 1.55 Hz.)

$\nu_{max.}$ 1490, 1420, 1375, 1330, 1190, 1020, 930, 870, 850, 800, 750 cms.$^{-1}$

$\lambda_{max.}$ 211 (4.29), 293 (4.28) nms.

(found: C, 42.8; H, 1.7% M [mass spectrometry] 282

$C_{10}H_4Cl_4O$ requires C, 42.6; H, 1.45% M 282)

b) A red oil (1.2 g.) which partially solidified on standing. The ^1H n.m.r. spectrum was similar to a) indicating that the compound was possibly the diazo-coupled product.

15. Preparation of 2,5-dimethyl furan

Hexane-2,5-dione (114. gms.), acetic anhydride (112 gms.) and zinc chloride (1 gm.) were warmed until a vigorous reaction ensued. When the reaction had subsided the mixture was heated under reflux for 3 hrs., and neutralised with dilute alkali. The solution was then steam distilled and the organic layer separated and dried over magnesium sulphate. The crude product was distilled and a middle fraction b.p. 94-5°C taken as pure 2,5-dimethyl furan (48.7 gms. 51%)(lit. b.p. 93-4°C.[77])

16. Reaction of 2,3,4-tetrachlorobenzenediazonium fluoroborate and 2,5-dimethyl furan

2,3,4,5-Tetrachlorobenzenediazonium fluoroborate (1.7 gms.) was added to a stirred suspension of sodium methoxide (280 mgs.) in carbon tetrachloride (50 mls.) containing 2,5-dimethyl furan and maintained at a temperature of 50°C for 60 mins. Removal of solvent gave a black residue which was slurried in benzene and placed on a column of silica (200 gms.). Elution with 20% diethyl ether-benzene gave, after a small quantity of brown 'gummy' material, 1(2',3',4',5'-tetrachlorophenyl)--3-acetyl-5-methyl pyrazole (615 mgs. 35%) m.p. 162-3°C (ethanol)

τ 2.45 (s, 1H), 3.28 (s, 1H), 7.45 (s, 3H), 7.83 (s, 3H)

$\nu_{max.}$ 3160, 1700, 1410, 1375, 1350, 1330, 1215, 1150, 940, 860, 815 cms.$^{-1}$

$\lambda_{max.}$ 272 (3.82) nms.

(found: C, 42.65; H, 2.5; N, 8.25% M [mass spectrometry] 338

$C_{12}H_8Cl_4N_2O$ requires C, 42.6; H, 2.35; N, 8.3% M 338)

Accurate mass measurement of molecular ion gave M 335.9419 and M-15, 320.9173:

$C_{12}H_8{}^{35}Cl_4N_2O$ requires M, 335.9391 and M-15, 320.9156.

17. Reaction of p-chlorobenzenediazonium fluoroborate and tetraphenylcyclopentadienone

p-Chlorobenzenediazonium fluoroborate (2.3 gms.) was stirred in a suspension of sodium acetate (1.0 gms.) in carbon tetrachloride containing tetraphenyl cyclopentadienone (4.0 gms.) and maintained at reflux for 6 hrs. The solvent was removed and the residue placed on a column of alumina (250 gms.). Elution with 30% benzene-light petroleum gave 1,2,3,4-tetraphenyl-6-chloronaphthalene (215 mgs. 5%) m.p. 230-2°C (lit.m.p. 229-30°C.[59a]) Further elution with benzene, gave unreacted tetraphenyl cyclopentadienone (2.6 gms).

18. Reaction of 2,3,4,5-tetrachlorobenzenediazonium fluoroborate and tetraphenylcyclopentadienone

The diazonium salt (1.0 gms.) was heated under reflux with sodium methoxide (166 mgs.) in a solution of tetraphenyl cyclopentadienone (1.92 gms.) in carbon tetrachloride (100 mls.) for 16 hrs. The solvent was removed and replaced with a solution of maleic anhydride (0.5 gms.) in p-xylene (100 mls.). The mixture was heated under reflux for 4 hrs. by which time the purple colour of the excess tetracyclone had disappeared. Sodium hydroxide solution (0.5 gms. in 50 mls. H_2O) was then added and the two-phase system heated under reflux for 3 hrs. The organic layer was separated and dried over magnesium sulphate and solvent removed to give a brown residue. ^1H n.m.r. of this material showed it to be mainly material derived from attack on the p-xylene as described previously.

19. Reaction of 2,3,4,5-Tetrachlorobenzenediazonium fluoroborate and sodium methoxide

Sodium (200 mgs.) was dissolved in methanol (50 mls.) and the solution cooled to 0°C. The diazonium salt was added and stirred at 0°C for 4 hrs. and then overnight at room temperature. The solution was filtered and solvent removed to give a brown crystalline solid (422 mgs.) shown by ^{1}H n.m.r. and recrystallisation from ethanol to be 1,2,3,4-tetrachlorobenzene (65%) m.p. 45° (lit. 46-7°C.[76])

20. Preparation of 1-phenyl-3,3-dimethyl triazene

Aniline (20 gms.) was dissolved in a solution of fluoroboric acid (60 gms. 40% soln.) in tetrahydrofuran (200 mls.) and cooled to 0°C. Isoamyl nitrite (25 mls.) was added dropwise with stirring and maintained below 10°C for 30 mins. An equal volume of ether was added, the diazonium salt filtered, and added to an ice-cold solution of dimethylamine hydrochloride in sodium carbonate (500 mls. 10% aqueous soln.). After stirring at room temperature for 60 mins. the solution was extracted with ether and the organic phase dried over magnesium sulphate. Removal of solvent gave a yellow oil which on distillation gave 1-phenyl-3,3-dimethyl triazene (24 gms. 75%) b.p. 73-5°C at 1.5 mms. (lit. b.p. 125-127°C at 19 m.m.[46]).

21. Preparation of 1(2',3',4',5'-tetrafluorophenyl)-3,3-dimethyl triazene

2,3,4,5-Tetrafluoroaniline (10.0 gms.) was dissolved in a mixture of fluoroboric acid (15 gms. 40% soln.) and tetrahydrofuran (50 mls.). The solution was allowed to stand for 30 mins. and the solvents removed and replaced with ether. The ether solution was cooled to 0°C and isoamyl nitrite (9 mls.) added dropwise maintaining the temperature below 5°C. The solution was stirred at this temperature for a further 30 mins. and the suspension of diazonium salt thus formed cooled to -20°C. Anhydrous

dimethylamine (10 mls.) was added and the solution stirred at 0°C for 30 mins. and then overnight at room temperature. The solvent was removed and the residual oil fractionally distilled to give isoamyl alcohol (b.p. 70°C at 15 mms.) and 1(2',3',4',5'-tetrafluorophenyl)--3,3-dimethyltriazene obtained as a yellow oil (b.p. 78-80°C at 1.5 mms.) solidifying in the receiver (5.5 gms. 42%) m.p. 51-2°C (from ethanol).

τ 2.70-3.25 (m, 1H), 6.48 (s, 3H), 6.80 (s, 3H).

$\nu_{max.}$ 3090, 2940, 1640, 1540-1440, 1410, 1380, 1350, 1305 1270, 1190, 1180, 1050, 960, 820, 710, 690 cms.$^{-1}$

$\lambda_{max.}$ 215 (4.00), 285 (4.02), 315 (4.12) nms,

(found: C, 43.4; H, 3.3; 18.85% M [mass spectrometry] 221

$C_8H_7{}_4N_3$ requires C, 43.6; H, 3.2; N, 19.1% M 221).

22. Preparation of 1(2',3',4',5'-tetrachlorophenyl)-3,3-dimethyltriazene.

2,3,4,5-Tetrachlorobenzenediazonium fluoroborate (5.0 gms.) was suspended in chloroform (100 mls.) and cooled to 0°C. Anhydrous dimethylamine (30 mls.) was added, and the resultant clear solution allowed to stand at room temperature for 15 mins. and then washed with water. The organic layer was dried over magnesium sulphate and solvent removed to give 1-(2',3',4',5'-tetrachlorophenyl)-3,3-dimethyltriazene (4.3 gms. 100%) m.p. 105-6°C (from ethanol)

τ 2.60 (s, 1H), 6.45 (s, 3H), 6.80 (s, 3H).

$\nu_{max.}$ 2930, 1560, 1480, 1415, 1350, 1250, 1160, 1110, 1090, 860, 830, 760, 650 cms.$^{-1}$

$\lambda_{max.}$ 209 (4.27), 244 (4.21), 304 (4.27), 335 (4.16) nms.

(found: C, 33.5; H, 2.2; N, 14.7% M [mass spectrometry] 287.

$C_8H_7Cl_4N_3$ requires C, 33.5; H, 2.4; N, 14.6% M 287).

23. Attempted decomposition of 1(2',3',4',5'-tetrahalophenyl)-3,3--dimethyltriazenes in p-xylene

Anhydrous potassium acetate (2.0 gms. 20 m.moles) was suspended in

a solution of trichloroacetic acid (1.4 gms. 10 m.moles), and 1(2',3',4',5'-tetrahalophenyl)-3,3-dimethyltriazene (X = Cl, 5 m.mole) in p-xylene (100 mls.) and stirred vigorously at 80°C for 16 hrs. and at reflux for a further 2 days. The solution was filtered and the starting material recovered unchanged.

The triazenes were also recovered unchanged when solutions in p-xylene were photolysed for 16 hrs.

24. Decomposition of 1-phenyl-3,3-dimethyltriazene in the presence of tetraphenyl cyclopentadienone

1-Phenyl-3,3-dimethyltriazene (0.75 gms. 5 m.moles) was dissolved in dry benzene (50 mls.) containing tetraphenyl cyclopentadienone (2.0 gms. 5 m.moles). Anhydrous sodium trichloroacetate (1.7 gms. 10 m.moles) was added and the solution brought to reflux with vigorous stirring. Trichloroacetic acid* (1.5 gms. 10 m.moles) in dry benzene (10 mls.) was added dropwise over 20 mins. and the mixture maintained at reflux for 16 hrs. The suspension was filtered and solvent removed from the filtrate to give a black residue which was placed on a column of alumina (300 gms.). Elution with light petroleum gave white solid shown by i.r. spectroscopy to be biphenyl (142 mgs. 18%) m.p. 69-70°C (lit. m.p. 71°C[34]).

Elution with 30% benzene-light petroleum gave a white solid shown by i.r. spectroscopy to be 1,2,3,4-tetraphenyl naphthalene (719 mgs. 35%) m.p. 204-5°C lit. m.p. 204°C.[78]

*In contrast to Hey's report we found that decomposition with acetic acid was slow but proceeded readily in the presence of trichloroacetic acid.

25. Decomposition of 1-phenyl-3,3-dimethyltriazene in the presence of anthracene

1-Phenyl-3,3-dimethyltriazene (750 mgs. 5 m.moles) was dissolved in anhydrous 1,2-dichloroethane containing anthracene (900 mgs. 5 m.moles)

and sodium trichloroacetate (1.7 gms. 10 m.moles). The mixture was warmed to ca. 60°C and trichloroacetic acid (1.5 gms. 10 m.moles) in 1,2-dichloroethane (10 mls.) added dropwise with stirring. The mixture was then heated under reflux with vigorous stirring for 16 hrs. The reaction mixture was filtered and solvent removed to give a brown residue which was placed on a column of silica (300 gms.) Elution with light petroleum gave unreacted anthracene (429 mgs. 34%). Elution with 20% benzene-light petroleum gave 9-phenyl anthracene (387 mgs. 31%) m.p. 148-52°C (lit. 154°C[79]) closely followed by triptycene 192 mgs. 15%) i.r. spectrum identical with authentic sample.

26. Preparation of 2-deuteriobenzenediazonium chloride

o-Bromoaniline (16.0 gms.) was dissolved in dry ether (50 mls.) and stirred vigorously with deuterium oxide (2 mls.) and deuterium chloride (2 drops) for 12 hrs. The aqueous layer was removed with a pipette and replaced with a fresh charge of deuterium oxide. After a further 12 hrs. the treatment was repeated once more. ^{1}H n.m.r. showed that virtually all the amino-protons had been exchanged. The o-bromo-N,N-dideuterioaniline thus obtained was redissolved in dry ether (300 mls.) and n-butyl lithium (120 mls. 3 equivs.) added dropwise with stirring. After 16 hrs. the yellow lithium salt had formed and was neutralised by the dropwise addition of deuterium oxide (16 mls.) After a further 16 hrs. at room temperature the lithium deuteroxide was dissolved by the addition of water. The ether layer was separated and dried over magnesium sulphate. Removal of solvent and distillation of the residue gave 3 fractions

a) b.p. 110°C n-butyl bromide

b) b.p. 110°C-180°C a mixture of n-butyl bromide and o-deuterioaniline

c) b.p. 184-7°C o-deuterioaniline.

A sample of the aniline was converted to acetanilide by warming for 60 mins. in a mixture of acetic acid and acetic anhydride (50:50) to 70°C following by quenching in water and recrystallisation of the resulting acetanilide from benzene, the acetanilide showed an incorporation of 81% d_1.

The o-deuterioaniline was dissolved in diethyl ether and hydrogen chloride bubbled through the solution until the hydrochloride had completely precipitated (60 mins.). The suspension was cooled to 0°C and isoamyl nitrite added dropwise and stirring continued for 30 mins. The diazonium chloride was filtered, washed with ether and dried *in vacuo* over phosphoric oxide.

In a separate experiment, a sample of o-deuterioaniline (d_1 41.6, d_2 10.6, d_3 1.3% determined as acetanilide) was diazotised and coupled with phenol. The resulting 4-hydroxyazobenzene showed a deuterium content of d_1 40.8, d_2 12.6, and d_3 1.1%.

27. Reaction of o-deuteriobenzenediazonium chloride and anthracene

o-Deuteriobenzenediazonium chloride (1 gm.) was added in portions to a stirred solution of anthracene (0.9 gms. 5 m.moles), anhydrous potassium acetate (1.8 gms.) and acetic acid (*ca.* 100 mgs.) in 1,2-dichloroethane (50 mls.) maintained at 70°C. The mixture was then heated under reflux for 16 hrs., filtered, and solvent removed. The products were isolated by preparative layer chromatography on silica (double elution in light petroleum). The triptycene obtained showed a deuterium content of 18% d_1. The 9-phenylanthracene showed a deuterium content of d_1 36%, d_2 7%.

