This is to certify that Mr STUART GORDON successfully sustained an oral examination on the subject matter of his thesis by a committee of the Department. The examination was held in April of this year.

Members of
Committee.

4 May, 1937.

SUBSTITUTION IN THE AROMATIC SERIES WITH SPECIAL REFERENCE TO NITRATION.

By

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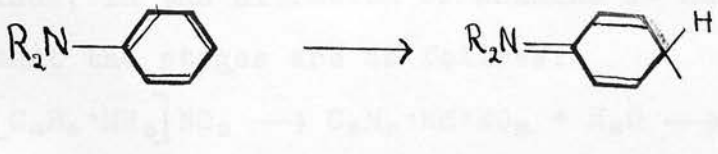
INTRODUCTION.

Though many attempts have been made to account for the qualitative facts of benzene substitution, a completely satisfying theory has not yet been obtained. In the first place it is not known whether, as assumed by Flürscheim, Kekulé, Armstrong and Holleman, an additive product is first formed, or whether direct substitution occurs, as assumed by Obermiller, Vorländer, Robinson and others. Moreover, if addition does take place it may not result in the production of a 1:2- or 1:4- addition compound as suggested; in some cases, according to Wieland, it may be preceded by the formation of an unsaturated quinonoid structure,



and it is only by further transformation of the additive product of the latter that the final result is attained.

Even in the process of nitration, which has been thoroughly studied, the mechanism of the apparently simple reaction is still obscure. It is not known why sulphuric acid is required in many nitrations; why nitrous acid often facilitates the reaction; or whether the nitric acid acts in the hydrated, ionised or associated form, as a derivative of sulphuric acid, or as the anhydride, dinitrogen pentoxide. Further, it has been shown that nitro-benzene forms a compound with sulphuric acid (and probably also with nitric acid) so that the addition of sulphuric acid may precede substitution; it has also been suggested that in the nitration of nitro-benzene it is a compound $(C_6H_5\cdot NO\cdot OH)^+$ and not a $C_6H_5\cdot NO_2$ which undergoes nitration (Hetherington and Masson, J.C.S., 1933, 105). It is probable, on the other hand, that in some cases of substitution an addition compound is, in fact, first formed - not, however, by direct addition to a carbon atom of the nucleus but to some substituent. Thus, in the nitration of aniline it has been suggested that the stages are as follows:-

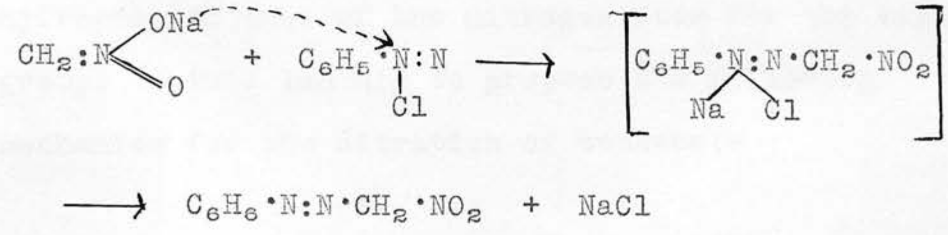
$$[C_6H_5\cdot NH_3]NO_3 \longrightarrow C_6H_5\cdot NH\cdot NO_2 + H_2O \longrightarrow C_6H_4(NH_2)\cdot NO_2$$

Again, the alteration of the order in which two groups of similar orientating effect are introduced is important. Benzenesulphonic acid gives a considerable proportion of o-nitrobenzenesulphonic acid when it is nitrated, but when nitrobenzene is sulphonated the m-derivative is formed; similar anomalies have been observed in other cases. An alteration in the experimental conditions may change the type of substitution, as in the chlorination of toluene, or it may have little effect, as in the nitration of toluene; nitration under ordinary conditions may give nuclear substitution, and nitration with dilute acid side-chain substitution, as in the case of ethylbenzene.

As regards the quantitative results of substitution, it may be noted that the proportions of the various isomerides vary very greatly, particularly in o-p substitution, in some cases the p-derivatives being formed almost exclusively. Very considerable differences in the proportions of the isomerides are often caused by relatively small differences in the experimental conditions, such as variations in the concentration of the substituting reagent. Phenylbromocyanonitromethane, for example, yields quantities of m-products varying from 32-94% as the concentration of the nitrating acid is varied. In the nitration of p-chlorobenzonitrile the density of the nitric acid used is of fundamental importance. Nitration with cold acid of S.G. 1·51 gives a theoretical yield of 4-chloro-3-nitrobenzonitrile, but attempts with acid of S.G. 1·49 give unchanged p-chlorobenzonitrile, even after boiling for 1 minute. Prolonged boiling gives a mixture of p-chlorobenzoic acid and p-chlorobenzonitrile. Hydrolysis is complete when p-chlorobenzonitrile is heated for 15 minutes with concentrated nitric acid of S.G. 1·42 (Dunlop, Macrae and Tucker, J., 1934). A change of temperature may have little or a very great effect, and if a catalyst is used, the nature of the latter may determine the proportion of the isomerides.

The mass of experimental data already accumulated shows that when strictly comparable substitution processes are considered, certain regularities which may even extend to the quantitative results are observed, but for such facts no satisfactory explanation has yet been given.

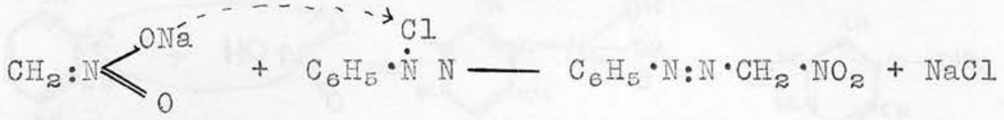
Amongst the earliest investigators who differed from the historical viewpoint that nitration was simply a direct substitution of hydrogen by the nitro group, was Michael. In 1896 he put forward the view that the formation of nitromethane-azobenzene was not a simple case of direct substitution, but involved the addition of the sodium of the nitromethane salt to the more negative of the unsaturated nitrogens of the diazo salt, setting free a carbon and a nitrogen bond which reciprocally saturated each other thus:-



$$CH_2{:}N\overset{ONa}{\underset{O}{<}} + C_6H_5\cdot\underset{Cl}{N}{:}N \longrightarrow \left[C_6H_5\cdot\underset{Na\quad Cl}{N}{:}N\cdot CH_2\cdot NO_2\right]$$

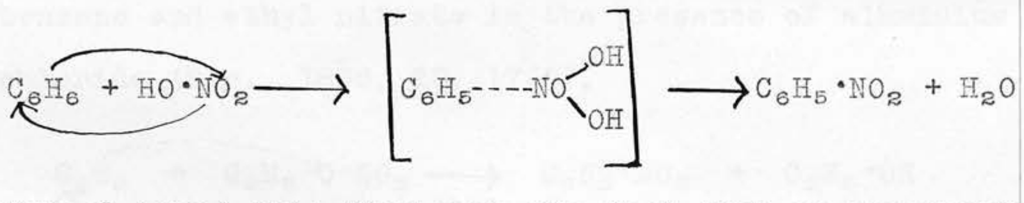
$$\longrightarrow C_6H_6\cdot N{:}N\cdot CH_2\cdot NO_2 + NaCl$$

Rejected Mechanism:



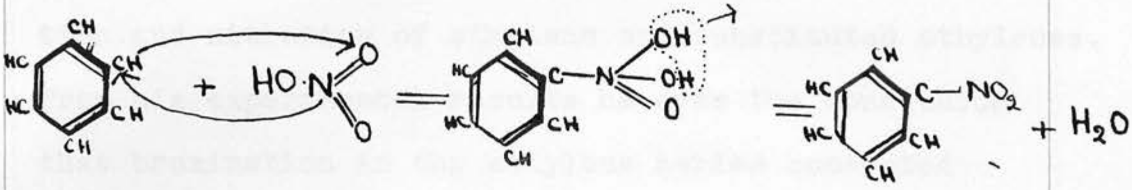
$$CH_2{:}N\begin{smallmatrix}ONa\\O\end{smallmatrix} + C_6H_5\cdot\dot{N}\,N\overset{Cl}{} \longrightarrow C_6H_5\cdot N{:}N\cdot CH_2\cdot NO_2 + NaCl$$

Michael applied this conception to all cases of substitution in which a radical containing oxygen replaced an H atom combined to carbon. This included such reactions as the nitration of benzene, which he explained (Ber., 1896, 29, 1795) as follows:-



$$C_6H_6 + HO\cdot NO_2 \longrightarrow \left[C_6H_5{-}{-}{-}NO\begin{smallmatrix}OH\\OH\end{smallmatrix}\right] \longrightarrow C_6H_5\cdot NO_2 + H_2O$$

Michael based this view upon the fact that an unsaturated oxygen atom of nitric acid must have a considerably higher content of free chemical energy than the partially hydrogenised oxygen atom of the OH, as well as a greater chemical affinity for hydrogen, and therefore can perform more easily the work necessary to separate the hydrogen atom that migrates from the carbon. Michael suggested that the dominating motive forces in nitric acid were the chemical potential of such an oxygen atom for hydrogen and that of the nitrogen atom for the aryl group. This led him to propose the following mechanism for the nitration of benzene:-

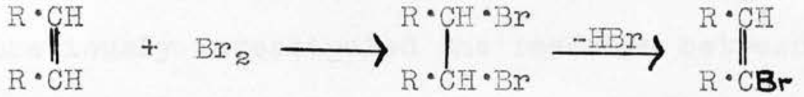


This indicates a mechanism somewhat similar to that of the aldol condensation. In confirmation of this conception, Michael synthesised nitrobenzene from benzene and ethyl nitrate in the presence of aluminium chloride (Ber., 1896, 29, 1795).

$$C_6H_6 + C_2H_5 \cdot O \cdot NO_2 \xrightarrow[AlCl_3]{} C_6H_5 \cdot NO_2 + C_2H_5 \cdot OH$$

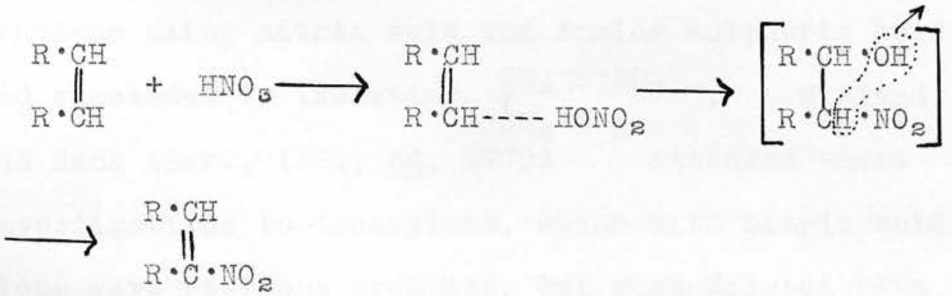
Nef (Ann., 1897, 298, 224) also attempted this synthesis of nitrobenzene and obtained only a low yield. He attributed its formation to the action of nitrous gases formed in the action of the chloride upon the nitric ester. Bodtker (Bull. Soc. Chim., 1908, 4 3, 727), however, obtained up to 32% yields of aromatic nitro compounds by this method. Tronov and Sibgatullin (Chem. Abs., 1931, 25, 3973) found that maximum yields (50% with benzene) were obtained by using only 0·5 moles of the chloride. Michael's views upon nitration, however, were not widely accepted.

Reddelien (J. prakt. Chem., 1915, 91, 220) next advanced a theory of nitration which was based upon the results obtained from a study of the bromination and nitration of ethylene and substituted ethylenes. From his experimental results he drew the conclusion that bromination in the ethylene series consisted essentially in the adding of a bromine atom to each end of the double bond with subsequent splitting off one molecule of HBr to give monobromethylenes:



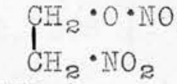
$$\begin{matrix}R\cdot CH\\ \|\\ R\cdot CH\end{matrix} + Br_2 \longrightarrow \begin{matrix}R\cdot CH\cdot Br\\ |\\ R\cdot CH\cdot Br\end{matrix} \xrightarrow{-HBr} \begin{matrix}R\cdot CH\\ \|\\ R\cdot CBr\end{matrix}$$

On analogy with this mechanism he considered that the nitration of ethylenes proceeded on similar lines. He considered that nitric acid added to either end of the double bond as $HO + NO_2$, thus:-

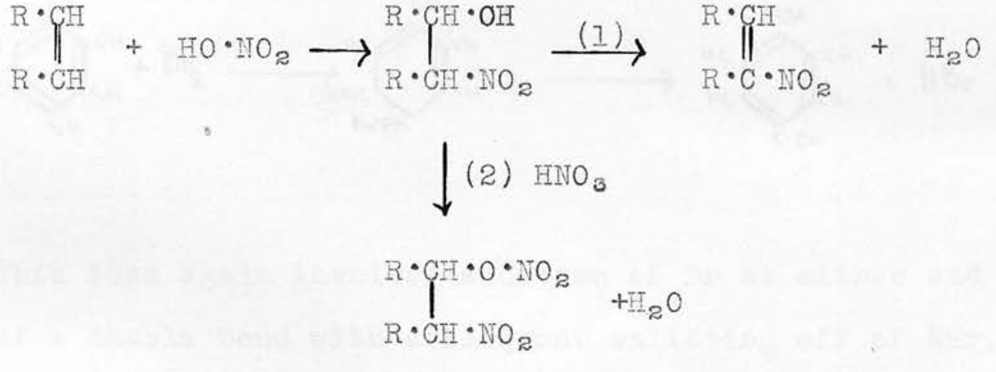


$$\begin{matrix}R\cdot CH\\ \|\\ R\cdot CH\end{matrix} + HNO_3 \longrightarrow \begin{matrix}R\cdot CH\\ \|\\ R\cdot CH\text{----}HONO_2\end{matrix} \longrightarrow \left[\begin{matrix}R\cdot CH\ OH\\ |\\ R\cdot CH\cdot NO_2\end{matrix}\right] \longrightarrow \begin{matrix}R\cdot CH\\ \|\\ R\cdot C\cdot NO_2\end{matrix}$$

In Reddelien's view, therefore, nitration in the ethylene series proceeded by the formation of an unstable addition complex, through addition of HNO_3 as $HO + NO_2$ to either end of the ethylenic linkage, with subsequent splitting off of water to give the nitro-compound. In these nitrations of Reddelien, sulphuric acid was always present, but he regarded it merely as a means of removing the water formed chemically in the course of the reaction. The nitric acid alone, according to Reddelien, had any direct effect upon the nitration.

Haitinger (Ann., 1878, 193, 366; Monatsh., 1881, 2, 286) investigated the action of abolute nitric acid on isobutylene, isoamylene and tertiary butyl and amyl alcohols, and obtained $(CH_3)_2C = CHNO_2$ and $(CH_3)_2C = C(NO_2)CH_3$. Kekulé (Ber., 1869, 2, 329) had previously investigated the reaction between nitric acid and ethylene. These nitro compounds were obtained in small yield only, the main products being oxidation products. With a view to obtaining further information on the mechanism of nitration, Wieland and Sakellarios (Ber., 1920, 53, 201) repeated the nitration of ethylene using nitric acid and fuming sulphuric acid, and succeeded in isolating  $\begin{array}{l}CH_2\cdot O\cdot NO_2\\ |\\ CH_2\cdot NO_2\end{array}$. Wieland and Rahn (Ber., 1921, 54, 1770) extended these investigations to isoamylene, which with nitric acid alone gave resinous products, but when diluted with CCl_4 gave some of Haitinger's nitroamylene along with $(CH_3):C(ONO_2)\cdot CH(NO_2)\cdot CH_3$. Similarly $(C_6H_5)_2:C(OH)\cdot CH_2NO_2$ was obtained from α:α-diphenylethylene, and the ether of 8-hydroxy-9-nitrophenanthrene was obtained from phenanthrene.

Upon these results Wieland based an interpretation of the mechanism of nitration. He stipulated that nitric acid did not function as an electrolyte, i.e., as $H^+ + NO_3^-$, but that in additions to ethylene groups it acted as $HO + NO_2$, forming firstly the corresponding nitroalcohols. With aliphatic derivatives the nitroalcohols either decomposed into nitroalkylenes and water, underwent identification with nitric acid to the corresponding nitric esters, or these processes occurred simultaneously:-

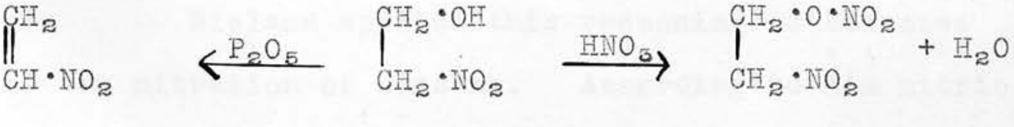


$$\begin{matrix} R\cdot CH \\ \| \\ R\cdot CH \end{matrix} + HO\cdot NO_2 \longrightarrow \begin{matrix} R\cdot CH\cdot OH \\ | \\ R\cdot CH\cdot NO_2 \end{matrix} \xrightarrow{(1)} \begin{matrix} R\cdot CH \\ \| \\ R\cdot C\cdot NO_2 \end{matrix} + H_2O$$

$$\big\downarrow (2)\ HNO_3$$

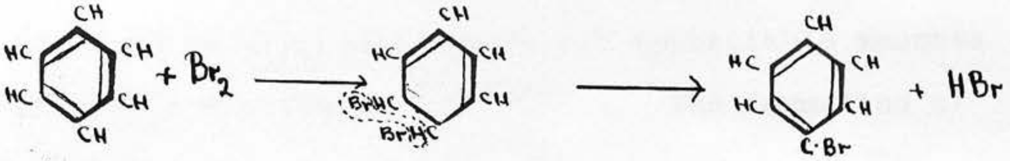
$$\begin{matrix} R\cdot CH\cdot O\cdot NO_2 \\ | \\ R\cdot CH\cdot NO_2 \end{matrix} + H_2O$$

In support of this view Wieland and Sakellarios (Ber., 1919, 52, 898 ; 1920, <u>53</u>, 201) showed that ethylene nitrohydrine yielded the corresponding nitric ester with nitric acid and gave nitroethylene with a strong dehydrating agent.

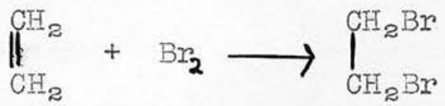


$$\begin{matrix} CH_2 \\ \| \\ CH\cdot NO_2 \end{matrix} \xleftarrow{P_2O_5} \begin{matrix} CH_2\cdot OH \\ | \\ CH_2\cdot NO_2 \end{matrix} \xrightarrow{HNO_3} \begin{matrix} CH_2\cdot O\cdot NO_2 \\ | \\ CH_2\cdot NO_2 \end{matrix} + H_2O$$

Wieland next applied Reddelien's conceptions to the subject of aromatic nitrations. Wieland and and Sakellarios (Ber., 1920, 53, 201) considered, first of all, the bromination of benzene. For this purpose they accepted the structure of benzene as formulated by Kekulé, which assigned three double bonds to benzene and assumed a tautomeric mixture of the two possible forms. They also accepted the hypothesis of Holleman and Thiele that every substitution is preceded by a primary addition. According to these views the bromination of benzene proceeded as follows:-

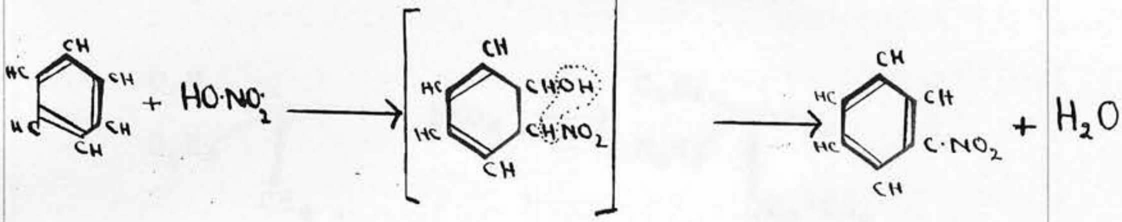


This idea again involved addition of Br at either end of a double bond with subsequent splitting off of HBr. This stipulated the formation of an unstable benzene dibromide. In the case of ethylene, the dibromide is stable and the reaction stops at that stage:



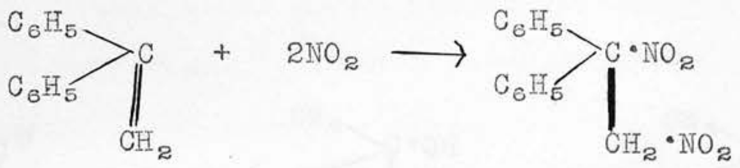
$$\begin{array}{c}CH_2\\ \| \\ CH_2\end{array} + Br_2 \longrightarrow \begin{array}{c}CH_2Br\\ | \\ CH_2Br\end{array}$$

Wieland applied this reasoning to the case of the nitration of benzene. According to him nitric acid adds on to either end of a double bond as HO + NO_2 , forming an unstable nitroalcohol, which split off one molecule of water, thus:-



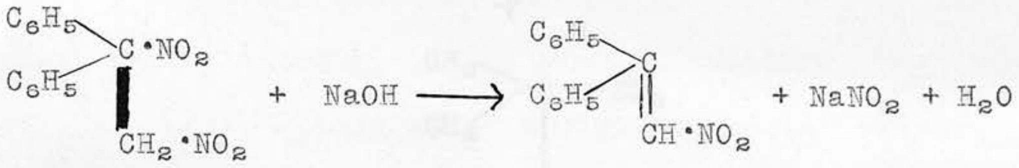
In the nitration of ethylene, Wieland and Sakellarios (loc. cit.) obtained appreciable amounts of glycol dinitrate $\begin{array}{l}CH_2\cdot ONO_2\\ |\\ CH_2\cdot ONO_2\end{array}$. The formation of this product was explained as follows. Nitric acid could add on to either end of a double bond as HO + ONO as well as HO + NO_2. If the nitric acid added as HO + ONO, the intermediate product would be $\begin{array}{l}CH_2\cdot OH\\ |\\ CH_2\cdot ONO\end{array}$, and this product, in the presence of nitric acid, would easily pass into the dinitrate $\begin{array}{l}CH_2\cdot ONO_2\\ |\\ CH_2\cdot ONO_2\end{array}$. Oxidation products of ethylene, such as $(COOH)_2$ and CO_2, were obtained in large amounts.

In the following year, Wieland and Rahn (Ber., 1921, <u>54</u>, 1770) published the results of their investigations into the action of absolute nitric acid on isoamylene, α:α-diphenylethylene and phenanthrene. They tried unsuccessfully to isolate their stipulated nitroalcohols. They found, however, that absolute nitric acid reacted upon α:α-diphenylethylene in dilute, dry carbon tetrachloride solution to give α:α-diphenyl-β-nitro-ethyl-alcohol. By the action of NO_2 in dry petrol ether on α:α-diphenylethylene they succeeded in preparing α:α-diphenyl-α:β-dinitroethane.

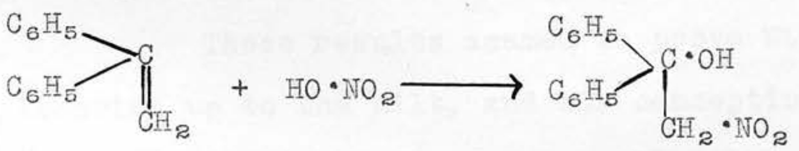


$$\begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\underset{\underset{CH_2}{\|}}{C} + 2NO_2 \longrightarrow \begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\underset{\underset{CH_2\cdot NO_2}{|}}{C\cdot NO_2}$$

When this was shaken up with NaOH in ether it yielded α:α-diphenyl-β-nitroethylene.