28. Effect of acetic acid concentration on the decomposition of benzenediazonium chloride

Four reactions were performed using benzenediazonium chloride (1.4 gms.), anthracene (900 mgs.), potassium acetate (1.9 gms.) and acetic acid

(0-20 m.moles) using the same conditions as described in experiment 27. The ratio of 9-phenylanthracene to triptycene was estimated by gas chromatography using column A at 200°C and N_2 pressure of 10 p.s.i. The recorder was run at a slow speed to produce sharp peaks and the ratio of the products was taken as the ratio of their respective peak heights.

Sample	Acetic Acid (m.moles)	Pk Height 9-phenylanthracene	Pk Height triptycene	Ratio	Mean
1	0	13.1	10.7	**1.22**	1.3
		13.7	10.7	**1.28**	
		13.5	10.9	**1.24**	
2	5	11.3	4.1	2.75	2.6
		19.6	7.5	2.62	
		20.2	8.7	2.33	
3	10	16.8	6.0	2.80	2.9
		13.9	4.6	3.00	
		14.9	5.4	2.76	
4	20	18.0	5.3	3.40	3.8
		22.2	5.2	4.25	
		19.0	5.2	3.70	

29. Preparation of 2-deuterio-3,4,5,6-tetrafluoroaniline

A solution of 2,3,4,5-tetrafluoroaniline (8.25 gms.) in tetrahydrofuran (30 mls.) was added slowly to a stirred solution of n-butyl lithium in hexane (60 mls.) maintained at -70°C. Stirring was continued at this temperature for 4 hrs. and the solution then quenched by the

addition of deuterium oxide (6 mls.) maintaining the temperature at -70°C. The mixture was then allowed to warm to room temperature and the solvent removed. The residue was dissolved in diethyl ether (200 mls.) and washed with an equal volume of dilute hydrochloric acid. The ether layer was washed once with water and dried over magnesium sulphate. Removal of solvent followed by distillation of the residue gave 2-deuterio-3,4,5,6-tetrafluoroaniline (5.5 gms.) A sample was converted to the acetyl derivative and showed a deuterium content of 31%.

30. Reaction of 2-deuterio-3,4,5,6-tetrafluorobenzene diazonium fluoroborate and p-xylene

2-Deuterio-3,4,5,6-tetrafluoroaniline was converted to the diazonium fluoroborate by the same procedure as in experiment 4 on one quarter of that scale. The decomposition was carried out in p-xylene according to the details described in experiment 7. The biaryl obtained showed a deuterium content of 30%.

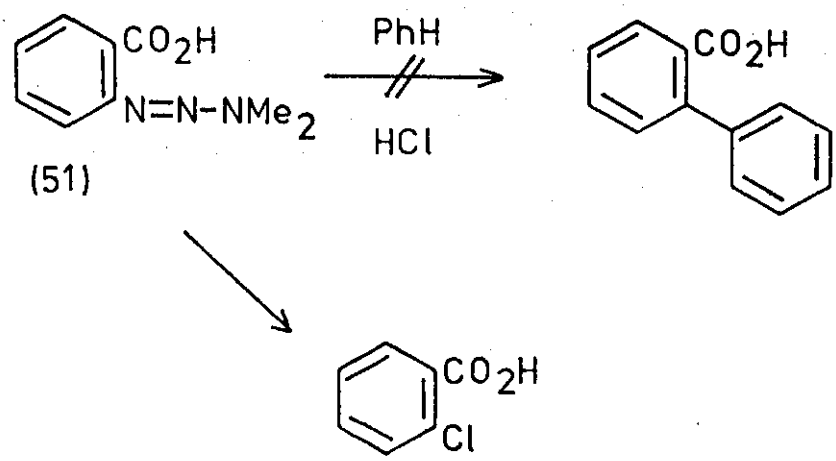
CHAPTER 3

THE FORMATION OF ARYNES FROM

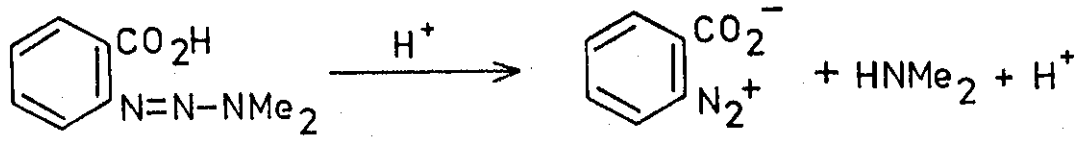
o-CARBOXY-3,3-DIMETHYL TRIAZENES

Introduction

In 1943 Elks and Hey,[46] in examining the scope of the arylation reaction with triazenes noted that the o-carboxy derivative (51) did not arylate benzene as anticipated but gave only o-chlorobenzoic acid. No explanation was advanced for this, but it is of interest to note

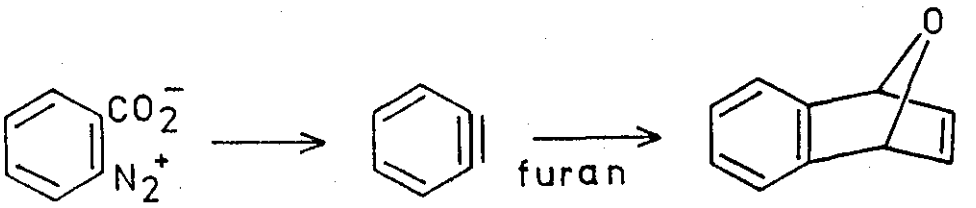


that the triazene (51) is potentially convertible in acid solution to benzenediazonium-2-carboxylate, a well established precursor of benzyne. Thus Gompper[80] and Simamura[81] have recently shown that



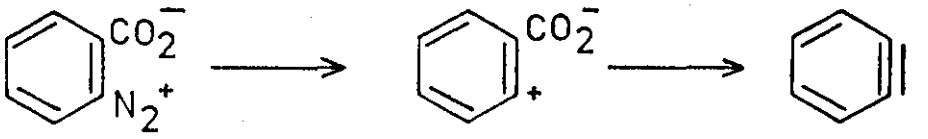
benzyne adducts may be obtained if the triazene (51) is heated to ca. 150°C in the presence of anthracene or tetraphenylcyclopentadienone. Carbon dioxide, nitrogen, and dimethylamine are liberated, evidenced in one case by the formation of N,N-dimethyl aniline. The mechanism of decomposition has not previously been examined but may well be expected to involve benzenediazonium-2-carboxylate.

Benzenediazonium-2-carboxylate was first isolated by Hantzsch[82] who noted its decomposition in aqueous solution to salicylic acid, but does not appear again in the literature until 1960 when Miller and Stiles[3a] made the remarkable discovery that in aprotic solvents benzyne was formed by elimination of carbon dioxide and nitrogen (Scheme 32). The considerable synthetic utility of this reaction



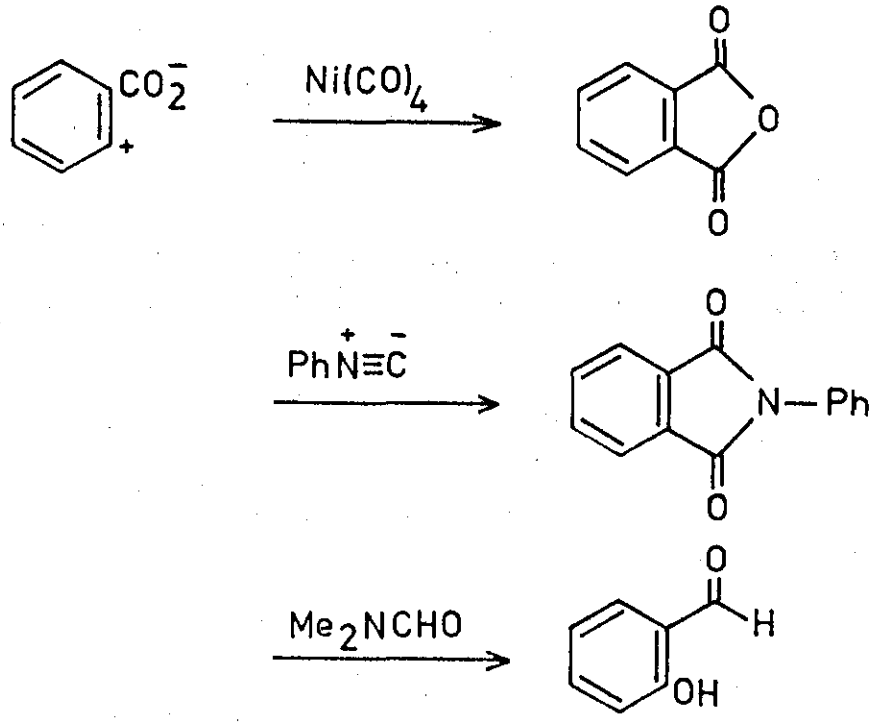
Scheme 32

stimulated interest in the mechanism of decomposition. Friedman showed that in nucleophilic solvents such as butanol or polar solvents like benzene the ratio of nitrogen to carbon dioxide evolved was greater than unity. This, taken with Hantzsch's original observation of the formation of salicylic acid, was interpreted as evidence for a

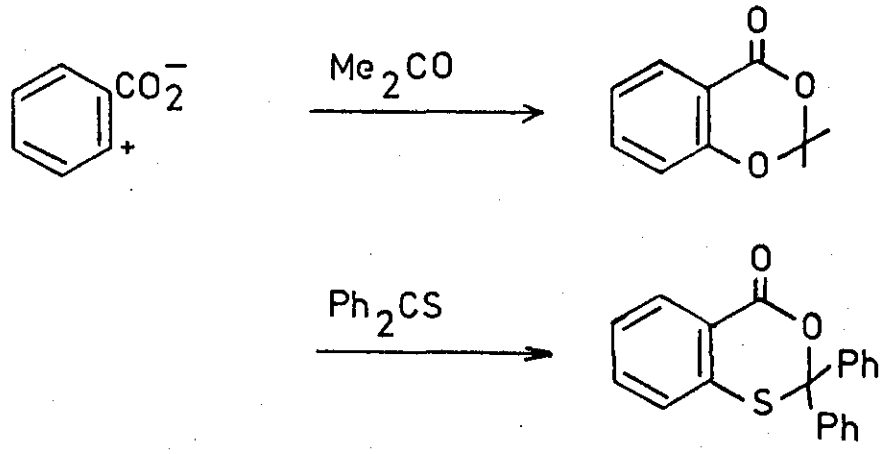


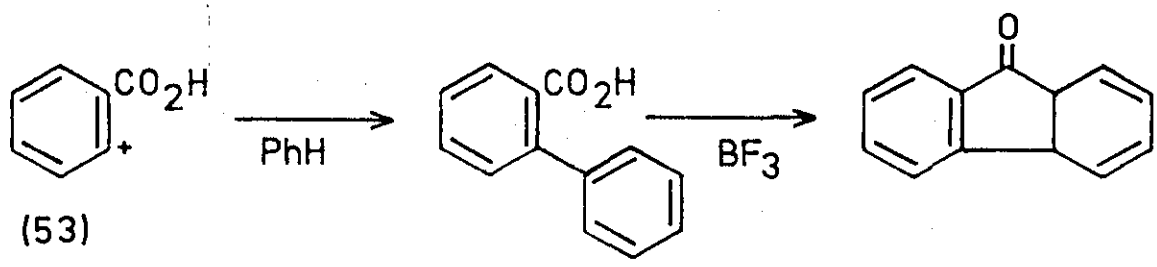
(52)

stepwise decomposition. Thus in aqueous solution the intermediate betaine (52) is trapped by water to form salicylic acid before it can decompose to benzyne. In the last ten years further reports have come forward indicating the existence of this intermediate. Phenyl isocyanide,[83] nickel carbonyl,[83] and dimethyl formamide[84] have all been reported to intercept (52). Similarly reactions in solvents



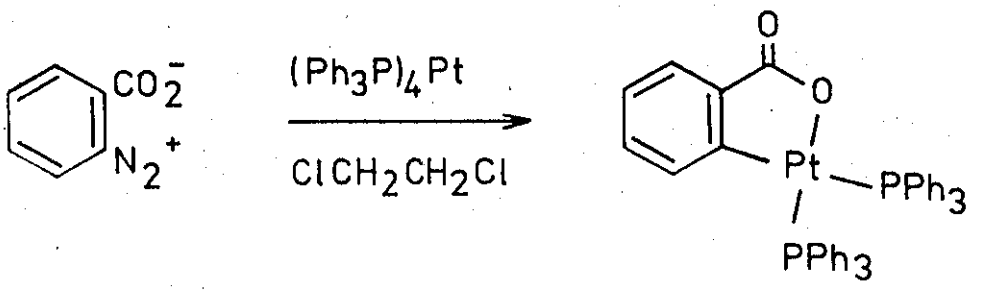
such as acetone[85] or thiobenzophenone[86] also give products which can be rationalised as involving this cation. The formation of fluorenones has also been shown to involve the protonated cation (53).[87] Further





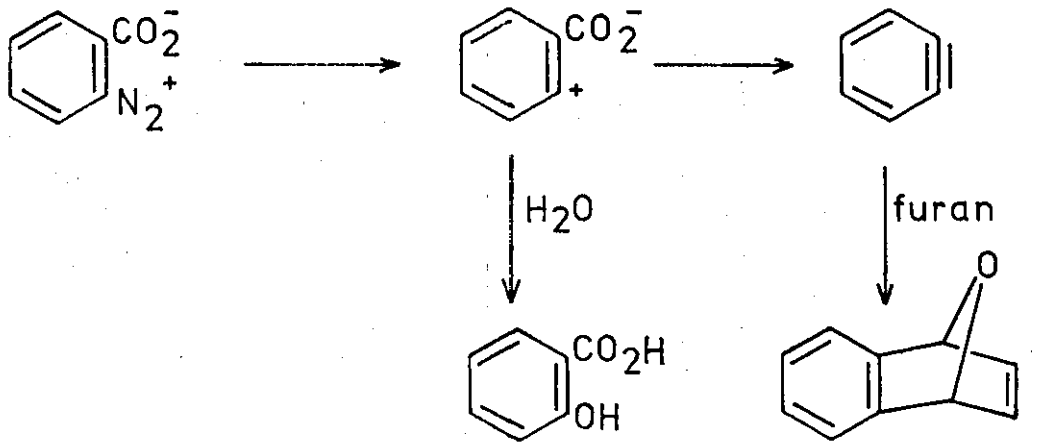
(53)

evidence for the existence of (52) has come from Rees,[88] who in attempting to prepare a benzyne-transition metal complex obtained only the compound (54). However, by far the most definitive and



(54)

quoted work on the decomposition of benzenediazonium-2-carboxylate to benzyne has been done by Gompper.[89] His approach was to allow benzenediazonium-2-carboxylate to decompose in acetonitrile containing mixtures of water and furan. If scheme 33 is operating then as the