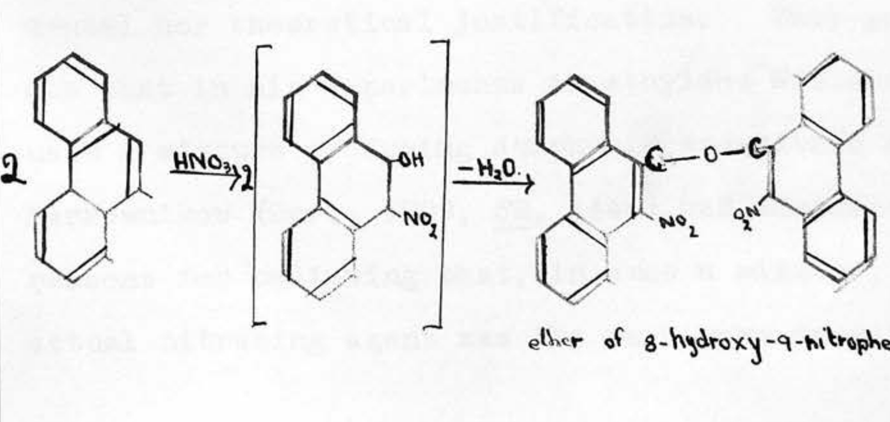


$$\begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\underset{\underset{CH_2\cdot NO_2}{|}}{C\cdot NO_2} + NaOH \longrightarrow \begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\underset{\underset{CH\cdot NO_2}{\|}}{C} + NaNO_2 + H_2O$$



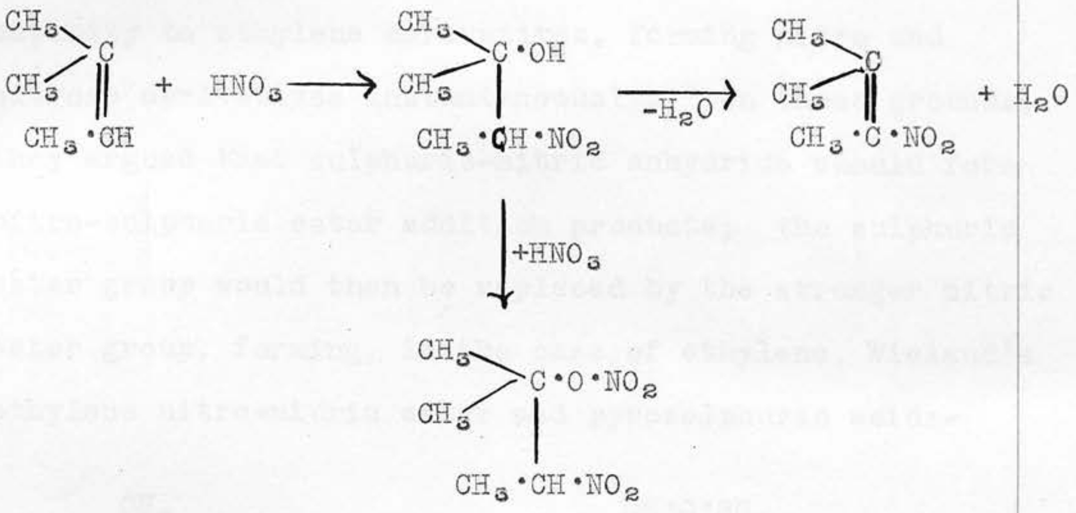
$$\begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\underset{\underset{CH_2}{\|}}{C} + HO\cdot NO_2 \longrightarrow \begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\underset{\underset{CH_2\cdot NO_2}{|}}{C\cdot OH}$$

From phenanthrene, Wieland obtained the ether of 8-hydroxy-9-nitrophenanthrene. This result he explained as follows:-



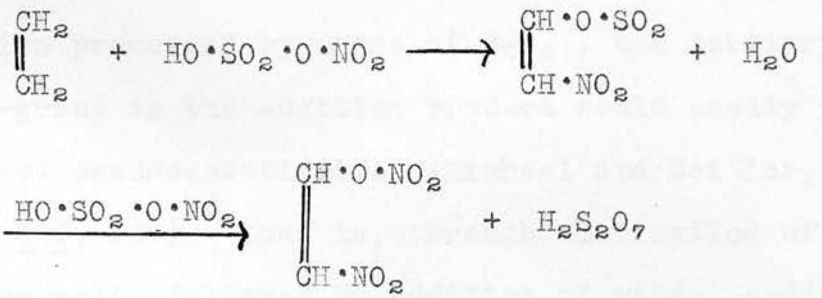
ether of 8-hydroxy-9-nitrophenanthrene.

In the case of isoamylene $(CH_3)_2:C:CH\cdot CH_3$ the products were $(CH_3)_2:C:C(NO_2)\cdot CH_3$ and $(CH_3)\cdot C(ONO_2)\cdot CHNO_2\cdot CH_3$. This result was explained thus:-



These results seemed to prove Wieland's theories up to the hilt, and his conception of the mechanism of nitration was generally accepted.

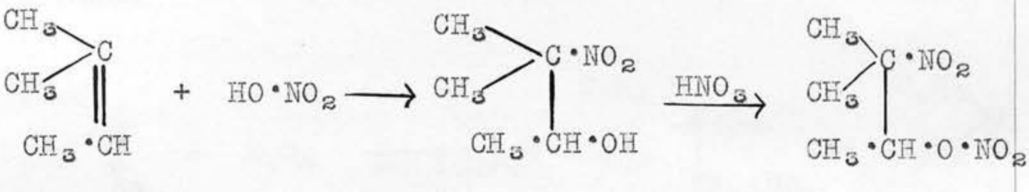
Recently Michael and Carlson (J.A.C.S., 1935, 57, 1268) published a paper on the subject of the mechanism of the nitration process, in which they contended that Wieland's speculations had neither experimental nor theoretical justification. They pointed out that in his experiments on ethylene Wieland had used a mixture of fuming sulphuric and nitric acids. Markownikow (Ber., 1899, 32, 1444) had advanced good reasons for believing that, in such a mixture, the actual nitrating agent was the much more reactive mixed anhydride $HO\cdot SO_2\cdot ONO_2$, and not nitric acid, Michael and Carlson argued that its formation in such a nitrating mixture could not be doubted. It was also well known that other mixed anhydride, e.g., nitrogen tri- and tetroxides, showed a very marked additive capacity to ethylene derivatives, forming nitro and nitroso derivatives instantaneously. On these grounds, they argued that sulphuric-nitric anhydride should form nitro-sulphuric ester addition products; the sulphuric ester group would then be replaced by the stronger nitric ester group, forming, in the case of ethylene, Wieland's ethylene nitro-nitric ester and pyrosulphuric acid:-



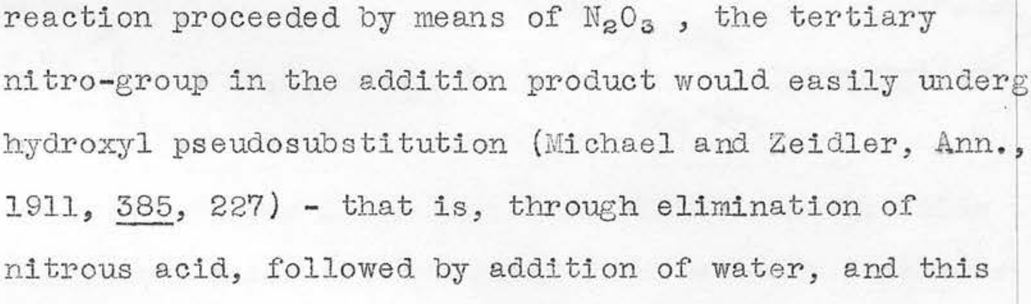
$$\begin{array}{c}CH_2\\ \|\\ CH_2\end{array} + HO\cdot SO_2\cdot O\cdot NO_2 \longrightarrow \begin{array}{c}CH\cdot O\cdot SO_2\\ \|\\ CH\cdot NO_2\end{array} + H_2O$$

$$\xrightarrow{HO\cdot SO_2\cdot O\cdot NO_2} \begin{array}{c}CH\cdot O\cdot NO_2\\ \|\\ CH\cdot NO_2\end{array} + H_2S_2O_7$$

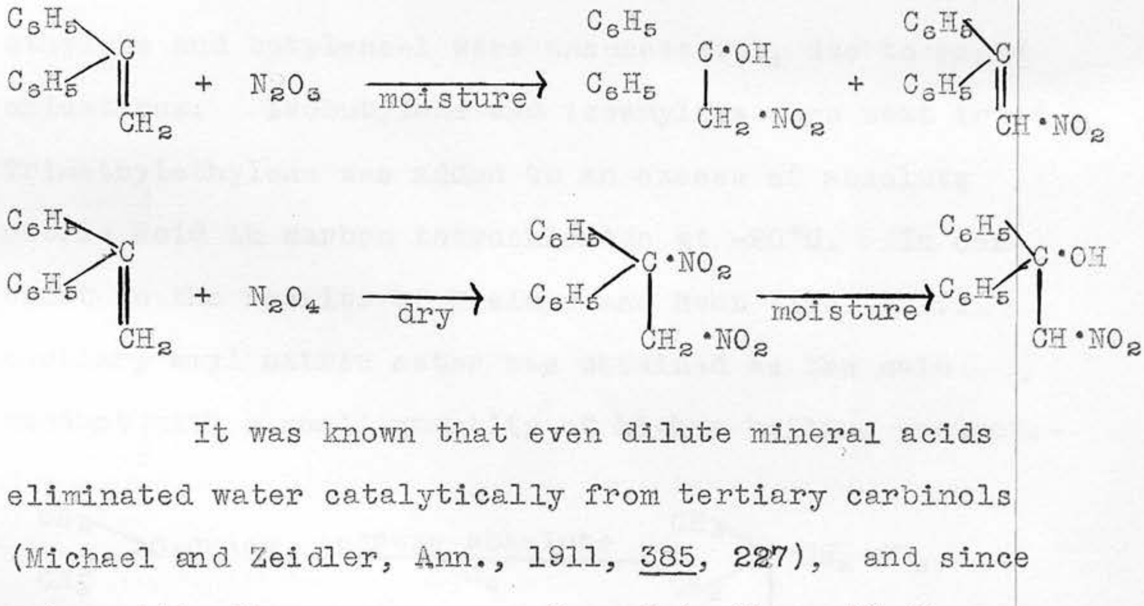
It was also remarked by Michael that in Wieland's experiments he always obtained, as a large part of his yield, oxidation products. As soon as oxidation began, nitrogen trioxide and nitrogen tetroxide would be formed. These two oxides would immediately add on to the ethylene, forming directly, or indirectly by oxidation, Wieland's nitro-nitric ester. Michael also observed, with reference to Wieland's experiments with isoamylene, that if nitric acid added to isoamylene as $HO + NO_2$, according to the positive-negative addition rule, the main product should be $(CH_3)_2:C(NO_2)\cdot CHOH\cdot CH_3$ and, according to the principle of partition, a small amount of $(CH_3):C(OH)\cdot CH(NO_2)\cdot CH_3$. The first nitroalcohol would then be converted to the corresponding nitric ester and would not yield the α-nitroisoamylene obtained by Wieland, but a compound isomeric with the one he isolated.



In addition, it was pointed out that if the reaction proceeded by means of N_2O_3 , the tertiary nitro-group in the addition product would easily undergo hydroxyl pseudosubstitution (Michael and Zeidler, Ann., 1911, 385, 227) - that is, through elimination of nitrous acid, followed by addition of water, and this 2-nitro-3-hydroxyisopentane should give the products obtained by Wieland:-



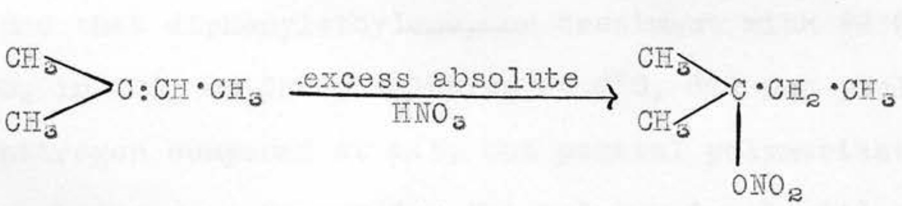
Lipp (Ann., 1926, 449, 15) studied the behaviour of α:α-diphenylethylene towards moist nitrogen trioxide and tetroxide. With the trioxide a blue oil was first obtained, which decomposed at 0°C into the nitroalcohol and nitroethylene derivatives; with dry tetroxide, Wieland (Ber., 1921, 54, 1770) obtained the dinitro addition product, but the presence of even a trace of water caused the formation of the α:β-nitroalcohol.



It was known that even dilute mineral acids eliminated water catalytically from tertiary carbinols (Michael and Zeidler, Ann., 1911, 385, 227), and since water with nitrous gases was formed in the oxidation process, it was obvious that the appearance of nitroalkylenes, nitroalcohols and their nitric esters, in addition to ethylene derivatives, was without significance for the interpretation of the mechanism of nitration.

In view of these objections to Wieland's results, Michael carried out a series of investigations on the mechanism of nitration under conditions which eliminated oxidation as far as possible, thus avoiding interference of N_2O_3 and N_2O_4 in the course of the reactions. To bring this about he worked at low temperatures with vigorous mechanical stirring, and used colourless, freshly prepared 98·6% nitric acid diluted with CCl_4, $CHCl_3$ or CH_2Cl_2. The latter solvent was stable to the acid under the conditions used, and its lower b.p. enabled a better separation of the reaction products from the solvent.

Attempts to carry out nitrations with ethylene and butylene-1 were unsuccessful, due to rapid oxidations. Isobutylene and isoamylene were next tried. Trimethylethylene was added to an excess of absolute nitric acid in carbon tetrachloride at -20°C. In contrast to the results of Wieland and Rahn (loc. cit.) tertiary amyl nitric ester was obtained as the main product with a small quantity of higher boiling product:-



$$\begin{matrix}\mathrm{CH_3}\\\mathrm{CH_3}\end{matrix}\!>\mathrm{C{:}CH\cdot CH_3}\xrightarrow[\mathrm{HNO_3}]{\text{excess absolute}}\begin{matrix}\mathrm{CH_3}\\\mathrm{CH_3}\end{matrix}\!>\underset{\mathrm{ONO_2}}{\mathrm{C}}\mathrm{\cdot CH_2\cdot CH_3}$$

The tertiary nitric ester was obtained as the sole product when 98·6% nitric acid was added to a CCl_4 or $CHCl_3$ solution of isoamylene at -20°C. Isobutylene in CH_2Cl_2 solution reacted with 98·6% HNO_3 at -20°C. to yield tertiary butyl nitric ester. Bouveault and Wahl (Bull. Soc. Chim., 1903, <u>29</u>, 956) obtained almost quantitative yields of nitric esters by the action of 98% nitric acid at 0-5°C upon primary alcohols. Secondary carbinols yielded only oxidation products. With tertiary derivatives they observed only the formation of complex nitrogen compounds in contrast to Haitinger (loc. cit.) who obtained small yields of nitroalkylenes. Michael and Carlson (loc. cit.) reported that under their conditions, tertiary butyl and amyl alcohols were esterified nearly completely, in a few minutes, when treated with two equivalents of 98·6% HNO_3 at -20°C. to -17°C. Oxidation was not observed and the esters were shown to be identical with those obtained from the isoalkylenes.

From his experiments on diphenylethylene, Michael concluded that the nitro derivatives obtained by Wieland were due to the action of nitrous compounds formed in the deoxidation of nitric acid. Michael found that diphenylethylene, on treatment with 98·6% HNO_3 in CCl_4 or $CHCl_3$ solution at 0°C, did not yield a nitrogen compound at all, but partial polymerisation was observed. On warming the polymer in glacial acetic acid with nitric acid, nitrous fumes were evolved, and α:α-diphenyl-β-nitroethyl alcohol was isolated. Michael declared that in view of these results, the formation of this compound in Wieland's experiments constituted no proof that nitric acid added directly as stipulated.

Turning to the Wieland-Reddelien scheme of aromatic nitration, Michael rejected it as very improbable. He pointed out that halogens were only slightly additive towards benzene but, due to intramolecular energy changes, addition at a single pair of conjoined carbon atoms caused the two remaining pairs of carbons to acquire marked additive properties. Hence it was possible to add six, but not two or four, halogen atoms to benzene. Nitric acid, therefore, functioning as HO + NO_2, should have behaved like halogen and, according to the Wieland-Reddelien scheme, should have led to trinitro- , not mononitrobenzene. To explain the formation of trinitro-benzene, along with picric acid, on warming benzene with N_2O_4 , Wieland (Ber., 1920, 54, 1776) assumed that this vigorous deep-seated decomposition reaction involved, as well as N_2O_4 , nascent oxygen, nitrous oxide, and nitrous and nitric acids, and proceeded by elimination of 3 molecules of nitric acid from a primarily formed hexanitrohexahydrobenzene. Michael regarded this explanation as highly improbable.

Modified intramolecular energy relations in one of the nuclei of several higher aromatic hydrocarbons, e.g., naphthalene, permitted addition to a single pair of linked carbons and, as Michael (J. prakt. Chem., 1903, 68, 506) had previously shown, these mono-derivatives were comparatively stable. Wieland had explained the formation of the ether of 8-hydroxy-9-nitrophenanthrene, from phenanthrene and absolute nitric acid, by spontaneous condensation of 2 moles of the 8-hydroxy-9-nitrophenanthrene first formed by addition of HO + NO_2 at the 8 and 9 carbon atoms, with splitting off of one molecule of water (vide supra). At these particular atoms, phenanthrene exhibits almost the additivity of the alkylene carbons, and addition of nitric acid should take place. Schmidt and Heinle (Ber., 1911, 44, 1494) reported the formation of 3-nitrophenanthrene, in acetic acid solution, in the reaction between phenanthrene and nitric acid, S.G. 1·45.

According to Wieland's hypothesis this was unintelligible, as it would have involved the relatively inert, as far as additive properties go, 2-3 or 3-4 carbon atoms. The ether of 8-hydroxy-9-nitrophenanthrene was first prepared by Schmidt (Ber., 1900, 33, 3251) by the action of nitrous fumes upon phenanthrene, which indicated that its formation in Wieland's experiments was due to that reagent and not directly to nitric acid. Michael obtained an unidentified product containing the elements of nitric acid more than the original hydrocarbon. When treated with sodium methylate a small amount of sodium nitrate was obtained. The main product appeared to be a mixture of nitrophenanthrenes which Michael could not separate.

It was well known that cyclohexene added halogens readily. Michael examined its reaction with nitric acid in $CHCl_3$ solution at -20°C., and found that it was not a simple addition reaction, but yielded a high-boiling product of which only about a half was distillable.

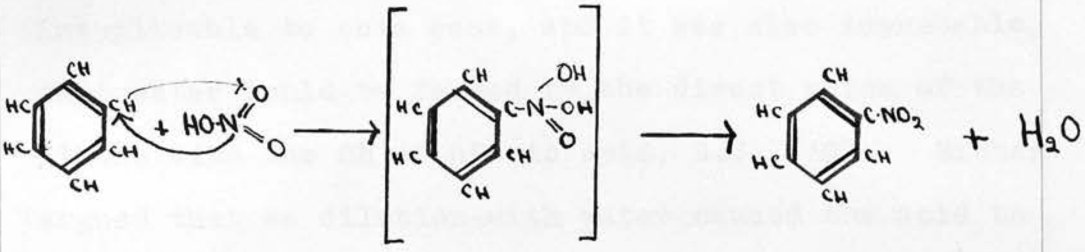
From these results Michael drew the conclusion that the previously observed nitrations of ethylene derivatives were indirect, and had been brought about by nitrous gases evolved in oxidation side reactions. Nitric acid, when it acted like other strong acids, behaved normally according to the positive negative addition rule with the addition of $H + ONO_2$ to the ethenic carbons.

In the case of aromatic nitrations, Michael rejected the Reddelien-Wieland conception as untenable. In its place he stated that two other interpretations were possible:

1) The historic substitution conception, implying direct replacement of H by NO_2.

2) Indirect or pseudo-substitution. This latter view was based upon the fact, as Michael (Ber., 1901, <u>34</u>, 4030) had pointed out, that an unsaturated oxygen atom of nitric acid must have a considerably higher free chemical energy content than the partially hydrogenised O of the OH, as well as a greater chemical affinity for H, and, therefore, could more easily perform the work necessary to separate the H that migrates from the C

atom. The dominating motive forces in nitric acid were the chemical potential of an unsaturated O for H and the chemical potential of the N for the anyl group. Thus Michael represented the nitration of benzene, as follows:-



In support of this view of benzene nitration Michael quoted the synthesis of nitrobenzene by the action of a mixture of nitric ethyl ester and benzene in presence of aluminium chloride (vide supra, p. 7).

Giersbach and Kessler (Z. physik. Chem., 1888, 2, 676) had put forward the view that two molecules of nitric acid entered into the nitration of benzene, and Tronov, who accepted the viewpoint that aromatic nitrations proceeded through aldolisation, attached the second acid molecule at the same carbon by a dotted line. Michael pointed out that when the simplest possible polymolecule has not sufficient free chemical energy to overcome the chemical hindrance to a reaction, it may do so by assimilating a second molecule of the reagent. This, however, did not imply two kinds of linkage, and Tronov's assumption was therefore superfluous.

As another argument against Wieland's conception of the mechanism of nitration, Michael pointed out that Konowalow (Compt. Rend., 1892, 114, 26) had demonstrated that alkanes could be nitrated with practically dilute nitric acid. Wieland's ideas were inapplicable to this case, and it was also improbable that water would be formed by the direct union of the alkane with the OH of nitric acid, S.G. 1·07. Michael argued that as dilution with water caused the acid to lose part of its negative chemical energy, this partial neutralisation would favour pseudo-substitution over oxidation.

The views put forward by Reddelien and Wieland and those put forward by Michael constituted two attempts to account for nitration by advancing mechanisms for the reactions. Many workers, however, have advanced other theories. Hetherington and Masson carried out a series of investigations into the nitration of nitrobenzene (J.C.S., 1933, 105) in order to throw some light on the question of why a dehydrating agent such as sulphuric acid was required in many aromatic nitrations, for the withdrawal of a reaction product as such could not of itself facilitate a reaction which was irreversible, and ordinary nitration is irreversible. Hetherington and Masson (loc. cit.) argued as follows:- Evidently the prejudicial effect of water in nitrations must be due to its acting upon one of the initial reagents: the first obvious hypothesis is that if water were allowed to be present it would hydrate nitric acid, and that only unhydrated nitric acid (rendered so by sulphuric acid) could perform the reaction $R \cdot H + HNO_3 \longrightarrow R \cdot NO_2 + H_2O$. Such a mechanism was, in fact, put forward in connection with the nitration of cellulose by Kullgren (Ann. 1908, 1, 768), largely on the basis of the work of Saposchnikoff (Z. Ges. Schress. Sprengstoffw., 1904, 24, 453; Z. physik. Chem., 1904, 49, 697) and others. Saposchnikoff made valuable experiments upon the vapour pressures of nitric acid in its mixtures with sulphuric acid, which showed clearly the hydration of sulphuric acid at the expense of nitric acid; and he drew attention to a rough parallelism between the partial pressure of nitric acid vapour and the nitrogen content of the nitrocellulose which the acid mixture would yield. A survey of this subject has been made by Farmer (J. Soc. Chem. Ind., 1931, 50, 75 T), using Hantzsch's ideas of the existence of acids in a "pseudo acid" form. It would not, however, be safe to apply inferences drawn from reversible aliphatic esterifications to true aromatic nitration, and still less from esterifications of heterogeneous colloidal material in which not only the formation of sulphuric esters, but also rates of selective diffusion, play a considerable part (cf. Berl and Klage, Ann., 1908, 1, 504).

From the work of Veley and Manley (J., 1903, 83, 1015), Schaefer (Z. anorg. Chem., 1916, 98, 70), and Hantzsch (Ber., 1925, 58, B 941), on the optical and other properties of aqueous nitrates, nitric esters, solutions of nitric acid and sulphuric-nitric mixtures, it has been inferred by Hantzsch (loc. cit.) that in the two last-named cases, nitric acid is present, not only as ionised $(H_3O)^+(NO_3)^-$ and non-ionic $HO\cdot NO_2$, but also as "nitronium" salts, analagous to the isolated crystalline compounds $2HClO_4$, HNO_3 and $HClO_4,HNO_3$ or $(HHNO_3)^+ClO_4^-$. Hantzsch's work on electrical conduction and molecular weights in sulphuric acid is also taken into account. Thus, in highly concentrated nitric acid, the polymeric form $H_2N_2O_6$, recognised by earlier workers, is regarded by Hentzsch and Wolf as nitronium nitrate; and in a sulphuric solution of nitric acid the corresponding acid sulphate is believed to be present.