(55)

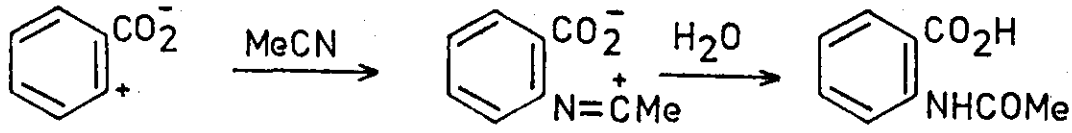
Scheme 33

water concentration is increased the yield of salicylic acid will increase and the yield of benzyne, as the furan adduct (55) will correspondingly decrease. Furthermore it can be shown that under these conditions the yield ratio of the furan adduct to salicylic acid is inversely proportional to the water concentration and hence that the

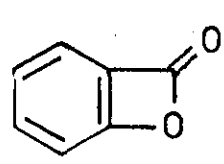
product of the yield ratio and water concentration is constant i.e.

$$\frac{(\text{Yield of furan adduct})}{(\text{Yield of salicylic acid})}\,[H_2O] = K_A$$

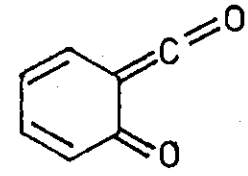
Gompper's results showed that this was indeed the case. He also showed that it was unlikely that the intermediate cation (52) existed in the till then supposed form. By using methanol instead of water it was found that the major product was methyl salicylate and not o-methoxy benzoic acid as anticipated. More important was the absence of any product derived from the reaction of the excess acetonitrile with the cation (52). Meerwein's earlier results[90] predicted that N-acetyl anthranilic acid would be formed. These results prompted Gompper to propose that the intermediate present



was either (56) or (57). As his results pointed to a common intermediate

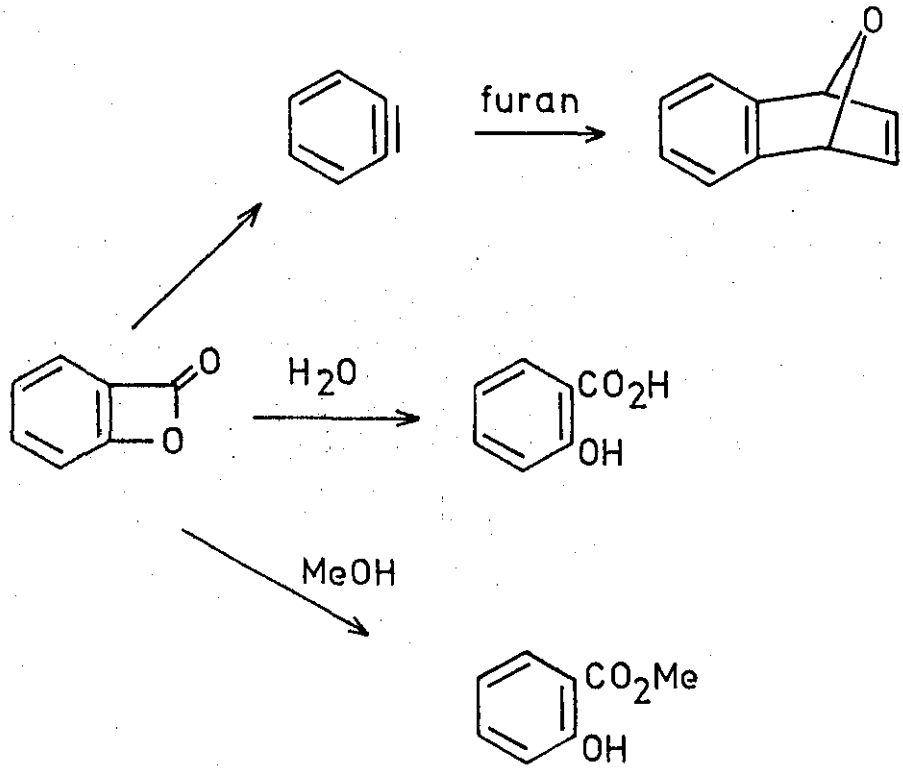


(56)



(57)

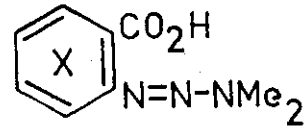
for all the products it was considered that the β-lactone (56) was involved (Scheme 34). Thus the formation of benzyne from benzene-diazonium-2-carboxylate was shown to be a stepwise reaction involving formation of the β-lactone (56) followed by elimination of carbon dioxide.



Scheme 34

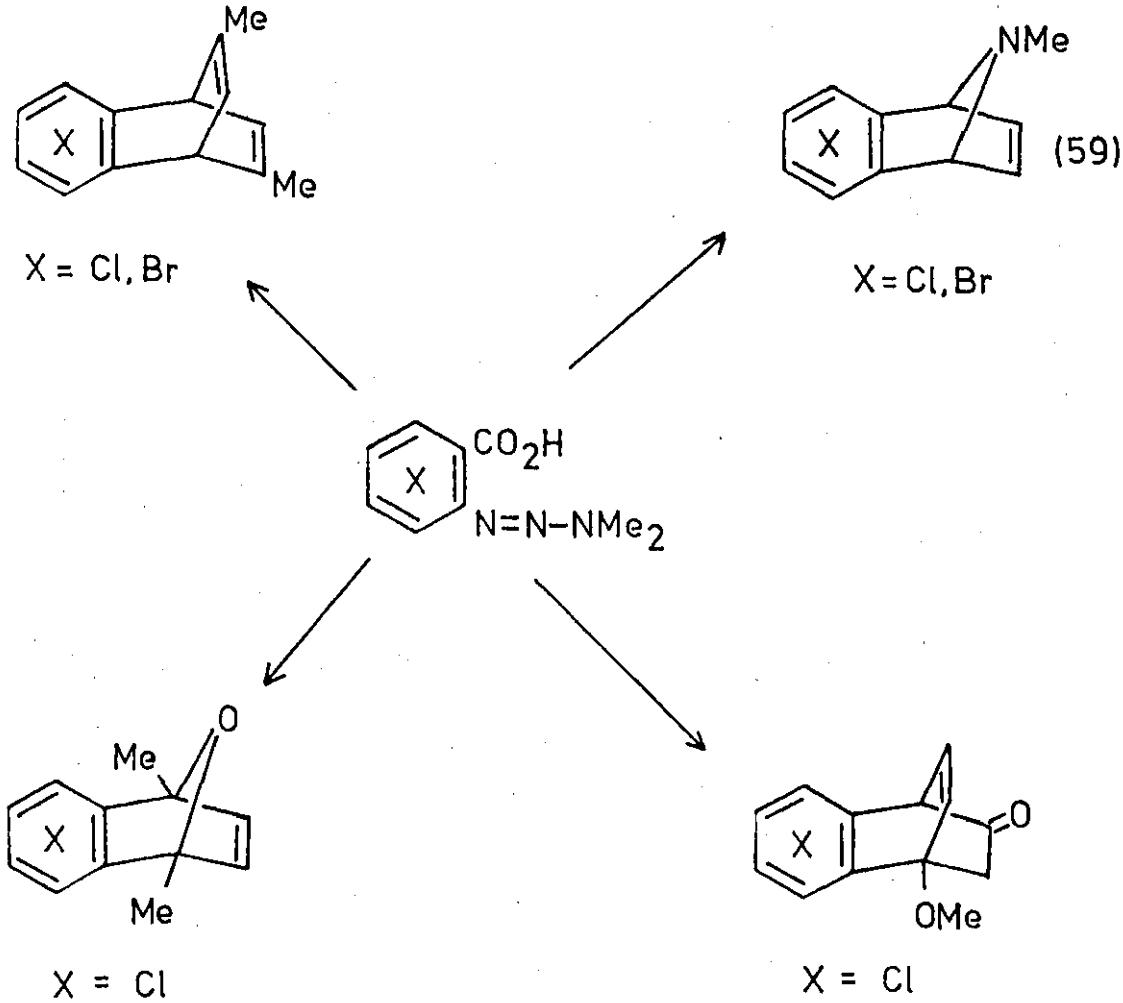
Discussion

Our interest in the decomposition of triazenes and potentially stable sources of arynes led us to examine the decomposition of the o-carboxy derivatives (58, X = H, Cl, Br). Reports have recently appeared that the triazene (58, X = H) yields benzyne upon thermolysis



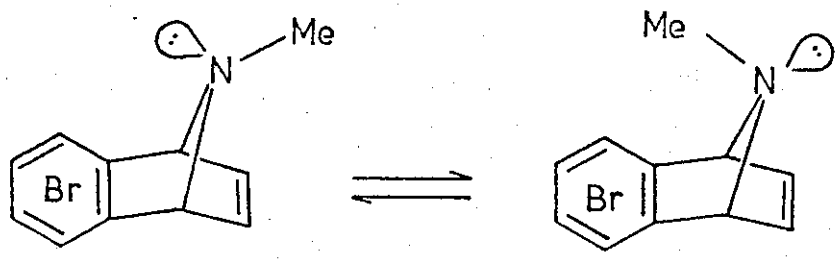
(58)

in the presence of anthracene[80] and tetraphenylcyclopentadienone.[81] We have prepared the triazenes (X = Cl,Br) and have confirmed that tetrahalobenzyne is formed upon thermolysis. A variety of cyclo adducts has been obtained by using either tetrachloroethane or tetrachloroethylene as solvent (scheme 35).



Scheme 35

Particularly interesting are the adducts obtained with N-methyl pyrrole. These adducts (59) are not readily available from the anthranilic acid as considerable decomposition of the pyrrole system takes place. Presumably the triazenes are not so acidic and leave the pyrrole system intact for sufficient time to allow the aryne to form. Interest in these adducts has been shown recently in connection with the formation of isoindoles[91] and also with studies of nitrogen inversion.[92] As with other members of the series the adduct (59, X = Br) shows rapid inversion of

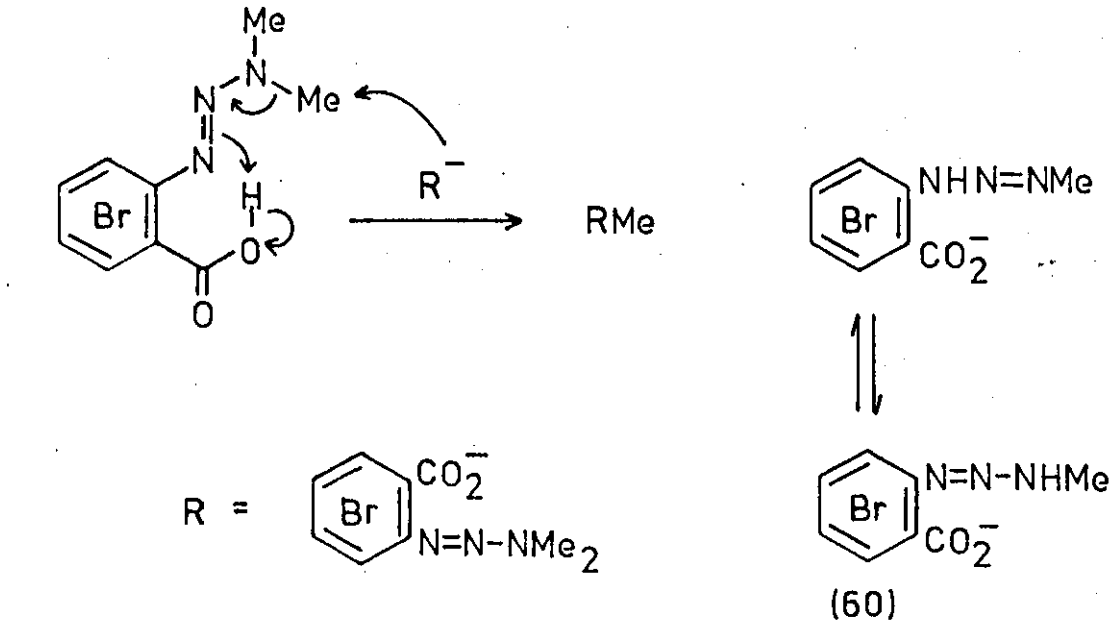


(59a) (59b)

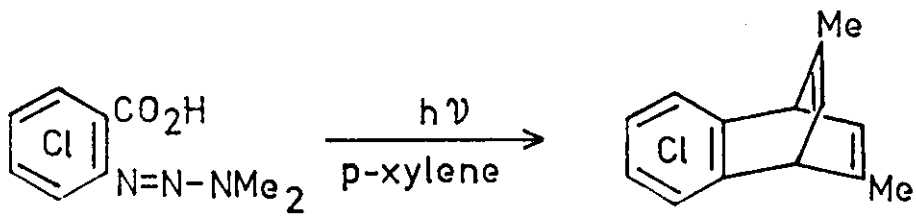
nitrogen at room temperature, but at -20°C there are two different methyl resonances corresponding to the two conformers 59a and 59b. On warming to -10°C however the two resonances coalesce.

An interesting side product from the reaction of the brominated triazene with N-methyl pyrrole was the methyl ester of the starting material. This could arise by a process outlined in scheme 36. Once formed, the monomethylated triazene (60) could continue the reaction since these compounds are known to be efficient methylating agents.[93]

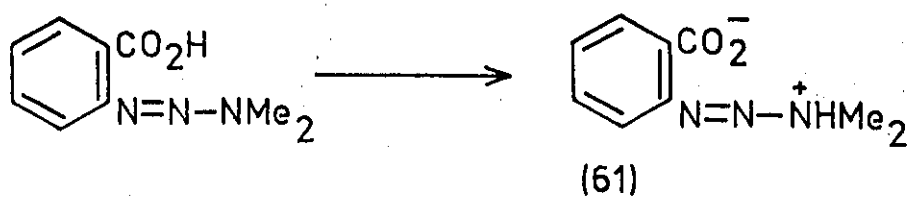
It has also been found possible to generate tetrachlorobenzyne by photolysis of the chlorinated triazene (58, X = Cl) in p-xylene. The unhalogenated triazene however was recovered unchanged when photolysed under similar conditions in furan.



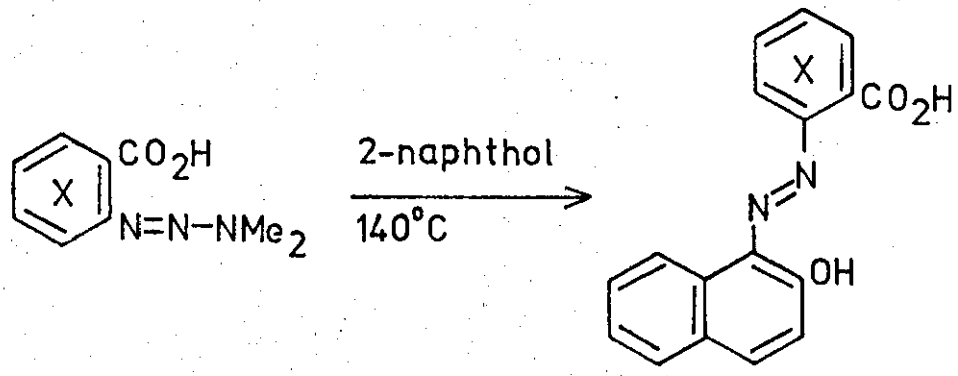
Scheme 36



The initial step in the decomposition is postulated as a proton transfer from the carboxylic acid group to the basic nitrogen atom.

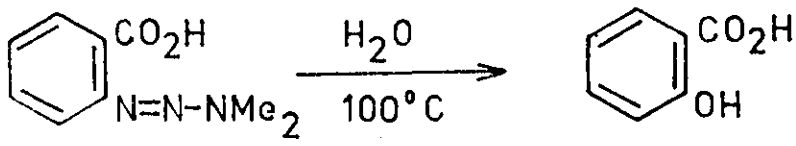


It is worth noting that if any agent is present that is more basic than the triazene then the acidic proton is preferentially removed. For instance, no reaction occurs in the presence of N,N-dimethyl aniline[94] since it is a stronger base and the sp^3 nitrogen atom in the triazene cannot become protonated. The intermediate (61) is then set up to eliminate nitrogen, carbon dioxide, and dimethylamine. The sequence that is followed determines the intermediates that will exist in the decomposition. The first possibility is that dimethylamine will be liberated to form the diazonium-2-carboxylate. We thus performed reactions to determine the intermediacy of the diazonium salt. Decompositions of the triazenes (58)(X = H, Cl) in the presence of 2-naphthol gave the azo-dyes(62.)

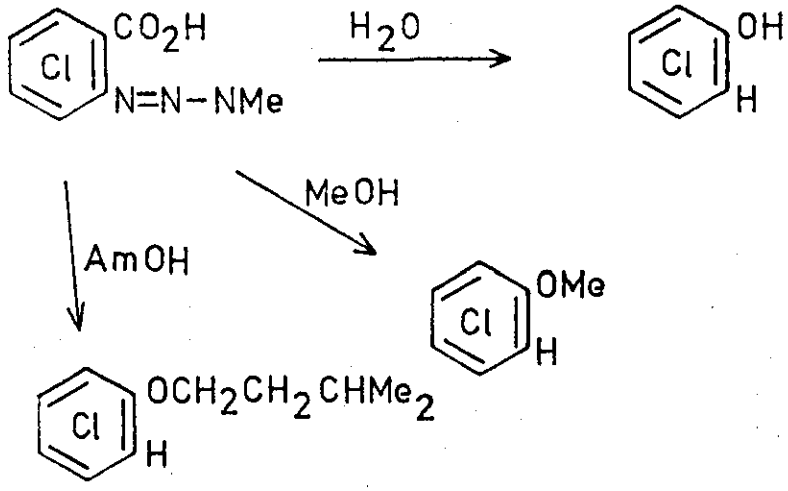


(62)

Thus the decomposition involves conversion to the diazonium-2-carboxylate and then loss of nitrogen and carbon dioxide to form benzyne. Further confirmation of this is afforded by allowing the triazene (58, X=H) to decompose in aqueous solution. Salicylic acid, as its methyl ester, was isolated in 70% yield, which is close to that obtained by the aqueous decomposition of benzenediazonium-2-carboxylate. It is at this point

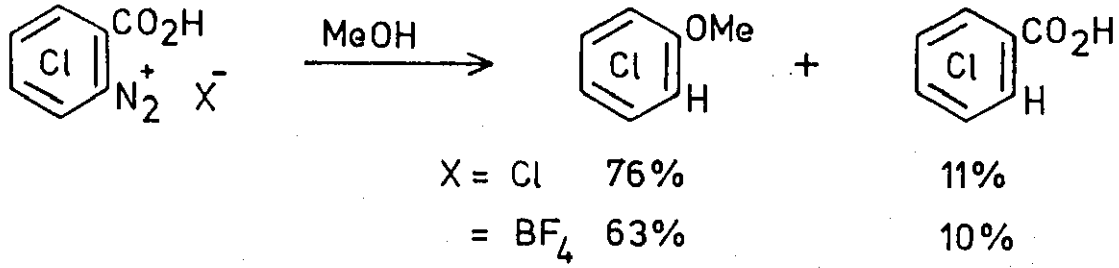


that the behaviour of the chlorinated triazene differs. When the chlorinated triazene (58, X = Cl) was allowed to decompose in aqueous solution the only product found was 2,3,4,5-tetrachlorophenol, in low yield; there was no tetrachlorosalicylic acid formed. Similarly in the presence of other simple nucleophiles, methanol



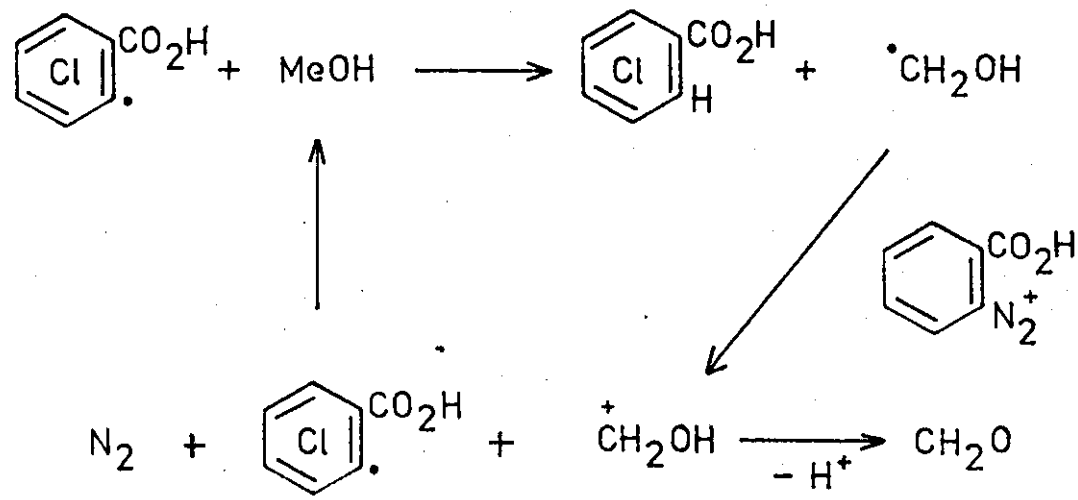
and isoamylalcohol only aryl ethers were formed; there were again no derivatives of tetrachlorosalicylic acid formed. These results would indicate that tetrachlorobenzyne is formed by a concerted loss of nitrogen and carbon dioxide with no intermediate cation. We decided to investigate this apparent anomaly by examining the decomposition of o-carboxy-tetrahalogenobenzenediazonium salts.

The products of the decompositions of 2-carboxy-tetrachloro-benzenediazonium chloride and fluoroborate with water or methanol gave the same results as the triazene (scheme 37). No products were obtained that were derived from any intermediate. The only product



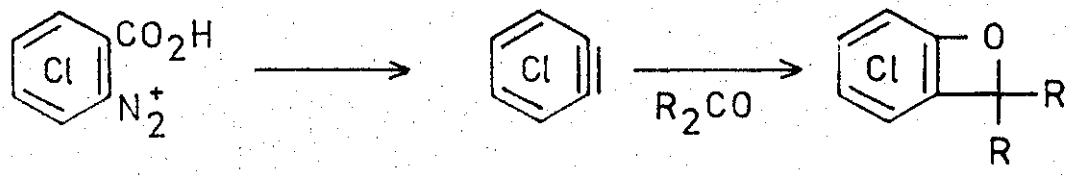
Scheme 37

that did not arise from tetrachlorobenzyne was 2,3,4,5-tetrachlorobenzoic acid in the reaction with methanol. This reduction is commonly encountered in reactions of diazonium salts containing electron withdrawing substituents and alcohols. This reaction has been regarded as a transfer of hydride ion to the phenyl cation but in the light of recent work[51] it is probably a radical process; (scheme 38), any intermediate cation would have been trapped by methanol in this case.



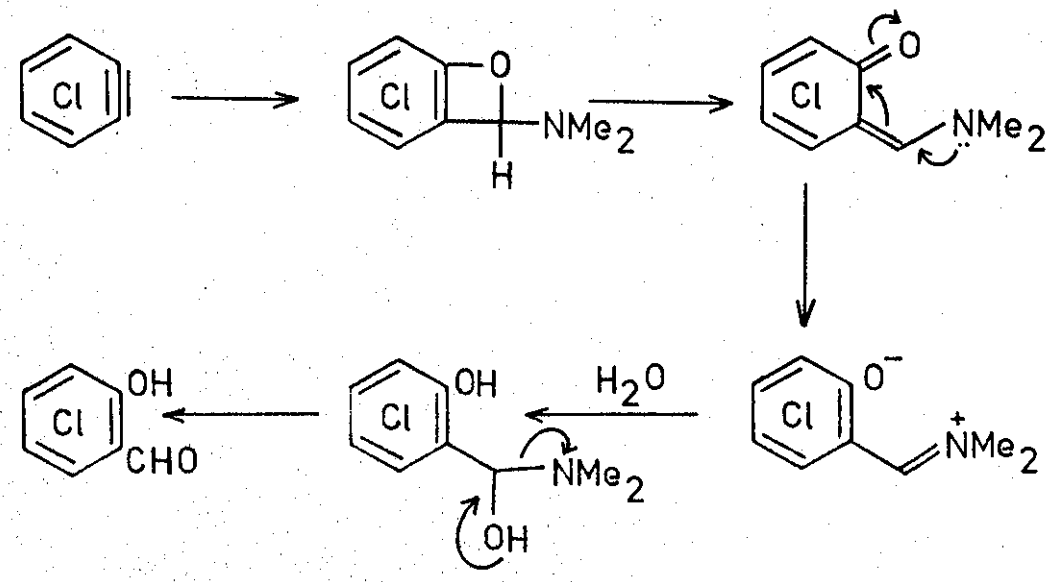
Scheme 38

Other work in these laboratories which might have been expected to trap any intermediates has similarly shown only products derived from tetrachlorobenzyne. Reactions with aldehydes and ketones give products that can be rationalised by the formation of an oxetane intermediate (63).[95]



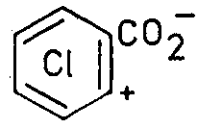
(63)

Tetrachlorosalicylaldehyde has been prepared by the diazotisation of tetrachloroanthranilic acid in the presence of dimethyl formamide.[94] In the non-halogenated case this reaction has been postulated as involving the intermediate cation but in this case it is likely that a mechanism similar to that operating with aldehydes and ketones occurs, (scheme 39).



Scheme 39

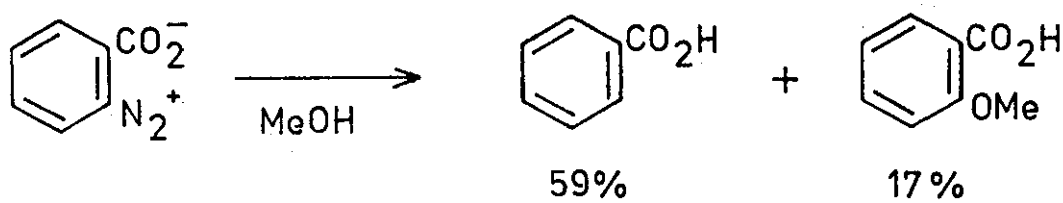
The formation of a similar four membered ring intermediate has also been noted in the reaction of benzenediazonium-2-carboxylate and dimethyl sulphoxide.[96] The only real inference that the cation (64) may be involved comes from Howe[97] who diazotised tetrachloroanthranilic



(64)

acid in conc. sulphuric acid at high temperatures to give a 5% yield of tetrachlorosalicylic acid along with the major product 2,3,4,5-tetrachlorophenol in 77% yield. This apart, it would still appear that a concerted elimination of nitrogen and carbon dioxide is occurring.

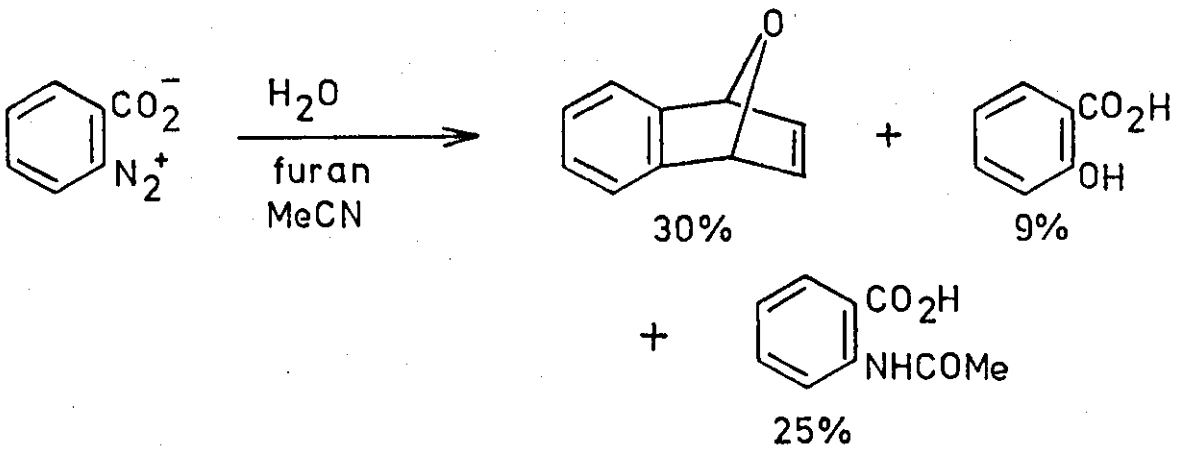
To obtain a strict comparison we decided to repeat some reactions with benzenediazonium-2-carboxylate, involving water, methanol and mixtures of these with furan in acetonitrile as Gompper had described. Decomposition in water went as described by both Hantzsch,[82] and Miller and Stiles,[3a] in that a good yield of salicylic acid was obtained. Decomposition in methanol was more complicated; the main products were benzoic acid (59%) and o-methoxybenzoic acid (17%). Other volatile products such as anisole and methyl benzoate were present in small quantities.