Hetherington and Masson (loc. cit.) pointed out that the compound $H_2SO_4\cdot H_2O$ was well recognised and melted fairly sharply at 8·6°C. Nitric acid forms two crystalline hydrates, $HNO_3\cdot 3H_2O$ and $HNO_3\cdot H_2O$, melting at -18°C, and with partial decomposition at -37°C. From their results they concluded that the primary condition for nitration to proceed at an appreciable rate was controlled by the equilibrium:

$$H_2SO_4 + HNO_3{\cdot}H_2O \rightleftharpoons H_2SO_4{\cdot}H_2O + HNO_3$$

or preferably adopting a more modern formulation:

$$H_2SO_4 + (H_3O)^+(NO_3)^- \rightleftharpoons (H_3O)^+(HSO_4)^- + HNO_3$$

Masson (J., 1931, 3200) proved the formation of a stable complex, electrolytic in nature, between nitrobenzene and sulphuric acid. Besides this, the high mutual miscibility of nitric acid and nitrobenzene, without any nitration occurring, suggested that these two could form a similar complex. This would be analagous to Hantzsch's nitronium nitrate. Gibby (J., 1932, 1540) had shown the conditions under which the nitrobenzene-sulphuric acid complex freezes out in the presence of water, and the extent of its solubility was shown in J., 1933, 109. There was clearly an equilibrium:

$$(Ph{\cdot}NO_2{\cdot}H)^+ + H_2O \rightleftharpoons Ph{\cdot}NO_2 + H_3O^+$$

It was suggested by Masson (loc. cit.) that in the meta nitration of nitrobenzene the immediate organic reagent was not molecular nitrobenzene but the cation $(Ph{\cdot}NO_2{\cdot}H)^+$ of this complex. On this view it was rather the group $(-NO_2H)^+$ than the simple nitro group which was responsible for the ensuing meta-substitution in acid media. Bringing together their observations, Hetherington and Masson stipulated as antecedents to the nitration of nitrobenzene at least four interconnected equilibria:-

1) $H_2SO_4 + (H_3O)^+(NO_3)^- \rightleftharpoons (H_3O)^+(HSO_4)^- + HNO_3$

2) $H_2SO_4 + Ph \cdot NO_2 \rightleftharpoons (Ph \cdot NO_2 \cdot H)^+(HSO_4)^-$

3) $HNO_3 + Ph \cdot NO_2 \rightleftharpoons (Ph \cdot NO_2H)^+(NO_3)^-$

4) $(Ph \cdot NO_2 \cdot H)^+ + H_2O \rightleftharpoons PhNO_2 + (H_3O)^+$

The ensuing bimolecular irreversible nitration itself then took the course:-

5) $(Ph \cdot NO_2 \cdot H)^+ + HNO_3 \Longrightarrow C_6H_4{:}(NO_2)_2 + (H_3O)^+$

That the nitrate ion could be the nitrating agent instead of the anhydrous nitric acid molecule appeared to be excluded by the fact that fuming nitric acid, although it so rich in nitrate ions, does not appreciably nitrate nitrobenzene dissolved in it. Hetherington and Masson, however, agreed that their work furnished no evidence as to the nature of the anhydrous nitric acid molecules. The function of the sulphuric acid was therefore shown to be the liberation of the anhydrous pseudo-nitric acid from the dissociated hydroxonium nitrate. The very strongly inhibiting effect of water was explained by the hydration of the acids and also by reaction (IV) in which it decomposed the organic cation formed by nitrobenzene with the unhydrated acids. The inhibiting effect of excess nitrobenzene was evidently due to its forcing equilibrium (2) towards the right-hand side - this by using up sulphuric acid displaced (1) towards the left, with consequent lowering in the concentration of anhydrous nitric acid.

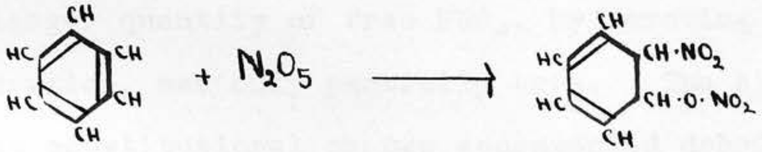
Evidence had been obtained already that some change took place in nitric acid in presence of excess of sulphuric acid. Saposchnikoff (Z. physik. Chem., 1904, 49, 697; 1905, 51, 609; 53, 225) deduced such a change from abnormalities in the vapour pressure, and from the electric conductivity of nitric acid in excess of sulphuric acid, and attributed it to the nitric anhydride. Walden (Z. angew. Chem., 1924, 37, 390) made a similar suggestion, and von Halban (Z. physik. Chem., 1928, 132, 433) attributed changes in the absorption spectrum to nitric anhydride. From physico-chemical studies Klemenc (Z. anorg. allgem. Chem., 1924, 141, 231) concluded that the nitrating effect of mixed acids was to be traced to the formation and activity of dinitrogen pentoxide, nitric anhydride.

It was well known that the anhydride of nitric acid could be obtained by distilling the acid in the presence of a strong dehydrating agent. When phosphorus pentoxide is employed as the dehydrating agent, hydrated phosphoric acid is produced, along with dinitrogen pentoxide. Thus, the following equilibrium can be shifted either to the side of the acid or the anhydride, by the addition or removal of water:

$$2HNO_3 \underset{H_2O}{\overset{P_2O_5}{\rightleftharpoons}} N_2O_5 + H_2O$$

According to Schaarschmidt (Z. angew. Chem., 1926, 39, 1457), the dinitrogen pentoxide which was made available in nitrating mixed acids was indeed among the most powerful of the nitrating agents.

For the interpretation of the mechanism of the reaction, the anhydride presumably added on to the aromatic compound, forming a derivative of dihydrobenzene:



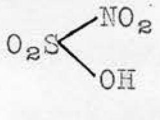
Owing to the instability of the addition complex, it decomposed into nitrobenzene and nitric acid. The liberated acid then reacted with sulphuric acid to regenerate the anhydride. The reaction cycle could be represented diagrammatically, as follows:-

$$\begin{tikzcd}
2HNO_3 + H_2SO_4 \arrow[r, shift left] & N_2O_5 + H_2SO_4\text{ aq.} \arrow[l, shift left] \arrow[d, "C_6H_6"] & \\
HNO_3 \arrow[u] & \left[C_6H_6 \begin{smallmatrix} NO_2 \\ ONO_2 \end{smallmatrix} \right] \arrow[l] \arrow[r] & C_6H_5\cdot NO_2
\end{tikzcd}$$

This hypothesis represented the function of sulphuric acid as merely that of dehydrating nitric acid. Wieland (Ber., 1919, 53, 201), however, assumed that the sulphuric acid functioned subsequent to the addition of $HO \cdot NO_2$. This is hardly probable, however, in the light of the knowledge that nitrations with other nitrating agents, e.g., $C_6H_5 \cdot CO \cdot O \cdot NO_2$, $CH_5CO \cdot O \cdot NO_2$, etc., can be carried out in organic solvents.

Schaefer (Zeit. anorg. allgem. Chem., 1916, 97, 285; 98, 70) concluded from absorption spectra studies that Saposchnikoff's interpretation (J. Russ. Phys. Chem. Soc., 1906, 38, 1192; 1914, 46, 1102) that the sulphuric acid acted only as a dehydrating agent which made possible a larger quantity of free HNO_3, by removing its water of hydration, was only partially true. The spectrum showed that constitutional change accompanied dehydration.

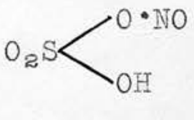
Although nitrosulphonic acid is introduced or formed in certain nitration operations, its role in the reaction is still obscure. Generally its activity has been interpreted as being that of an energetic dehydrating agent.



$O_2S{<}^{NO_2}_{OH}$

I.

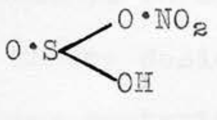
comparatively stable



$O_2S{<}^{O \cdot NO}_{OH}$

II.

nitrosyl sulphuric acid



$O \cdot S{<}^{O \cdot NO_2}_{OH}$

III.

It is doubtful whether nitrosulphonic acid could nitrate unless it was available in this form.

Three possible structures for nitrosulphonic acid are given.

Varma (J.A.C.S., 1925, 47, 143) produced a whole series of nitro compounds employing nitrosulphonic acid in fuming nitric acid. He concluded that nitrosulphonic acid functions because of its dehydrating action, in which respect it is more efficacious than sulphuric acid. Varma prepared the nitrating agent by passing in a stream of SO_2 into cold fuming nitric acid (S.G. 1·502) until the yield of nitrosulphonic acid was about 50%. Crystals of the acid had no effect on benzene, whereas a mixture of benzene, sulphuric acid and nitrosulphonic acid blackened on warming but yielded no nitrobenzene. However, when a 40% solution of nitrosulphonic acid in fuming nitric acid was used, a good yield of nitrobenzene was obtained.

From the above general summary of the views advanced by various workers upon the mechanism of nitration, it will readily be seen that no theory advanced so far can account for all the facts. Further, by the use of such solvents as sulphuric acid, uncertainty as to the nature of the actual nitrating reagent itself is introduced. In an attempt to obtain further information upon this subject, it was decided to carry out nitrations with pure nitrogen pentoxide as the nitrating reagent.

EXPERIMENTAL.

The experimental work carried out is described in the following pages. Yields of products are quoted as percentages of the maximum theoretical amounts obtainable. Melting points are corrected,the thermometer used having been calibrated against short-stemmed standard thermometers. All new compounds have been analysed and the method of analysis is noted in each case.

Preparation of Nitrogen Pentoxide.

(Although the official name of this reagent
is dinitrogen pentoxide, the old
name of nitrogen pentoxide
is retained throughout).

Nitrogen pentoxide was prepared by the dehydration of nitric acid with phosphorus pentoxide by a modification of the methods described by Berthelot and Weber (Weber, J. prakt. Chem., 1873, 6, 342 ; Berthelot, Ann. Chim. Phys., 1875, 6, 202): Daniels (J.A.C.S., 1920, 42, 1133), and Haines and Adkins (J.A.C.S., 1925, 47, 1425). Nitric acid was first dried by distilling fuming nitric acid (S.G. 1·51) from phosphorus pentoxide, i.e., an anhydrous nitric acid was first formed. An all-glass apparatus was used.

This acid, along with twice its weight of phosphorus pentoxide, which had been slowly added with external cooling to prevent local rise of temperature, was placed in a 2-litre Pyrex flask provided with a Pyrex condenser at right angles to the neck. This condenser side-arm had a ground glass end which fitted tightly into a Pyrex receiving flask which had another exit. This exit and the neck of the 2-litre distilling flask were loosely packed with glass wool impregnated with P_2O_5 to prevent access of moisture from outside. In cases where stirring was desirable, the condenser side-arm was fitted with an adaptor which led into a 3-necked Pyrex flask of the required capacity which was protected in a similar manner from the entry of moisture. The third neck was fitted with a suitable stirring arrangement. The distilling flask containing the pasty mass of anhydrous nitric acid and phosphorus pentoxide was immersed in a water-bath. On raising the temperature of this water-bath to 60-75°C, dinitrogen pentoxide slowly distilled over into the receiving flask which was held in an ice-salt mixture at from -15° to 0°C, where it solidified into a heavy, brittle, slightly yellow solid. The dinitrogen pentoxide so obtained could be kept in a glass-stoppered bottle in a cold desiccator containing a shallow layer of sulphuric acid. The desiccator was then kept in a refrigerator until required. Except for traces of nitrogen tetroxide, which were negligible in the following experiments, the product thus obtained was quite pure. The yield was about 50% of that calculated on the basis of the acid used. In many cases a solution of nitrogen pentoxide in dry carbon tetrachloride was used as the nitrating reagent. A 33% solution of nitrogen pentoxide in carbon tetrachloride was easily prepared; was much more easily handled than the solid nitrogen pentoxide; could be kept for long periods without decomposition, and gave a simple method of adding accurately a required weight of the nitrogen pentoxide.

EXPERIMENTS CARRIED Out With NITROGEN PENTOXIDE.

(1) Nitration of Benzene.

When benzene was placed in the receiving vessel and nitrogen pentoxide was distilled drop by drop into it, a violent reaction took place instantaneously as each drop fell into the cooled benzene, and a red-brown oil was formed. This was shaken up with water to remove nitric acid and distilled. Nitrobenzene distilled over in quantitative yield. It was necessary to keep the benzene at a low temperature, otherwise m-dinitrobenzene was formed in considerable quantity. Immersion in an ice-salt-hydrochloric acid (concentrated) freezing mixture was found to be very helpful in maintaining a temperature of below 0°C.

The nitration was repeated in dilute carbon tetrachloride solution and again a quantitative yield of nitrobenzene was obtained. One molecule of nitric acid was produced for every molecule of benzene nitrated. The equation for the reaction is, therefore, as follows:

$$C_6H_6 + N_2O_5 \longrightarrow C_6H_5.NO_2 + HNO_3$$

Yield: quantitative.

B.p.: 206°C.

(2) Dinitration of Benzene and Nitration of Nitrobenzene.

On the addition, as above, of 2 moles of nitrogen pentoxide to benzene at 0°C, a violent reaction took place on the addition of the reagent. When roughly about half of the theoretical quantity of nitrogen pentoxide had been added, crystals began to appear in the reaction vessel. On addition of the theoretical quantity of nitrogen pentoxide, and after washing with water to remove adherent nitric acid formed in the reaction, a quantitative yield of m-dinitrobenzene was obtained. Similar results were obtained when the theoretical amount of nitrogen pentoxide was added to nitrobenzene. Both these reactions were repeated in dilute carbon tetrachloride solution and again quantitative yields of m-dinitrobenzene were obtained. The equations for the reactions are as follows:-

$$C_6H_6 + 2N_2O_5 \longrightarrow C_6H_4(NO_2)_2 + 2HNO_3$$

$$C_6H_5{\cdot}NO_2 + N_2O_5 \longrightarrow C_6H_4(NO_2)_2 + 2HNO_3$$

Yield: quantitative.
M.p.: 90°C.