59% 17%

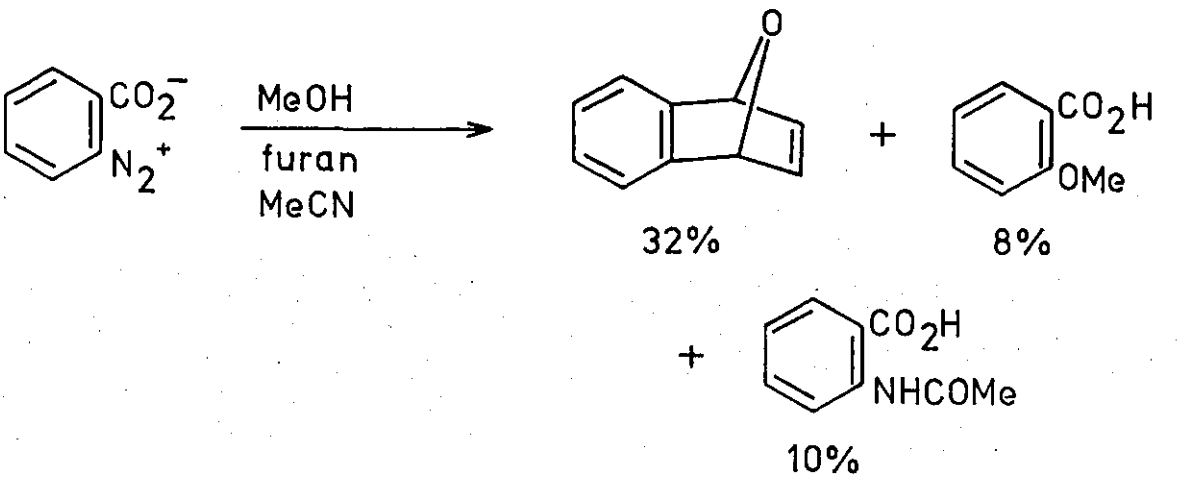
The main process which is occurring is the radical reduction of the diazo function. What is surprising is the presence of o-methoxy benzoic acid and the virtual absence of methyl salicylate. This points to the existence of the cation (52) and not the β-lactone. Others in the literature have examined the reaction with alcohols. Diazotisation of anthranilic acid in ethanol has been reported to yield ethyl benzoate,[98] and Miller and Stiles[99] reported that alcoholysis of the diazonium function takes place with simple alcohols, implying the formation of o-methoxy benzoic acid and not methyl salicylate.

Decomposition of benzenediazonium-2-carboxylate in aqueous and methanolic acetonitrile containing furan, exactly as Gompper has described, also yielded unexpected results. Using water as the trap for the intermediate cation three products were isolated (scheme 40); the furan adduct,



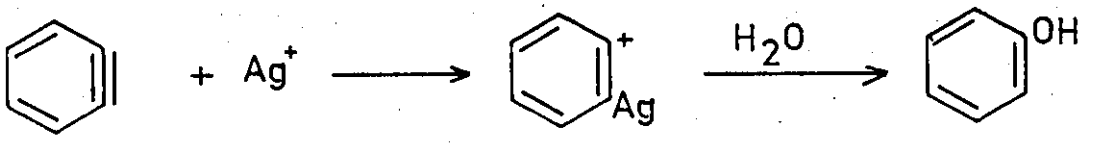
Scheme 40

salicylic acid, and N-acetyl anthranilic acid, the latter two being isolated as their methyl esters. Using methanol as the trap for the intermediate cation and identical reaction conditions the following products were obtained (scheme 41).



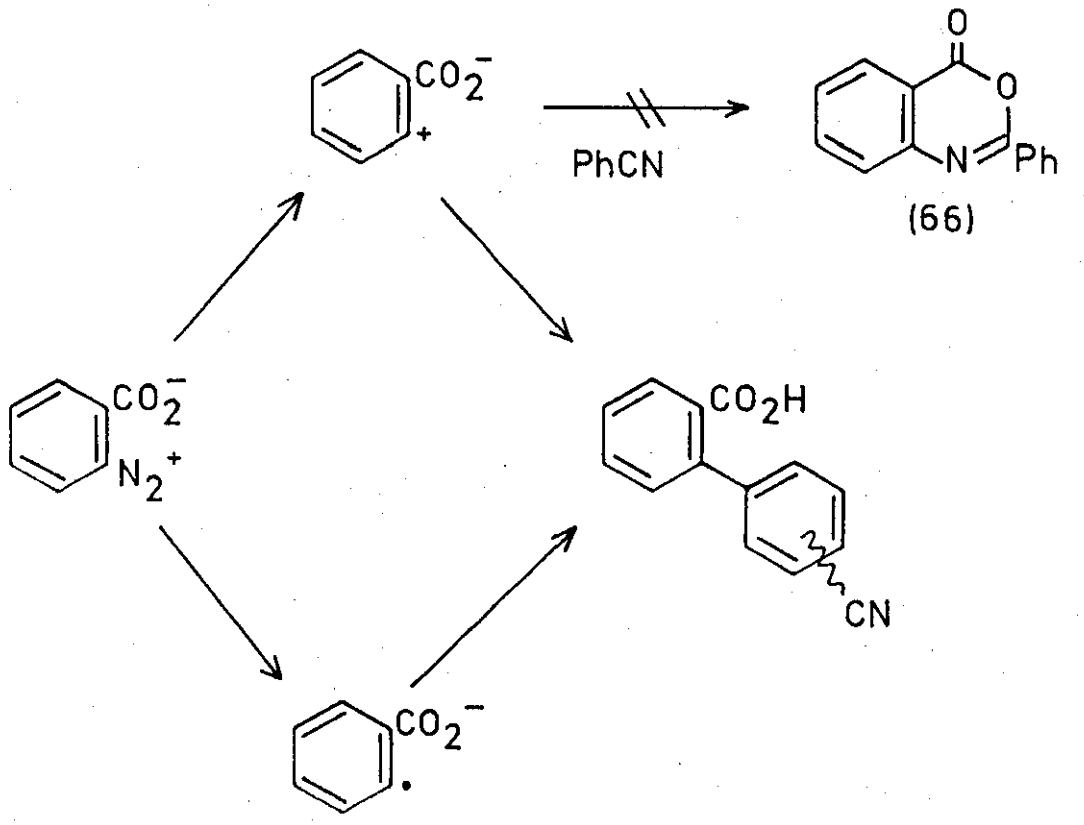
Scheme 41

Again only trace amounts of methyl salicylate were found. The important point that arises from these two reactions is the significant yield of N-acetyl anthranilic acid that was obtained. This product which arises from interaction between the intermediate cation and acetonitrile was not found by Gompper and was ignored in his calculations. Since it is possible that Gompper may have prepared his starting material by a technique involving silver nitrate we decided to check the effect of silver ions on the decomposition. In an identical competition reaction to that previously described with water, in the presence of silver nitrate the results were essentially similar. The only effect that the silver ions had on the reaction was to increase considerably the yield of phenol, which is virtually absent when silver ions are not present. This strange effect has been noted in reactions of benzenediazonium-2-carboxylate with benzene and has been ascribed to the formation of the organometallic



(65)

species (65).[100] The other products isolated were the furan adduct (6%), salicylic acid (24%) and N-acetyl anthranilic acid (16%). The reaction of benzenediazonium-2-carboxylate with acetonitrile was very tarry. The major acidic component, in less than 15% yield, was benzoic acid; N-acetyl anthranilic acid was detected by ^{1}H n.m.r. spectroscopy in ca. 6% yield. In a reaction performed in benzonitrile the only product isolated was an isomeric mixture of biphenyls. We had anticipated that the presence of the phenyl group might stabilise the benz-oxazinone (66), but this result shows that either a radical or an electrophilic process is dominant (scheme 42).[114]



Scheme 42

The isomers present were not determined.

Evidently Gompper's supposition that the betaine (52) was not present was incorrect; the apparent isolation of methyl salicylate is confusing as a control reaction established that o-methoxy benzoic acid is not interconvertible with methyl salicylate under these conditions. It thus became apparent to us that the question of the mechanism of formation of benzyne from benzenediazonium-2-carboxylate was by no means settled. As in the chloro series, was the formation of benzyne a concerted process, but with the formation of the betaine as a competing side reaction or was the stepwise decomposition previously assumed still the dominant process ? We considered that Gompper's arguments were essentially sound but that his system contained too many side-reactions. Furan is an effective trap for benzyne but water is not ideal for trapping the betaine for two reasons. Firstly, it considerably limits the solvents to those which are miscible with water and which invariably promote many side reactions, and furthermore in aprotic media the carboxylate moiety, as demonstrated in the previous chapter, may be considerably more basic and induce formation of the diazohydroxide which again will lead to a variety of side reactions. The system we decided on was to use furan to trap benzyne and chloride ion to intercept the cation; further, by using triethylamine hydrochloride as the source of chloride ion then it was possible to use chloroform, which is commonly used in benzyne reactions, as the solvent. We thus performed experiments involving 1 equ. of benzenediazonium-2-carboxylate, 1 equ. of furan, and varying amounts up to 1 equ. of triethylamine hydrochloride. The reactions were performed at room temperature and also at reflux. The results are shown in the table (fig. 2)

a) @ 25°C

Equ.Et_3NHCl	% furan adduct	% PhCl	Total benzyne	% acid
1.0	56	8	64	23
0.8	56	7	63	26
0.6	57	7	64	26
0.4	68	3	71	23
0.2	65	2	67	14
0.0				12

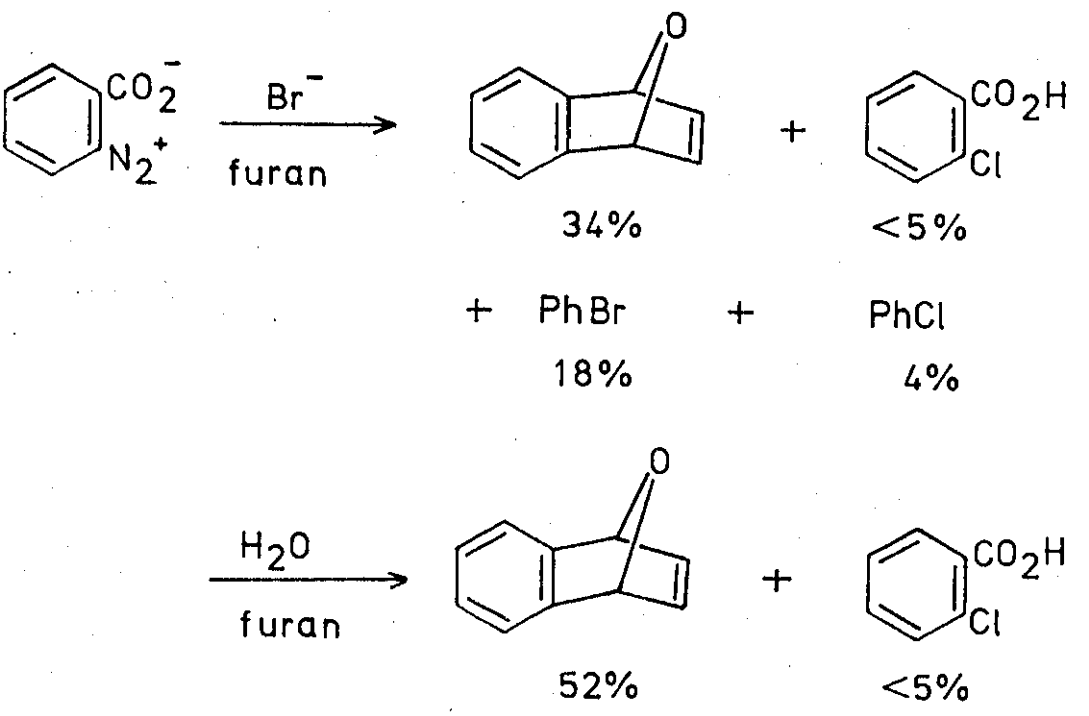
b) @ 60°C

0.8	55	20	75	14
0.6	56	12	68	16
0.4	75	7	82	19
0.2	85	6	91	15
0.0				14

fig. 2.

A control reaction of benzenediazonium-2-carboxylate with triethylamine hydrochloride in chloroform at ca. 25°C showed that the acidic fraction consisted mainly of o-chlorobenzoic acid. Two main points arise from these results; the yields of benzyne products and acid products are virtually constant. This is in accord with a concerted elimination of carbon dioxide and nitrogen and a small competitive side reaction to form o-chlorobenzoic acid. The more important point however, is that this side reaction is not entirely due to the formation of the betaine. Even with no triethylamine hydrochloride present there is still a significant amount of o-chlorobenzoic acid formed. This may be due to a radical displacement of chlorine from the solvent chloroform. This process accounts for nearly, if not all of the acid formed at 60°C.

At room temperature the proportion is slightly lower indicating the possibility of participation of the betaine, in albeit small amounts. The possibility of the abstraction of HCl from chloroform was ruled out as no chlorobenzene was formed from the liberated chloride ion reacting with benzyne. In a similar reaction using triethylamine hydrobromide (1 equ.), furan (1 equ.) and benzenediazonium-2-carboxylate (1 equ.) in chloroform the acidic components included o-bromobenzoic acid and o-chlorobenzoic acid in the ratio 1:23. Thus at 60°C the betaine is barely evident (overall yield 1%). Similar behaviour is displayed in other halogenated solvents. Decomposition of benzenediazonium-2-carboxylate in carbon tetrachloride was very slow at room temperature and the reaction products were mainly tars. The yield of benzyne was low and the acidic products contained only a small percentage of o-chlorobenzoic acid. The main acidic material was salicylic acid which was probably formed by hydrolysis of undecomposed diazonium salt on work-up. In 1,2-dichloroethane the generation of benzyne was very efficient, and the radical displacement process correspondingly reduced. The total acid fraction was always less than 5% and contained mainly o-chlorobenzoic acid. There was no evidence for the participation of the betaine (52). In reactions using both water (1 equ.) and bromide ion (1 equ.) there was no salicylic acid or o-bromobenzoic acid obtained. The acid fractions in each case formed less than 5% of the total yield and consisted of mainly o-chlorobenzoic acid (scheme 43). Interestingly there was some chlorobenzene formed in the presence of triethylamine hydrobromide. This is presumably due to an ionic displacement of chloride ion from the solvent.