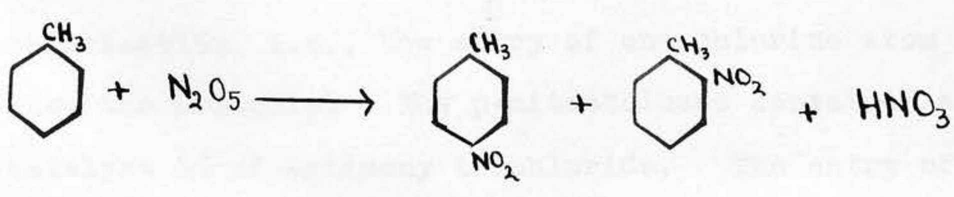
(3) Trinitration of Benzene.

On the addition of 3 moles of nitrogen pentoxide to 1 mole of benzene, as described above, the only product isolated was m-dinitrobenzene. Even on addition of excess nitrogen pentoxide no trinitrobenzene could be detected.

(4) Nitration of Toluene.

When toluene was nitrated in a similar manner to benzene a mixture of the isomeric ortho- and para-nitrotoluenes was obtained. The boiling point of this mixture was 228°C. The yield of the mixed mononitrotoluenes was quantitative.

Equation for the Reaction:



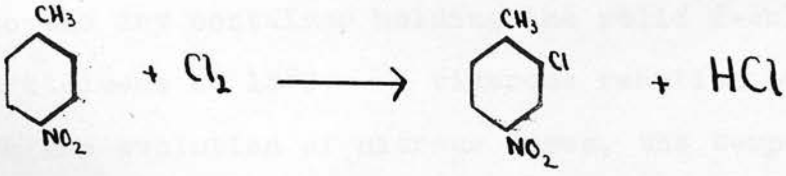
The reaction was repeated in carbon tetrachloride solution and a partial separation of the two isomers was carried out as follows. The carbon tetrachloride reaction mixture was shaken up with water to remove the nitric acid formed in the reaction. It was then distilled, carbon tetrachloride distilling at 80°C being first removed, and the fractions distilling at 218-225°C and 225-240°C were collected separately. The first fraction was pure o-nitrotoluene, a pale-yellow oil at ordinary temperatures. The second fraction was placed in an ice-salt freezing mixture, when a considerable amount of solid separated out. This solid was filtered off and on recrystallisation from methyl alcohol gave a melting point of 54°C. It was, therefore, pure p-nitrotoluene. The remaining mother liquor consisted of a mixture of ortho- and para-nitrotoluenes.

(5) The Nitration of 2-Chloro-4-nitrotoluene.

(a) Preparation of 2-Chloro-4-nitrotoluene.

Davies (J.C.S., 1921, 118, 860 ; 1922, 121, 806-815). This substance was prepared by passing a regulated amount of chlorine gas into p-nitrotoluene at 65-75°C until the increase in weight corresponded to monochlorination, i.e., the entry of one chlorine atom into the molecule. The p-nitrotoluene contained as catalyst 5% of antimony trichloride. The entry of the chlorine atom was accompanied by the evolution of a considerable amount of heat so that no external heating is required after the commencement of the reaction which proceeded smoothly. Care had to be taken that the temperature did not rise above 80°C., otherwise substitution might take place in the side-chain, as this reaction is favoured by higher temperatures.

The product which solidified on cooling was freed from antimony trichloride by stirring with water at 40°C and extracting with benzene. The benzene solution was filtered from antimony oxychloride, washed firstly with dilute NaOH and then with water, finally being dried over $CaCl_2$ overnight. The benzene was removed and the product distilled. It distilled over at 247-251°C at 750 mm., yielding white needles melting at 63-65°C. The yield obtained was 95% of the theoretical.



(b) Nitration of 2-Chloro-4-nitrotoluene. A dilute solution of 2-chloro-4-nitrotoluene in carbon tetrachloride was prepared in a 3-necked Pyrex flask. One neck carried a thermometer, the second a dropping funnel, and the third a glass exit tube for any nitrous gases evolved during the reaction. These were held in stoppers made from asbestos strips. These asbestos stoppers, unlike ordinary corks or rubber stoppers, were impervious to nitrous fumes.

In the first experiment the reaction vessel was held in an ice-salt freezing mixture at -5°C, and a solution of nitrogen pentoxide in carbon tetrachloride, of known concentration, was allowed to drop in. No reaction took place. This may have been due to the dilution of the reagents by the carbon tetrachloride, or to steric hindrance effects, as it was considered likely that the 5-position would be nitrated.

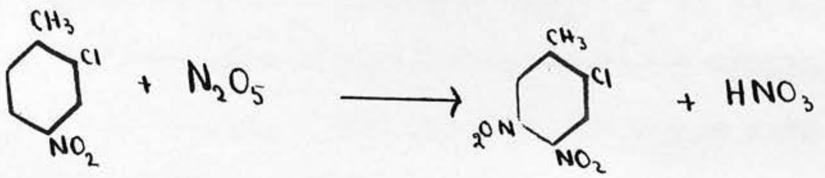
The experiment was repeated at 50°C, once more using carbon tetrachloride solutions of the reagents. Again no reaction took place.

To obviate the difficulty of dilution, nitrogen pentoxide was then slowly distilled directly into the dry container holding the solid 2-chloro-4-nitrotoluene at 15°C. A vigorous reaction took place with the evolution of nitrous fumes, the temperature meanwhile rising rapidly until in a few moments the contents of the reaction vessel became molten. After one molecular equivalent of nitrogen pentoxide had been added (found by weighing the reaction vessel at frequent intervals), the reaction mixture was poured into water and a solid was precipitated. This solid was shaken up with water to remove nitric acid, filtered off, and recrystallised from methyl alcohol, yielding a white crystalline compound, m.p. 88°C. This compound 2-chloro-4-5-dinitrotoluene crystallised in needles. The experiment was repeated on a larger scale, using 20 g. 2-chloro-4-nitrotoluene and adding the theoretical amount of nitrogen pentoxide. On shaking up with water and separation with ether, the crude product gave a m.p. of 46°C. The m.p. of pure 2-chloro-4-5-dinitrotoluene is 88-89°C. The m.p. of pure 2-chloro-4-6-dinitrotoluene is 49°C. Morgan and Drew (J.C.S., 1920, <u>117</u>, 786) found that on nitration of 2-chloro-4-nitrotoluene by means of a mixture of nitric and sulphuric acids, they obtained a mixture of these two isomers. They obtained 85% of the 2-chloro-4-5-dinitrotoluene and 12% of the 2-chloro-4-5-dinitrotoluene.

Separations of any possible isomers in the crude product, m.p. 46°C., were attempted as follows:-

1) Fractional crystallisation from methyl alcohol. This proved unsuccessful.
2) Steam distillation. On subjecting the crude product to steam distillation a separation took place. The substance remaining in the distillation vessel was recrystallised from methyl alcohol and yielded white needles melting sharply at 88-89°C. It was therefore 2-chloro-4-5-dinitrotoluene. This formed by far the greater part of the product.

The distillate was recrystallised from methyl alcohol and yielded white needles, m.p. 63·5 - 65°C. It was unchanged 2-chloro-4-nitrotoluene. In this way from 20 g. 2-chloro-4-nitrotoluene, 20·5 g. 2-chloro-4-5-dinitrotoluene and 3 g. unchanged 2-chloro-4-nitrotoluene were obtained on the addition of one equivalent of nitrogen pentoxide.



Yield = 81·3%

M.p. = 88-89°C.

(6) Nitration of Phenol and the Bromophenols.

A solution of phenol in carbon tetrachloride was rapidly and quantitatively nitrated to picric acid by the use of nitrogen pentoxide as nitrating agent, even below 0°C. This result was also reported by Haines and Adkins (J.A.C.S., 1925, 47, 1419).

(a) Nitration of the bromophenols. Phenol was dissolved in its own weight of glacial acetic acid and the calculated quantity of bromine, dissolved in the same solvent (1 c.c. containing 1·5 g. bromine), was added, drop by drop, to the phenol solution, keeping the temperature below 21°C. The product was diluted with water and the separated oil was washed repeatedly with water, and this mixture of ortho- and para-bromophenols was used for the first nitration.

The mixture of bromophenols was kept in a well-cooled receiver into which the nitrogen pentoxide was distilled, drop by drop. An ice-salt freezing mixture was necessary to keep the temperature down to the required degree. Crystals began to be deposited when about half the theoretically required amount of N_2O_5 had been added. The product was mixed with water and washed until free from acid. It was then transferred to a flask and steam distilled. The products at this stage were (a) 4-bromo-2-nitrophenol, (b) 2-bromo-4-nitrophenol, (c) 2-bromo-4-6-dinitrophenol. The proportions depend on the amount of N_2O_5 added, and the temperature at which the nitration was carried out. The nitration product was steam distilled, the 4-bromo-2-nitrophenol being thus removed. A little of the 2-bromo-4-6-dinitrophenol may come over but this solidifies in the condenser. When this happened, the distillation was stopped. The mixture in the flask was treated with excess ammonia to convert the bromonitrophenols to the ammonium salts, and filtered when cold to remove the 2-bromo-4-6-dinitrophenol ammonium salt which is only slightly soluble in cold water. The filtrate now contained the whole of the 2-bromo-4-

nitrophenol. The filtrate was acidified with HCl and the 3-bromo-4-6-dinitrophenol, which had been left behind in the filtrate, separated after stirring for a short time and was filtered off. The filtrate was now evaporated and allowed to stand, when the 2-bromo-4-nitrophenol crystallised out in flat white needles, m.p. 112°C.

Summary:

Phenol, when brominated, yielded a mixture of ortho and para bromophenol. When this mixture was nitrated by means of N_2O_5, the product obtained depended on the temperature at which the nitration was carried out.

1) At temperatures below 15°C. The ortho-bromophenol nitrated firstly in the 4-position, and then in the 6-position, yielding 2-bromo-4-6-dinitrophenol. On further nitration the product obtained was picric acid.

   The para-bromophenol nitrated firstly in the 2-position and then in the 6-position, yielding 4-bromo-2-6-dinitrophenol. On further nitration, the product was, as above, picric acid.

2) At higher temperatures. The ortho-bromophenol behaved as above.

   The para-bromophenol behaved in a curious manner. 2-Nitro-4-bromophenol was formed as above, but under the influence of the higher temperature the bromine atom in the 4-position migrated to the 6-position, and as the nitration progressed 6-bromo-2:4-dinitrophenol was formed, as in the case of the ortho-bromophenol. This is the same compound as the 2-bromo-4-6-dinitrophenol mentioned above. On further nitration, picric acid was again the final product.

The replacement of bromine by the nitro group in the bromophenols:

When tribromophenol in glacial acetic acid solution was treated with N_2O_5, replacement of the bromine atoms in the 2-, 4- and 6- positions took place readily, yielding finally picric acid. When insufficient N_2O_5 was added for replacement of all three bromine atoms, the product isolated was 2-bromo-4-6-dinitrophenol. This occurred at a moderately high temperature. When the nitration of tribromophenol was carried out in carbon tetrachloride solution below 15°C, by means of a solution of N_2O_5 in carbon tetrachloride, the product obtained was 2-6-dibromo-4-nitrophenol, m.p. 143°C.

When this result was considered along with those previously obtained, it was observed that in the progressive substitution of bromine atoms by nitro graphs, the bromine atoms in the 4-, 6-, and 2-positions were replaced in that order.

a) o-bromophenol--2-bromo-4-nitrophenol--2-bromo-4-6-dinitrophenol--picric acid.

b) p-bromophenol--4-bromo-2-nitrophenol--4-bromo-2:6-dinitrophenol--picric acid (below 15°C.).

c) p-bromophenol--4-bromo-2-nitrophenol-2-bromo-4-6-dinitrophenol--picric acid (above 15°C.).

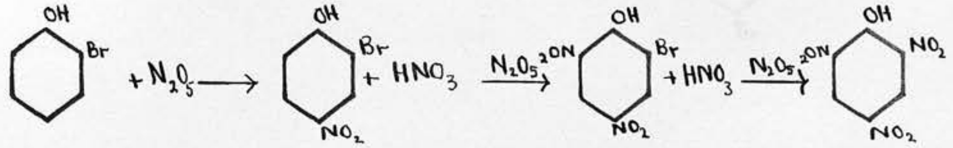
d) Tribromophenol (glacial acetic acid solution)--2-bromo-4-6-dinitrophenol (above 15°C.).

e) Tribromophenol (in carbon tetrachloride solution--2-6-dibromo-4-nitrophenol (below 15°C.).

In all cases the yields of the nitro compounds were theoretical.