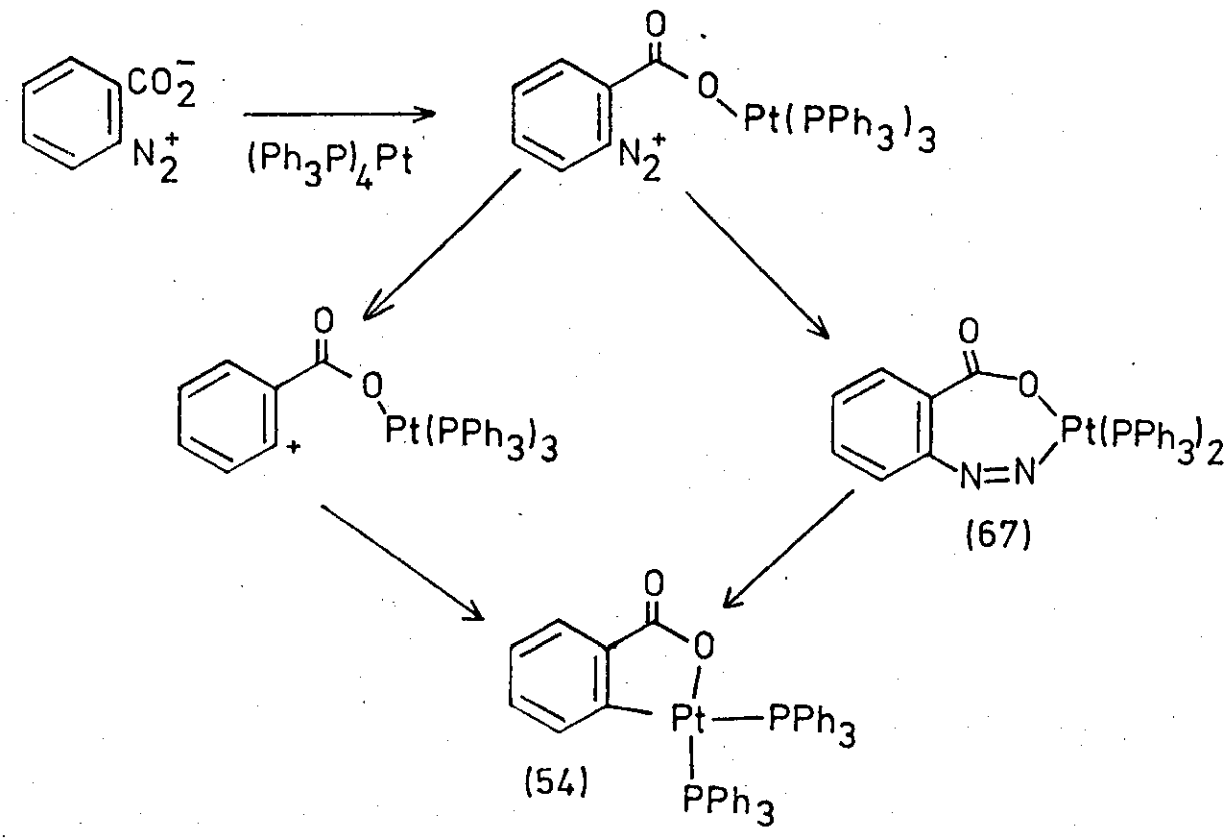


Scheme 43

Decomposition of benzenediazonium-2-carboxylate in bromotrichloromethane was very sluggish. The yield of benzyne, as the furan adduct, was very low. The yield of acidic material was also low and as in carbon tetrachloride most of the product was intractable. The acidic material consisted of a mixture of virtually equal amounts of o-bromo and o-chlorobenzoic acids, again produced by a radical displacement of halide from the solvent. The apparent lack of selectivity in this displacement has been noted before in decompositions of diazonium salts in halogenated solvents.[101] The factors affecting this type of reaction are currently under examination.[102]

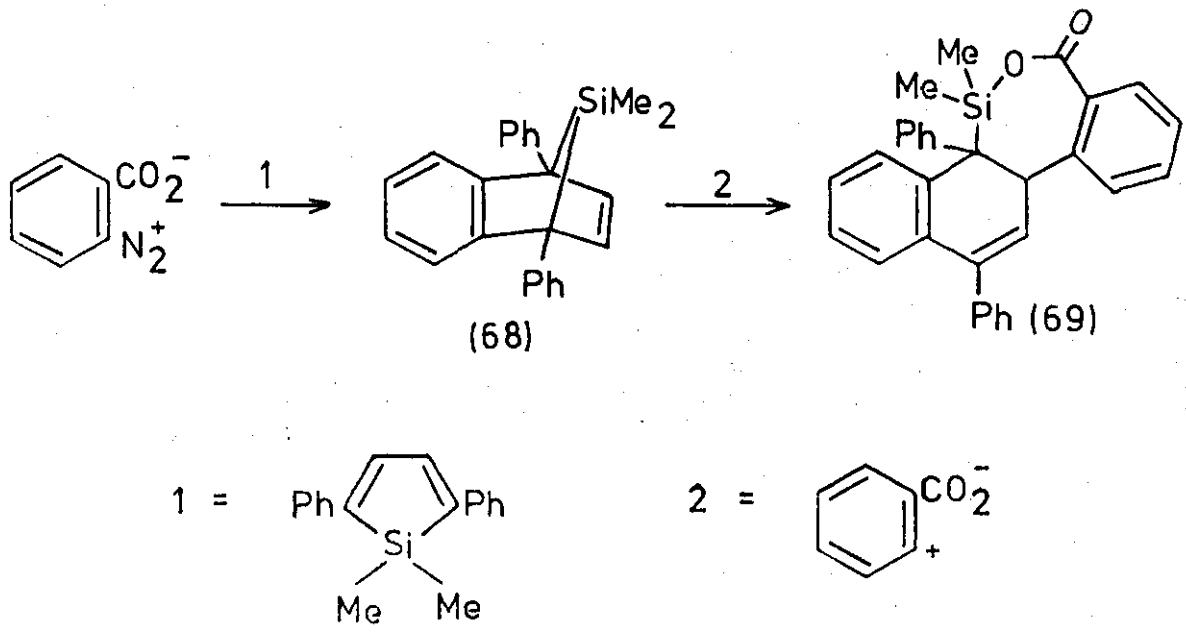
It has been noted earlier in the text that evidence for participation of the betaine had been recorded by Rees[88] in 1,2-dichloroethane. Attempts to prepare a transition metal complex with benzyne led only to the isolation of the compound (54). This was interpreted as an interception of the betaine. Since we have found no evidence for the

existence of the betaine in this solvent we are of the opinion that the product (54) arises from nucleophilic displacement on platinum by benzenediazonium-2-carboxylate followed by loss of nitrogen either



Scheme 44

before or after ring closure to give the product (scheme 44). The compound (67) has been isolated and shown to lose nitrogen on heating to give the compound (54).[103] This type of mechanism has been shown to exist in a similar context. Barton and Clardy,[104] in attempting to prepare the silacyclopentadiene adduct (68), obtained the product (69). It was initially assumed that the cycloadduct had formed but had further reacted with the betaine to form the product (scheme 45). A closer examination of the reaction, however, revealed two discrepancies. Firstly, the betaine has never been reported as adding to a double bond

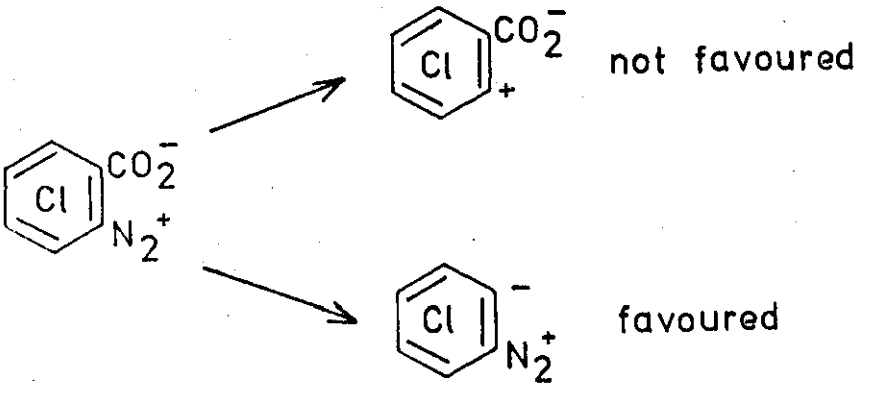


Scheme 45

and secondly the adduct (68), prepared by another route, reacts with benzenediazonium-2-carboxylate to give the product at temperatures where the latter is thermodynamically stable. It was then established that the mechanism operating was an attack on the silicon atom of the cycloadduct by benzenediazonium-2-carboxylate. The driving force for the process is the high strength of the silicon-oxygen bond.

As a whole these results and considerations lead us to believe that the decomposition of benzenediazonium-2-carboxylate is best accounted for by partition between several possible reaction mechanisms. In this respect it is no different from the decomposition of diazonium salts in general, although it must be conceded that the formation of arynes is more favourable in this case because of the thermodynamic stability of the leaving groups. The formation of arynes is then a concerted process which competes with the formation of the 2-carboxylato aryl cation which does not continue to benzyne. The main factors which appear to affect the balance between these two processes (and any others) appear to be the nature of the solvent and the substitution on the

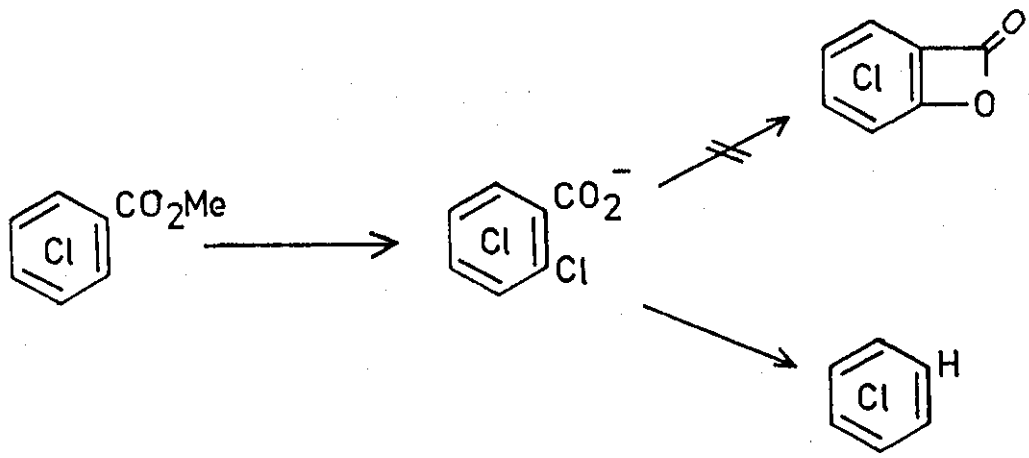
benzene ring. The cation only appears to be formed in the more polar solvents where it is immediately scavenged by solvent molecules or other nucleophilic species. This accounts for the isolation of a low yield of tetrachlorosalicylic acid in the aqueous diazotisation of tetrachloroanthranilic acid. The solvent employed was ca. 90% sulphuric acid which represents an extreme in polarity. In neutral aqueous solution no tetrachlorosalicylic acid is formed. The four chlorine atoms on the ring seem to make the concerted loss of nitrogen and carbon dioxide so favourable that the solvent has little effect on the balance of mechanisms. From a preparative viewpoint however, it should be noted that the highly energetic tetrachlorobenzyne reacts with many solvents. A consideration of the effects of the chlorine atoms on this decomposition would lead us to anticipate that a concerted elimination would be favoured. The diazonium function is stabilised, since the resultant cation is destabilised by the chlorine atoms, and conversely the stabilisation of the resultant carbanion would lower the activation energy for the decarboxylation process. This effect would seem to be sufficient to cause the simultaneous loss of both groups. In the unhalogenated case the activation energy for a



concerted loss is thus higher and polar solvents, tending to favour charge separation, will often make the formation of the cation a more

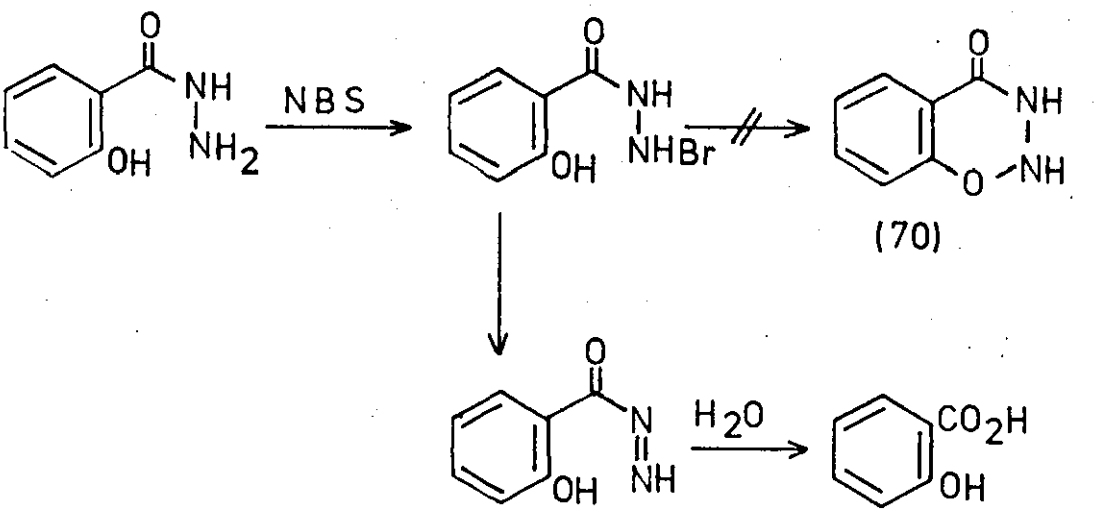
favourable process; the ideal solvent for aryne reactions involving benzenediazonium-2-carboxylate is 1,2-dichloroethane where the formation of benzyne is by far the dominant process.

The benzopropiolactone has continued to stimulate interest in its own right. We have no evidence to suppose that it is an intermediate in the breakdown of benzenediazonium-2-carboxylate. Attempts to prepare it in the halogenated and unhalogenated cases have been unsuccessful. Following the suggestion by some Indian workers[105] that the β-lactone may be an intermediate in some nucleophilic substitution reactions, we treated pentachloromethylbenzoate with pyridine



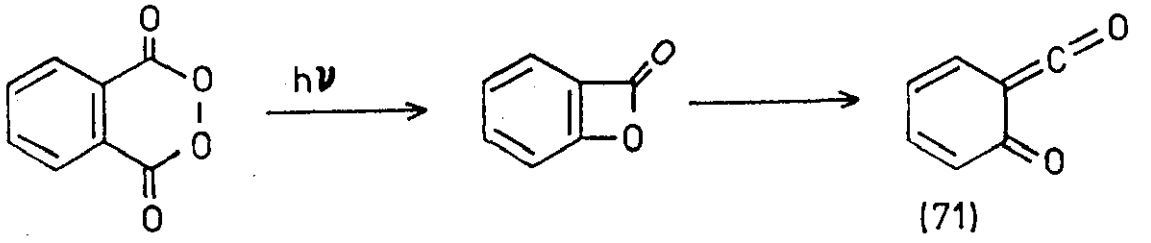
Scheme 46

in p-xylene. Only pentachlorobenzene was formed (scheme 46). We have also attempted to prepare the heterocycle (70) from salicylic acid hydrazide, but attempts at ring closure with reagents like N-bromosuccinimide gave only salicylic acid. Elimination of HBr to form the imino system appears to be favoured (scheme 47).