Equations for the reactions:

a)



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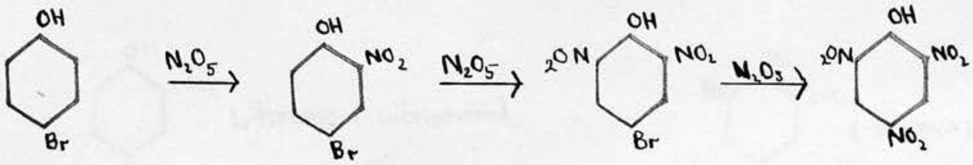
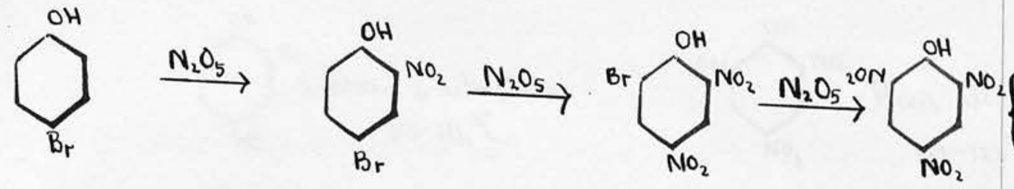


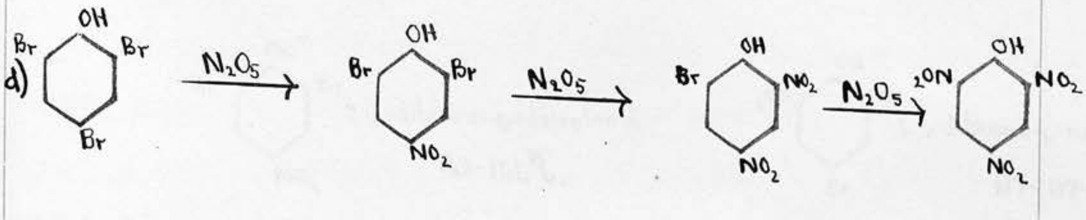
{below 15°C.}

c)



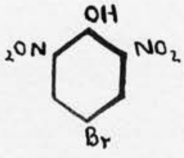
{above 15°C.}

d)

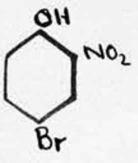


Melting Points

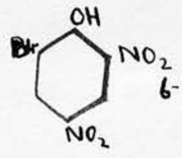
Phenol 42-43°C.



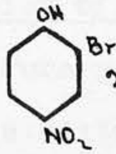
4-bromo-2:6-dinitrophenol.
76°C.



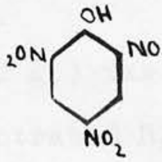
4-bromo-2-nitrophenol.
88°C.



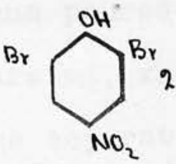
6-bromo-2:4-dinitrophenol.
119-120°C.



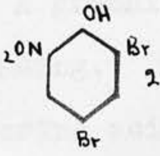
2-bromo-4-nitrophenol
113-114°C.



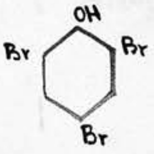
Picric Acid
121-122°C.



2:6-dibromo-4-nitrophenol
143-144°C.



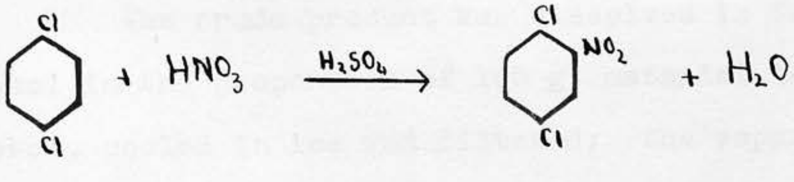
2:4-dibromo-6-nitrophenol
117-117.5°C.



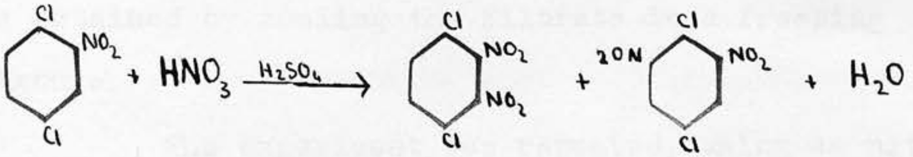
Tribromophenol
95-96°C.

(7) Nitration of p-dichlorobenzene.

Pure p-dichlorobenzene (100 g.) was added slowly to a mixture of 1000 g. concentrated H_2SO_4 and 400 g. fuming nitric acid (S.G. 1·51), and heated in a flask over a free flame at 70-100°C. for five hours with a large funnel inserted in the neck of the flask to act as a condenser. The mixture was partially cooled and poured on to cracked ice. A greenish-yellow oil separated, which solidified on standing. The solid was separated and freed from adhering acid by passing steam into the molten substance beneath water. The yield of 1-4-dichloro-2-nitrobenzene was 100%, m.p.



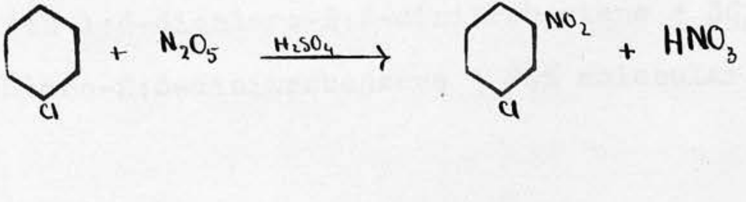
Nitrating acid (475 g.) of composition H_2SO_4 78·5%, HNO_3 16·7%, H_2O 5·0% (obtained by mixing 96% H_2SO_4 and 90% HNO_3 in the proportion of 480 - 133 c.c.) was placed in the nitrating vessel. Crude 1-4-dichloro-2-nitrobenzene (100 g.) was added gradually in the course of 20 minutes, with constant stirring, to the mixed acids which had been previously heated to 60°C. The temperature was kept below 75°C for 40 minutes. Then the temperature was raised to 120°C in 15 minutes and kept there for 80 minutes. The flask and contents were then allowed to cool to 80°C, when 70 c.c. water were run in, the temperature being allowed to rise to 90°C, stirring vigorously meanwhile. The mixture was allowed to settle, separated, and the molten product washed by blowing steam through the nitration product beneath water until the wash water was no longer acid. The yield of mixed dinitro compounds was theoretical.

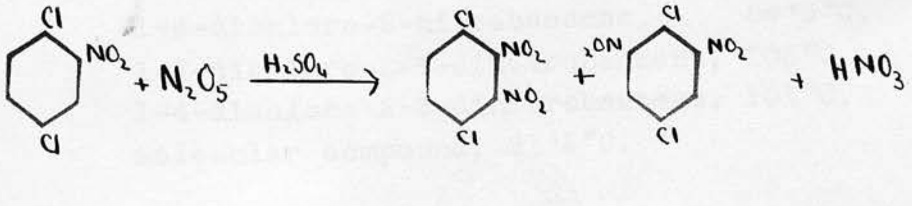


The crude product was dissolved in 95% alcohol in the proportion of 100 g. material to 3 litres alcohol, cooled in ice and filtered; the separated 1-4-dichloro-2-6-dinitrobenzene crystallised in a comparatively pure state. Two recrystallisations from alcohol gave a pure product, m.p. 105°C. The alcohol filtrate from which this isomer had been separated was distilled. It had been found that if the quantity of distillate was limited to about 750 c.c. per litre filtrate and the mixture allowed to cool very gradually in the water-bath overnight, a fraction consisting of a molecular compound of the two dinitro isomers crystallised in a fairly pure state and melted at 81-81·5°C. One recrystallisation from alcohol resulted in a product melting at 81·5°C. After this had been separated and the residual filtrate cooled in a freezing mixture, a fraction consisting of fairly pure 1-4-dichloro-2-3-dinitrobenzene separated. When the quantity of alcohol distilled varied much from that given, a mixture of both of these substances is obtained on cooling. It was almost invariably true that after the substance melting at 81·5°C had separated slowly at room temperature, the isomer melting at 101°C could be obtained by cooling the filtrate in a freezing mixture.

The experiment was repeated, using as nitrating reagent N_2O_5 instead of HNO_3. The N_2O_5 was distilled, in theoretical amount, into sulphuric acid solutions of the dichlorobenzene and dichloronitrobenzene. The procedure, apart from this, was as detailed above.

Equations for the reactions:





Yields: a) with HNO_3

1) 95% 1-4-dichloro-2-nitrobenzene.

2) 94% crude dinitro product consisting of 13·1% 1:4-dichloro-2-6-dinitrobenzene + 26·2% 1:4-dichloro-2-3-dinitrobenzene + 45·6% molecular compound (Mason, McLeod, Pfund and Kilpatrick, J.A.C.S., 1922, 64, 2260).

3) 1:4-Dichloro-2-6-dinitrobenzene and 1:4-dichloro-2-3-dinitrobenzene formed in about equal amounts (Page and Heasman, J.C.S., 1923, 123, 2, 3247).

4) 24% 1:4-dichloro-2:6-dinitrobenzene + 26% 1:4-dichloro-2:3-dinitrobenzene + 50% molecular compound (In this work).

b) with N_2O_5

1) in glacial acetic acid solution only mononitration could be accomplished and gave a quantitative yield of 1:4-dichloro-2-nitrobenzene.

2) in sulphuric acid solution. Quantitative yield of 1:4-dichloro-2-nitrobenzene.

3) 44% 1:4-dichloro-2:6-dinitrobenzene + 30% 1:4-dichloro-2:3-dinitrobenzene + 26% molecular compound.

Melting Points.

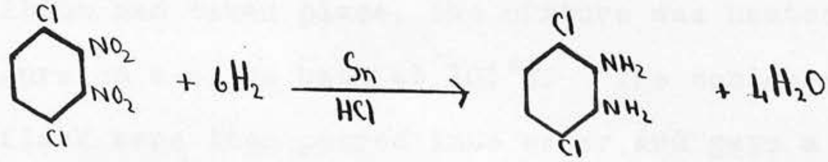
1-4-dichloro-2-nitrobenzene,	54·6°C.
1-4-dichloro-2-6-dinitrobenzene,	105°C.
1-4-dichloro-2-3-dinitrobenzene,	101°C.
molecular compound,	81·5°C.

Identification of 1:4-dichloro-2:3-dinitrobenzene.

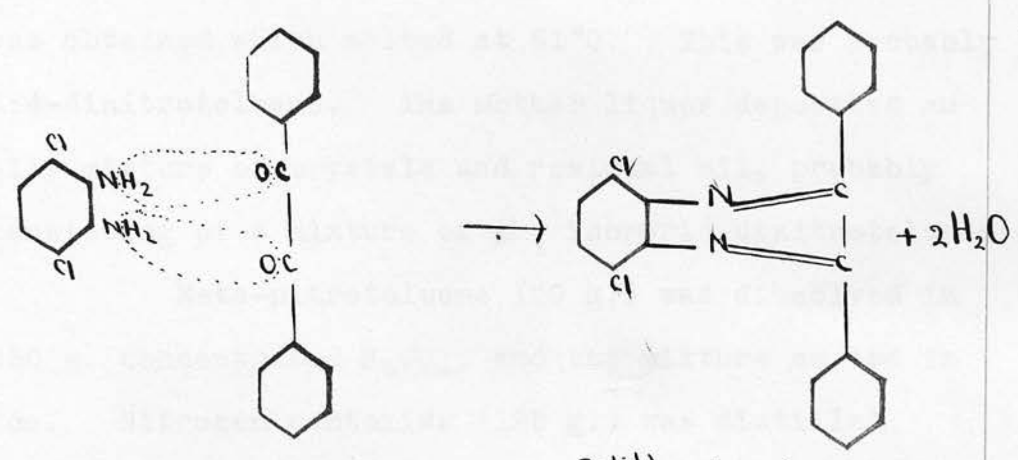
10 g. of 1:4-dichloro-2:3-dinitrobenzene, 30 g. of stannous chloride, and an excess of granulated tin were heated with 110 c.c. conc. HCl on the water-bath for 5 hours. After filtering off the residual tin, the excess HCl was evaporated off and 250 c.c. benzene were added. The acid liquid was treated with NaOH in the presence of the benzene. Under these conditions no black precipitate formed, and the precipitated tin hydroxide dissolved readily in the excess NaOH. After the NaOH had been added, the mixture was steam-distilled. The benzene distilled over first and was removed. The distillation was continued. Very fine white crystals of 1:4-dichloro-2:3-diaminobenzene separated from the distillate, forming a felt. These were crystallised from 50% alcohol and melted at 98°C.