Scheme 47

Recent work would suggest that the β-lactone is very unstable. Photolysis of phthaloyl peroxide at 77°K in an argon matrix led to



the spectroscopic identification of the cumulenone (71).[106] Although some biphenylene was formed the authors concluded that the formation of the cumulenone is very fast and must proceed via the β-lactone. A more recent examination of this reaction[107] has revealed that the cumulenone and the β-lactone are interconvertible, the interconversion being a function of wavelength. In this way the β-lactone was present in sufficient quantities to allow its detection by infra-red spectroscopy.

Experimental

All general methods were those described previously. Diazomethane was generated in ether from N-nitrosomethyl urea.[108]

1. Preparation of 1-(2'-carboxyphenyl)-3,3-dimethyl triazene

Anthranilic acid (20 gms.) and trichloroacetic acid (ca. 0.2 gms.) were dissolved in tetrahydrofuran (200 mls.) and the solution cooled to ca. 5°C. Isoamyl nitrite (25 mls.) was added dropwise and stirring continued for 90 mins. at room temperature. The precipitate was allowed to settle and the supernatant liquid decanted and replaced with dichloromethane. This process was repeated three times and the suspension cooled to 0°C. Anhydrous dimethylamine (25 mls.) was added with stirring. The solution became red and after 60 mins. at 0°C, was washed with dilute sulphuric acid. The organic layer was separated and dried over magnesium sulphate. Removal of solvent gave a white solid which on crystallisation gave 1-(2'-carboxyphenyl)--3,3-dimethyl triazene (16 gms. 70%) m.p. 122-6°C (lit. m.p. 124-6°C,[46] 119-20°C[80]).

2. Preparation of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene

2-Carboxy-tetrachlorobenzenediazonium chloride (from tetrachloro-anthranilic acid (14.0 gms.) page 27) was added to an aqueous solution of sodium carbonate (10 gms.) and dimethylamine (18 mls.) maintained at 5°C. The reaction mixture was stirred at this temperature for 30 mins. and at room temperature for a further 60 mins. The solution was filtered to remove a small amount of suspended solid and the filtrate acidified with dilute sulphuric acid. The precipitated solid was extracted into ether and dried over anhydrous sodium sulphate. Removal of solvent gave a pale tan solid which on recrystallisation from diethyl ether-light petroleum (1:4) gave 1-(2'-carboxytetrachloro-phenyl)-3,3-dimethyl triazene (9.2 gms. 52%) m.p. 155-60°C lit.[95] m.p.155-60°C.

3. Preparation of 1-(2'-carboxytetrabromophenyl)-3,3-dimethyl triazene

2-Carboxytetrabromobenzenediazonium fluoroborate (from tetrabromoanthranilic acid (5 gms.) page 28) was reacted with dimethylamine (3 mls.) in the same way as described for the chloro analogue. Identical work-up procedure gave 1-(2'-carboxytetrabromophenyl)-3,3-dimethyl triazene (2.3 gms. 41%) m.p. 137°C (dec.)

ν_{max} (nujol) 3200 - 2500, 1700, 1540, 1340, 1270, 1100 cms.$^{-1}$

τ 3.80 (1H), 6.50 (s, 3H), 6.78 (s,3H)

(found: C, 21.35; H, 1.4; N, 8.15% M [mass spectrometry] 509

$C_9H_7N_3O_2Br_4$ requires C, 21.25; H, 1.4; N, 8.25% M 509)

A sample was methylated with ethereal diazomethane to give 1-(2'-carbomethoxytetrachlorophenyl)-3,3-dimethyl triazene m.p. 96-8°C (methanol)

$\nu_{max.}$ 2950, 1740, 1480, 1390, 1340, 1330, 1250, 1105, 970, 860 cms.$^{-1}$

τ 6.25 (s, 3H), 6.52 (s, 3H), 6.78 (s, 3H)

(found: C, 22.95; H, 1.75; N, 7.75% M [mass spectrometry] 523

$C_{10}H_9N_3O_2Br_4$ requires C, 22.95; H, 1.75; N, 8.05% M 523)

4. Reaction of 1-(2'-carboxyphenyl)-3,3-dimethyl triazene and 2-naphthol

The triazene (1 gm.) was heated under reflux for 4 hrs. in a solution of 2-naphthol (0.75 gms.) in tetrachloroethane (50 mls.). The solvent was then removed by distillation under reduced pressure to give a red residue which was triturated with warm benzene and filtered to give a red azo dye (178 mgs. 12%) m.p. 275-6°C.

The ^{1}H n.m.r., i.r., and u.v. spectra were all identical to an authentic sample of 1-(2'-carboxyphenylazo)-2-naphthol prepared from benzenediazonium-2-carboxylate and 2-naphthol m.p. 274-5°C (lit.[109] m.p. 272-4°C).

5. Reaction of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene and 2-naphthol

The triazene (1 gm.) was heated under reflux for 90 mins. in a solution of 2-naphthol (0.5 gms.) in tetrachloroethylene (25 mls.). On cooling a red precipitate crystallised from the solution which on drying yielded a crystalline solid (472 mgs. 37%). The insoluble solid was methylated by the addition of ethereal diazomethane and 2 drops of methanol to give a further red dye. Crystallisation from benzene-methanol gave a pure sample (m.p. 221-3°C) which had identical i.r. and u.v. spectra to an authentic sample of 1-(2'-carbomethoxytetrachlorophenylazo)--2-naphthol).

2-Carboxytetrachlorobenzenediazonium fluoroborate (2.0 gms.) was added to a solution of 2-naphthol (1.0 gms.) in chloroform (50 mls.) and stirred at room temperature for 60 mins. The red precipitate was filtered, washed with chloroform and dried to give 1-(2'-carboxytetrachlorophenylazo)-2-naphthol (3 gms.). A sample was recrystallised from a large volume of chloroform to give a pure product m.p. 228-30°C.

A further sample was methylated with ethereal diazomethane to give 1-(2'-carbomethoxytetrachlorophenylazo)-2-naphthol m.p. 215-8°C (carbon tetrachloride)

$\nu_{max.}$ 1740, 1620, 1490, 1250, 1200, 870, 840, 750 cms.$^{-1}$

$\lambda_{max.}$ 224 (4.40), 285 (3.84), 303 (3.72), 462 (4.01) nms.

(found: C, 48.2; H, 2.35; N, 6.5%

$C_{18}H_{10}Cl_4N_2O_2$ requires C, 48.6; H, 2.25; N, 6.3%)

6. Reaction of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene and N-methyl pyrrole

The triazene (1 gm.) was heated under reflux for 45 mins. in a solution of N-methyl pyrrole (1 gm.) in tetrachloroethylene (25 mls.). The solution was allowed to cool and then washed with 10% sodium carbonate solution. The organic layer was dried over anhydrous sodium

sulphate and solvent removed to give 5,6,7,8-tetrachloro-1,4-methylimino--1,4-dihydronaphthalene (245 mgs. 28%) m.p. 157-9°C (methanol) lit.[22] m.p. 157-8°C. The ^{1}H n.m.r. and i.r. spectra were identical with those of an authentic sample.

In an identical reaction using a longer reaction time, no base wash and isolating the product by column chromatography the yield was raised to 37%.

7. Reaction of 1-(2'-carboxytetrabromophenyl)-3,3-dimethyl triazene and N-methyl pyrrole

The triazene (1 gm.) was heated under reflux in a solution of N-methyl pyrrole (3 gms.) in tetrachloroethane (50 mls.) for 2 hrs. The solvents were removed by distillation under reduced pressure to give a black residue which was dissolved in chloroform and washed with 10% sodium carbonate solution (50 mls.). The organic layer was separated, dried, and solvent removed to give a brown residue which was warmed in benzene and activated charcoal, filtered, the process repeated once more and solvent removed to give a brown solid which was shown by ^{1}H n.m.r. to contain ca. 30% of the adduct (overall yield ca. 20%). The brown solid was recrystallised from benzene-light petroleum to give 5,6,7,8-tetrabromo-1,4-methylimino-1,4-dihydronaphthalene (25 mgs.) m.p. 202-4°C.

$\nu_{max.}$ 3000, 2945, 2870, 2795, 1330, 1290, 1195, 1093, 830, 780 cms.$^{-1}$

τ 3.05 (b.s. 2H), 5.25 (m, 2H), 7.80 (s, 3H)

(found: C, 28.5; H, 1.55; N, 3.20% M[mass spectrometry] 473 acc. mass 468.7314 $C_{11}H_7N\,Br_4$ requires C, 27.9; H, 1.5; N, 2.95% M 473 $C_{11}H_7N^{79}Br_4$ requires 468.7315).

When the crude reaction product was worked up by column chromatography the adduct was not found. The only product identified

was 1-(2'-carbomethoxy)-3,3-dimethyl triazene in 4% yield.

8. Reaction of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene and 2,5-dimethyl furan

The triazene (1 gm.) was heated under reflux in a solution of 2,5-dimethyl furan (1 gm.) in tetrachloroethylene (50 mls.). After 60 mins. the mixture became intensely black and the reaction was stopped. The reaction mixture was washed with 10% sodium carbonate solution (60 mls.) and the phases separated. Acidification of the aqueous phase with dilute hydrochloric acid gave on work-up unreacted triazene (321 mgs.). The organic layer was dried over magnesium sulphate and solvent removed to give a black oil, which was then placed on a column of alumina (50 gms.). Elution with benzene gave 5,6,7,8--tetrachloro-1,4-dimethyl-1,4-epoxynaphthalene (167 mgs. conversion 26%) m.p. 69-71°C (ethanol)

$\nu_{max.}$ 1390, 1355, 1340, 1310, 1295, 1270, 890, 865, 845, 690 cms.$^{-1}$

τ 3.24 (s, 2H), 8.05 (s, 6H)

(found: C, 46.6; H, 2.5% M [mass spectrometry] 310

$C_{12}H_8Cl_4O$ requires C, 46.5; H, 2.6% M 310).

9. Reaction of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene and m-dimethoxybenzene

The triazene (1.0 gms.) was heated under reflux for 3 hrs. in a solution of m-dimethoxybenzene (1.0 gms.) in tetrachloroethylene (50 mls.). The solution was allowed to cool and washed with 10% sodium carbonate solution (50 mls.). Acidification of the aqueous phase gave on work-up 284 mgs. of unreacted triazene. The organic phase was dried, solvent removed, and the residue placed on a column of silica (100 gms.). Elution with benzene gave unreacted m-dimethoxybenzene (22 mgs.); elution with 5% ether-benzene gave 5,6,7,8-tetrachloro-1-methoxy-1,4-etheno-tetral-3-one (346 mgs. conversion 35%) m.p. 146-8°C.

^{1}H n.m.r. and i.r. spectra were identical with those of an authentic sample (page 49).

10. Reaction of 1-(2'-carboxytetrabromophenyl)-3,3-dimethyl triazene and p-xylene

The triazene (688 mgs.) was heated under reflux in p-xylene (50 mls.) for 3 hrs. Removal of solvent gave a brown residue which was placed on a column of alumina. Elution with light petroleum gave 5,6,7,8--tetrabromo-1,4-dihydro-2,10-dimethyl-1,4-etheno-naphthalene, (43%), m.p. 166-8°C (lit.[7] m.p. 167°C.)

^{1}H n.m.r. and i.r. spectra were identical with published values.

11. Reaction of 1-(2'-carboxyphenyl)-3,3-dimethyl triazene and water

The triazene (1.0 gms.) was heated under reflux in water (50 mls.) for 2 hrs. The water was then removed to give an oily solid which was suspended in ether (20 mls.) and treated with an ethereal solution of diazomethane. G.l.c. and t.l.c. indicated one product with the same retention time and R_f value as authentic methyl salicylate. The ether was removed and the oil purified by column chromatography on silica using benzene as eluent to give a pure sample of methyl salicylate (576 mgs. 70%) identified by comparison of its i.r. spectrum with that of an authentic sample.

12. Hydrolysis of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene

The triazene (1 gm.) was heated under reflux in water (50 mls.) for 2 hrs. The red solution was extracted into ether (50 mls.) and washed with 10% sodium carbonate solution. Acidification and extraction into ether gave 211 mgs. of unreacted triazene. The organic layer was further extracted with sodium hydroxide solution. Acidification of the aqueous phase gave a tan solid (86 mgs. 12%) the i.r. spectrum of which was identical with an authentic sample of 2,3,4,5-tetrachlorophenol. The

remaining organic phase on removal of solvent gave a black intractable gum.

13. Reaction of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene and methanol

The triazene (1 gm.) was heated under reflux for 4 hrs. in a solution of methanol (1 ml.) and tetrachloroethane (50 mls.). The solution was allowed to cool and extracted with firstly 10% sodium carbonate solution and then dilute sodium hydroxide solution. Considerable emulsification occurred during the extractions such that work-up of the sodium carbonate extract gave only 2,3,4,5-tetrachloroanisole (65 mgs.); there was no acidic material. Acidification of the alkali wash gave only 22 mgs. of tarry material which was not examined further. The organic phase, after drying and removal of solvent by distillation under reduced pressure, gave a crystalline solid (447 mgs.) m.p. 82-4°C shown by comparison of ^{1}H n.m.r. and i.r. spectra to be 2,3,4,5-tetrachloroanisole (total yield 502 mgs. 67%) (lit.[111] m.p. 82-3°C.)

14. Reaction of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene and isoamyl alcohol

The triazene (1 gm.) was heated under reflux in isoamyl alcohol (50 mls.) for 60 mins. The solvent was removed and the residue redissolved in ether. The organic solution was washed successively with 10% sodium carbonate solution and dilute sodium hydroxide. Acidification of the sodium carbonate extract gave 295 mgs. of unreacted triazene. No material was obtained from the alkali wash. The organic phase after drying and removal of solvent gave a clear oil which crystallised on standing (331 mgs. 52%) m.p. 40-2°C. Comparison of ^{1}H n.m.r. and i.r. spectra showed the product to be 2,3,4,5-tetrachlorophenyl-3'-methylbutyl ether (lit.[111] m.p. 62°C.)

15. Photolysis of 1-(2'-carboxytetrachlorophenyl)-3,3-dimethyl triazene

The triazene (0.5 gms.) was suspended in dry p-xylene (50 mls.) and photolysed for 48 hrs. with a medium pressure external source. The reaction mixture was washed with sodium carbonate solution which on work-up gave unreacted triazene (342 mgs.). The organic phase was dried and solvent removed to give 5,6,7,8-tetrachloro-2,10--dimethyl-1,4-dihydro-1,4-etheno-naphthalene (146 mgs. 30%) identified by ^{1}H n.m.r. and i.r. spectroscopy.

16. Decomposition of 2-carboxytetrachlorobenzenediazonium fluoroborate in water and methanol

a) The diazonium salt (1.0 gms.) was added to a solution of water (3 gms.) in acetonitrile (30 mls.) resulting in a spontaneous evolution of gas lasting for approximately 30 mins. The solvents were removed, replaced with ether and the organic solution extracted successively with 10% sodium carbonate solution and dil.sodium hydroxide. Standard work-up of the carbonate wash gave only a trace of tetrachlorophthalic acid shown to be an impurity in the original anthranilic acid. Work-up of the alkali wash gave a tan solid (362 mgs. 58%) shown by i.r. spectroscopy and t.l.c. to be 2,3,4,5-tetrachlorophenol.

b) The diazonium salt (1 gm.) was added to methanol (30 mls.). There was a spontaneous reaction and a clear yellow solution was obtained. The solvent was removed, replaced with carbon tetrachloride (30 mls.) and extracted with 10% sodium carbonate solution. Acidification of the aqueous phase and standard work-up gave 2,3,4,5-tetrachlorobenzoic acid (79 mgs. 10%) m.p. 164-5°C (lit.[112] m.p. 168°C) ^{1}H n.m.r. τ 2.90.

The organic phase was dried and solvent removed to give a crystalline solid shown to be 2,3,4,5-tetrachloroanisole (480 mgs. 63%).

17. Decomposition of 2-carboxytetrachlorobenzenediazonium chloride in water and methanol

a) The reaction was performed in the same way as previously described

(Expt. 16a), and gave similar results. The organic phase after the carbonate wash was shown to be a mixture of tetrachlorophenol and pentachlorobenzene (total yield 38%).

b) Identical procedure to that described in experiment 16b gave 2,3,4,5-tetrachlorobenzoic acid (89 mgs. 11%) and 2,3,4,5-tetrachloroanisole (567 mgs. 76%).

18. Decomposition of benzenediazonium-2-carboxylate in water and methanol

a) Benzenediazonium-2-carboxylate (1.1 gms.) was dissolved in water (30 mls.), warmed at 60°C for 2 hrs. and left overnight. The crystalline solid which formed was filtered and dried to give salicylic acid (720 mgs. 72%) m.p. 156-8°C (lit.[34] m.p. 159°C), the i.r. spectrum was identical to that of an authentic sample.

b) Benzenediazonium-2-carboxylate (1.0 gms.) was allowed to decompose in methanol (30 mls.) for 48 hrs. G.l.c. (column C) indicated the presence of methyl benzoate and anisole. The solvent was removed, replaced with ether and extracted with 10% sodium carbonate solution. Acidification and extraction into ether gave an acidic fraction shown by ^{1}H n.m.r. to be a mixture of benzoic and o-methoxybenzoic acids (15:4) 59% and 17% yields respectively. G.l.c. of the organic phase showed traces of anisole, methyl benzoate, methyl salicylate and o-methoxy-methyl benzoate.

19. Decomposition of benzenediazonium-2-carboxylate in acetonitrile containing mixtures of furan and water, and furan and methanol. Re-examination of Gompper's experiments.

a) Benzenediazonium-2-carboxylate (1.3 gms.) was dissolved in a solution of furan (5 gms. 0.073 moles) and water (8 gms. 0.44 moles) in acetonitrile (150 mls.). After 30 hrs. the solvent was carefully removed and the residual oil redissolved in ether (100 mls.). The

solution was then extracted with 10% sodium carbonate solution and the phases separated. On acidification and extraction into ether a crude acid fraction was obtained (668 mgs.) which showed an acetyl resonance at τ 7.75. The acid extract was methylated with ethereal diazomethane and the products separated by preparative layer chromatography (3 plates, 1 metre x 20 cms. x 0.5 mms, eluent - 5% ether-benzene) to give :

i) at R_f 0.7 methyl salicylate (124 mgs. 9%) identified by t.l.c., i.r. spectroscopy and g.l.c.

ii) at R_f 0.2 methyl-N-acetyl anthranilate (379 mgs. 25%) m.p. 99-101°C (lit.[34] 101°C.) The ^1H n.m.r. and i.r. spectra were identical with those of an authentic sample.

Solvent was carefully removed from the original organic phase to give a yellow oil which was shown by g.l.c. (column C) to be virtually pure furan adduct (438 mgs. 30%). There was less than 1% of phenol in the product.

b) Benzenediazonium-2-carboxylate (0.7 gms.) was dissolved in a solution of furan (5.0 gms. 0.074 moles) and methanol (12.5 gms. 0.39 moles) in acetonitrile (150 mls.). After 48 hrs. at room temperature the solvent was carefully removed and replaced with ether. The organic solution was then washed with 10% sodium carbonate solution to give on standard work-up a mixture of acids (241 mgs.). This crude product was then methylated with ethereal diazomethane and the products separated by preparative layer chromatography on silica (2 x 1 metre x 20 cms. x 0.5 mms plates:eluent 5% ether-benzene). The main products obtained were:

a) methyl o-methoxybenzoate (55 mgs. 8%)

b) methyl N-acetylanthranilate (80 mgs. 10%).

Other bands were scraped and gave methyl benzoate, methyl salicylate

and methyl anthranilate in trace amounts. The identity of all products was confirmed by i.r. spectroscopy.

Solvent was removed from the original organic phase to give a yellow oil (397 mgs.). Purification by preparative layer chromatography on silica (3 x 1 metre x 20 cms. x 0.5 mms plates eluent: 5% ether-benzene) to give the furan adduct, 1,4-epoxy-1,4--dihydro-naphthalene (220 mgs. 32%).

c) A reaction was performed exactly as described in part a) with the addition of silver nitrate (100 mgs.). Work-up of the acidic material by chromatographic separation of the methyl esters gave methyl salicylate (330 mgs. 24%) and methyl N-acetylanthranilate (235 mgs. 16%). Removal of solvent at room temperature from the organic phase gave a yellow oil (219 mgs.) shown by g.l.c. (column B) to contain 3 components, phenol, furan adduct and an unknown in the ratio 50:6:23 i.e. yields of phenol and furan adduct were 17% and 6% respectively.

20. Reaction of benzenediazonium-2-carboxylate and organic nitriles

a) Benzenediazonium-2-carboxylate (1 gm.) was allowed to decompose at room temperature in acetonitrile (30 mls.) over 48 hrs. The solvent was removed, replaced with ether and extracted with 10% sodium carbonate solution. ^{1}H n.m.r. of the acid mixture (214 mgs.) showed it to be a mixture of benzoic acid and N-acetylanthranilic acid in the ratio 3:1 giving overall yields of 15% and 6% respectively.

Removal of solvent from the organic phase gave a black tarry substance which was not identified.

b) In an identical reaction with benzonitrile a mixture of acids was obtained (242 mgs.) which were methylated with diazomethane. The i.r. spectrum showed the presence of a cyano group and mass

spectrometry indicated the molecular weight to be 237. G.l.c. analysis (column A 200°C) showed it to be a mixture of two isomeric biphenyls, probably 2-carbomethoxy-3'-cyano-biphenyl and 2-carbomethoxy--4'-cyano-biphenyl.

The organic phase gave 332 mgs. of a brown oil which apart from containing some benzonitrile was not identified.

21. Investigation of the decomposition of benzenediazonium-2--carboxylate in chloroform

Benzenediazonium-2-carboxylate (1 gm.) was allowed to decompose in chloroform (20 mls.) containing furan (1 equ.) and triethylamine hydrochloride (up to 1 equ.) at room temperature for 48 hrs. and at 60°C for 60 mins. The reaction mixtures were analysed by g.l.c. for chlorobenzene and 1,4-epoxy-1,4-dihydro-naphthalene. The acidic material was washed from the mixtures with 10% sodium carbonate solution, the aqueous phase acidified and the precipitated acids extracted into ether. Removal of solvent and drying in vacuo gave the acid extract. This weight was taken as the yield of o-chlorobenzoic acid. A control reaction established that this fraction was mainly o-chlorobenzoic acid by g.l.c. analysis of the methyl esters. The acid fractions were similarly methylated with diazomethane and examined by g.l.c. to check that o-chlorobenzoic acid was the major component.

Calibration curves were constructed plotting peak height and concentration for both chlorobenzene and the furan adduct using columns B and C at 160°C. Each determination was made from the average of at least three injections. The following results were obtained:

(i) At room temperature

a) furan adduct

No.Equivs.Et_3NHCl	% Yield B	% Yield C	Mean % yield
1.0	54	57	56
0.8	50	61	56
0.6	53	62	57
0.4	63	74	68
0.2	62	67	65

b) chlorobenzene

No.Equivs.Et_3NHCl	% Yield B	% Yield C	Mean % yield
1.0	8.1	8.5	8
0.8	7.1	7.5	7
0.6	6.8	6.8	7
0.4	3.6	3.3	3
0.2	2.8	1.8	2

c) No. Equivs. Et_3NHCl 1.0, 0.8, 0.6, 0.4, 0.2, 0.0

% Yield of o-chlorobenzoic acid 23, 26, 26, 23, 14, 12

(ii) At 60°C

a) furan adduct

No.Equivs.Et_3NHCl	% Yield B	% Yield C	Mean % yield
0.8	51	58	55
0.6	54	57	56
0.4	74	76	75
0.2	85	84	85

b) chlorobenzene

No.Equivs.Et_3NHCl	% Yield B	% Yield C	Mean % yield
0.8	24	15	20
0.6	12	12.5	12
0.4	7.7	6.8	7
0.2	5.9	6.4	6

c) No.Equivs. Et_3NHCl 0.8, 0.6, 0.4, 0.2, 0.0

% yield of o-chlorobenzoic acid 14, 16, 19, 15, 14

Both runs were on a temperature programme of 100°C for 5 mins. followed by an increase of 48°C/min. to 160°C.

22. Decomposition of benzenediazonium-2-carboxylate in chloroform in the presence of bromide ion

Benzenediazonium-2-carboxylate (1 gm.) was allowed to decompose in a solution of furan (500 mgs. 1 equ.) and triethylamine hydrobromide (1.25 gms. 1 equ.) in chloroform (20 mls.) at 60°C. The mixture was extracted with 10% sodium carbonate solution and the acidic material isolated by acidification and extraction into ether. The acidic mixture (220 mgs.) was methylated and shown to consist of mainly methyl o-chlorobenzoate and only a trace amount of methyl o-bromobenzoate (ratio 23:1). There was also a trace of methyl benzoate.

23. Decomposition of benzenediazonium-2-carboxylate in 1,2-dichloroethane

a) Benzenediazonium-2-carboxylate (1 gm.) was heated under reflux in a solution of 1,2-dichloroethane containing furan (500 mgs. 1 equ.) for 2 hrs. G.l.c. analysis indicated a yield of furan adduct of 88%. Extraction with 10% sodium carbonate solution and subsequent work-up gave a mixture of acids (60 mgs.) shown by g.l.c. on the methyl esters to be o-chlorobenzoic acid and salicylic acid.

b) An identical reaction with the addition of 1 equ. of triethylamine hydrochloride gave chlorobenzene 37% and furan adduct 29%. The acid fraction weighed only 30 mgs.

c) A further reaction in the presence of triethylamine hydrobromide gave chlorobenzene (4%), bromobenzene (18%) and furan adduct (34%). The acid fraction weighed 57 mgs. and contained no o-bromobenzoic acid (by g.l.c. of methyl esters).

d) A similar reaction using 1,2-dichloroethane (40 mls. dried over

molecular sieve) and water (0.12 mls. 1 equ.) gave only 30 mgs. of acid material. G.l.c. of the methyl esters showed it to contain o-chlorobenzoic and salicylic acids in the ratios previously observed.

24. Decomposition of benzenediazonium-2-carboxylate in other halogenated solvents

a) Benzenediazonium-2-carboxylate (1 gm.) was heated under reflux in a solution of carbon tetrachloride (20 mls.) containing furan (500 mgs. 1 equ.) for 2 hrs. The reaction mixture was very tarry and the yield of furan adduct (g.l.c.) was less than 20%. Extraction of the crude mixture with 10% sodium carbonate solution and subsequent work-up gave an acid fraction (139 mgs.) shown to be mainly salicylic acid by g.l.c. of the methyl esters. There was also some o-chlorobenzoic acid and benzoic acid.

b) An identical reaction was performed in bromotrichloromethane. The mixture was again very tarry and the yield of furan adduct low. The yield of acidic material was 149 mgs. and consisted of a mixture of salicylic, o-chlorobenzoic, and o-bromobenzoic acids in the ratio 2:1:1 and overall yields of 8%, 4%, and 3% respectively.

25. Reaction of methyl pentachlorobenzoate and tetraphenyl cyclopentadienone

Methyl pentachlorobenzoate (1.0 gms.) was dissolved in pyridine (50 mls.) containing tetracyclone (1.2 gms.). The solution was warmed at 100°C for 16 hrs. and the solvent removed. The residue was placed on a column of alumina (250 gms.) and elution with light petroleum gave pentachlorobenzene (707 mgs. 86%) m.p. 84-6°C (lit.[34] m.p. 86°C.)

26. Reaction of N-bromosuccinimide and salicylic hydrazide

Methyl salicylate (60 gms.) was heated in a steam bath with hydrazine hydrate (30 mls.) for 3 hrs. On cooling a white precipitate

was obtained which recrystallised from water to give salicylic hydrazide (45 gms. 75%) m.p. 146°C.(lit.[113] m.p. 145°C.)

Salicylic hydrazide (1.0 gms.) was dissolved in tetrahydrofuran (20 mls.) and cooled to 0°C. N-bromosuccinimide (1.2 gms.) was added in small portions. There was an immediate reaction, after which the solution was stirred at 0°C for 45 mins. The solvent was removed and the residue triturated with methanol. The insoluble succinimide was filtered and solvent removed from the filtrate to give a white solid shown by i.r. spectroscopy to be crude salicylic acid.

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