To a solution of 2-3 g. benzil in hot alcohol, 2 g. (a slight excess) of 1:4-dichloro-2:3-diaminobenzene were added, and the mixture heated in a water-bath. Crystals began to separate almost immediately but the heating was continued for 1½ hours. The product was very soluble in benzene and alcohol, from which it separated in minute white needles (m.p. 214-215°C.) of p-dichloro-diphenylquinoxaline.

1)



2).



p-dichloro-diphenylquinoxaline

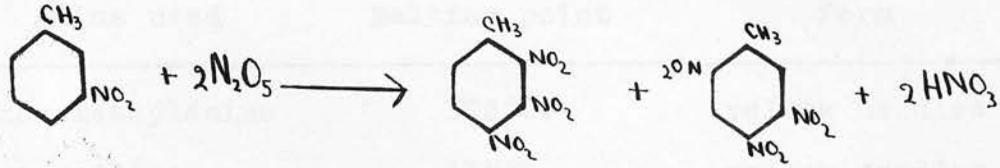
(8) Nitration of m-nitrotoluene.

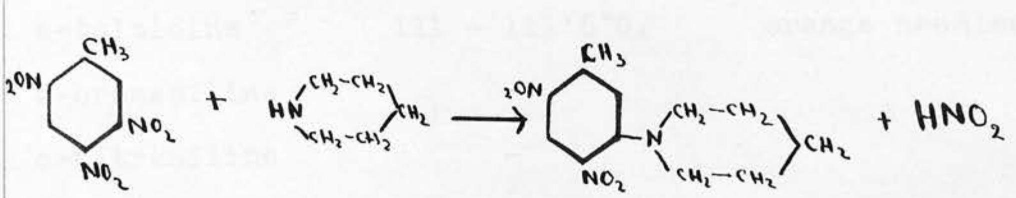
Meta-nitrotoluene (25 g.) was placed in the receiving vessel which was surrounded by an ice-salt freezing mixture, and the calculated amount of N_2O_5 for a dinitration was slowly distilled into it. After the addition had taken place, the mixture was heated for 6 hours on a brine bath at 103°C. The contents of the flask were then poured into water and gave a heavy green oil which solidified slowly on standing in ice, but melted on filtering. On dissolving the greasy solid in alcohol, a white crystalline substance was obtained which melted at 61°C. This was probably 3:4-dinitrotoluene. The mother liquor deposited an oily mixture of crystals and residual oil, probably consisting of a mixture of the isomeric dinitrotoluenes.

Meta-nitrotoluene (20 g.) was dissolved in 350 g. concentrated H_2SO_4, and the mixture cooled in ice. Nitrogen pentoxide (125 g.) was distilled slowly into the mixture which was then heated to 100°C. on a water-bath for some time. The mixture was then poured into 400 ml. water, when copious nitrous fumes were evolved. A white solid settled on the surface of the water, and a green oil, which rapidly solidified, settled on the bottom of the beaker. The solid was filtered off, ground and thoroughly washed with water to remove adhering acid. According to Hepp (Ann., 1862, <u>215</u>, 366) this solid consisted of a mixture of an α-trinitrotoluene, m.p. 104°C., and a β-trinitrotoluene, m.p. 112°C. On shaking up with CS_2, it was supposed that any β modification would dissolve, but on evaporation of the CS_2 the solid obtained melted at 80°C. - the same melting point as the crude nitration product. Fractional crystallisation from alcohol successfully yielded 14·7 g. of the α-isomer, m.p. 104°C., i.e., 3:4:6-trinitrotoluene and 11·3 g. of a crystalline solid, m.p. 80-82°C. No further separation could be performed without serious loss of the compound.

It was well known that in a trinitrotoluene such as 3:4:6-trinitrotoluene the nitro group in the 3 position is very labile. Compounds such as monomethylamine, piperidine, aniline, etc. will react with such a compound, and the labile nitro group will be replaced. To this mixture (m.p. 80°C.), dissolved in alcohol, excess piperidine was added. In a short time a mass of crystals appeared. Further precipitation of this yellow solid occurred in the addition of water. The lumpy solid was filtered off and recrystallised from methyl alcohol, yielding yellow needles, m.p. 115°C. This was the piperidine derivative of 3:4:6-trinitrotoluene. 11·9 g. of this compound were obtained from the mixed compound (11·3 g.). This corresponds to 10·2 g. 3:4:6-trinitrotoluene. By difference there must have been 11·3 - 10·2 = 1·1 g. of the β modification 2:3:4-trinitrotoluene present.

Equation for the reactions:





A whole series of amino derivatives of 3:4:6-trinitrotoluene were formed by heating a methyl alcohol solution of the trinitrotoluene with either the amine or a methyl alcohol solution of the amine for $\frac{1}{2}$ minute and allowing to cool. The derivatives crystallised out in well-determined crystals. The melting points of these are given below:

Amine used	Melting point	Crystalline form
monomethylamine	173°C.	yellow needles
piperidine	115°C.	yellow needles
aniline	146°C.	red needles
o-toluidine	111 - 111·5°C.	orange needles
o-bromaniline	-	
o-nitraniline	-	
anthranilic acid	124°C.	red needles
ethylamine	125°C.	yellow needles
n-propylamine	99°C.	yellow needles
n-butylamine	96°C.	yellow needles
iso-butylamine	88°C.	yellow needles
glycine	-	
hydrazine hydrate	196·5°C.	orange needles

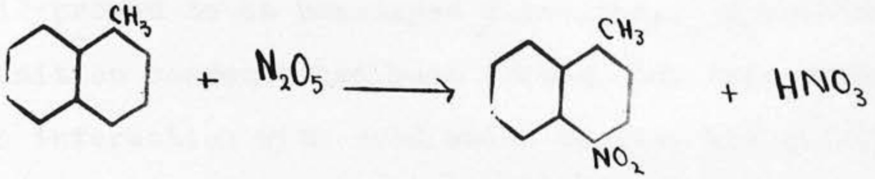
In the ortho-substituted aniline no compound could be obtained. This was probably due to the steric hindrance of the ortho-substituent to the reaction. These reactions constitute a useful series of tests, both for the 3:4:6-trinitrotoluene and the amines themselves. No further investigation along these lines was attempted, however, as a separate investigation is being carried out elsewhere.

(9) Nitration of α-Methylnaphthalene.

A quantity of 4-nitro-α-methylnaphthalene was required in the Department as the starting point of a synthesis of a benzanthrone derivative. A nitration using N_2O_5 was, therefore, tried in order to obtain an increased yield. α-Methylnaphthalene (44 g.) was placed in the receiver and surrounded by a freezing mixture. Nitrogen pentoxide (33·5 g.) was slowly distilled into the α-methylnaphthalene. This was done by weighing the reaction vessel at frequent intervals until the required increase in weight was observed. The oil so obtained was washed thoroughly with water to remove the nitric acid formed in the reaction, and was then extracted with ether. The ethereal solution was introduced into a Claisen distilling flask and the ether drawn off at the pump. The oil rapidly thickened and finally solidified into a crystalline mass. This crude product weighed 60 g., and represented a quantitative yield of nitro-compound. The m.p. was, however, rather indefinite.

This crude product was, therefore, subjected to a vacuum distillation, and the fraction distilling at 176°C. under 12 mm. pressure was collected. It solidified into a crystalline mass which, upon recrystallisation from methyl alcohol, yielded bright yellow needles, m.p. 71°C. The yield obtained was 75% of the theoretical but this might have been higher but for considerable charring which took place towards the end of the vacuum distillation.

Equation for the Reaction:



To prove the identity of the compound, 1·87 g. of the nitro-compound were dissolved in 30 g. H_2SO_4, and the solution was treated, drop by drop, with 3 g. of a 26% solution of HNO_3, and then heated for 5 hours at 30-40°C., and, after cooling, poured on ice. The precipitated solid crystallised from alcohol in light yellow needles of m.p. 91°C. This was a mixture of the mononitro-derivative, m.p. 71°C., and a 4:x:x-trinitro-derivative, m.p. 180-181°C. These can be separated by fractional crystallisation from carbon tetrachloride. The positions of the nitro goups in this compound are unknown.

(10) Nitration of Quinoline.

Quinoline (50 g.) was placed in the receiver which was surrounded by an ice-salt freezing mixture, and the theroetical quantity of N_2O_5 slowly distilled into it. A vigorous reaction took place with considerable evolution of nitrous gases. On pouring the reaction mixture into water, the yellow solid which had formed in the reaction vessel turned into a brown oil and collected in the foot of the beaker. A strong smell of quinoline was noticed. On investigation, the oil proved to be unchanged quinoline. Apparently an addition compound had been formed, but this decomposed on interaction with cold water to give the quinoline back again. Similar results were obtained with pyridine, in agreement with the results of Haines and Adkins (J.A.C.S., 1925, 47, 1419).

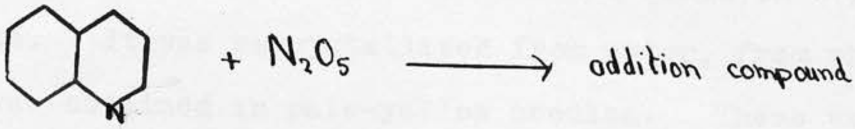
To 50 g. quinoline the theoretical amount of N_2O_5 was added as above, and the whole cooled. The solid cake of addition compound was powdered up and added in five portions to 50 c.c. concentrated sulphuric acid in a 1 litre flask, and 10 c.c. fuming sulphuric acid (S.G. 2·0) added after each addition of nitrate, the mixture being kept cool. The completion of the reaction (½ hour - 1 hour) was recognised by diluting a few drops of the mixture with water and neutralising with NaOH; the smell of quinoline had practically disappeared and the milky precipitate formed by the caustic soda solidified after a few minutes to a mass of crystals. The mixture was then poured into water, filtered, after cooling, from a small quantity of yellow crystalline substance, and gradually neutralised with NaOH. When cold, the crude, precipitated nitroquinolines were collected and dissolved in a large volume of boiling, very dilute nitric acid; on cooling, the nitrate of ananitroquinoline crystallised out in powdery crystals which were almost insoluble in cold water and very different from the large, well-formed tablets of the ortho-compound.

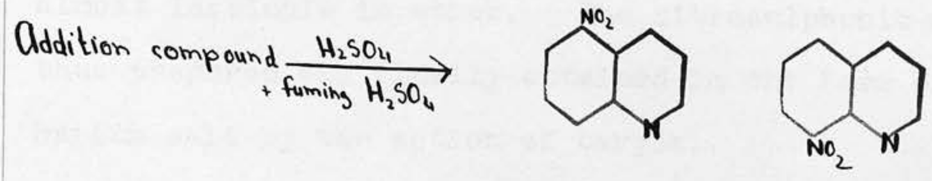
The mother liquors from the ananitrate were treated with excess NaOH; the precipitate, after being well pressed, was crystallised from alcohol; one recrystallisation gave practically pure orthonitroquinoline, m.p. 89°C. The alcoholic mother liquor contained both ana- and ortho-nitroquinolines, of which the former was extremely soluble in alcohol. These were separated after distilling off the solvent.

The recrystallised ananitrate was heated in a basin with a small quantity of water, and concentrated NaOH was added until the liquid, after continued boiling, remained alkaline; the nitroquinoline thus liberated was collected, washed with water, dried by gentle heating in a dish over a small flame, and crystallised from petrol-ether (b.p. 100-120°C.), when it formed pure, almost-white needles, m.p. 72°C. Yield: 50 g. quinoline gave 33·3 g. ananitroquinoline + 25 g. orthonitroquinoline; a total yield of 87%.

The insoluble yellow substance first obtained was dinitrohydroxyquinoline. It was recrystallised from a large amount of boiling water in small, shining, greenish-yellow leaflets which decomposed at 255°C.

Equation for the reaction:

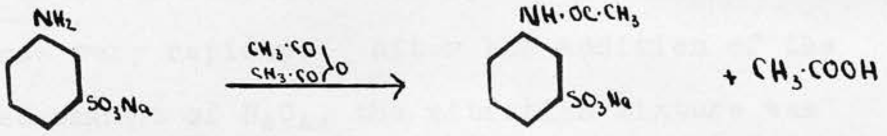


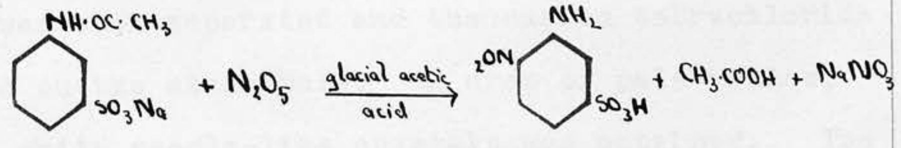


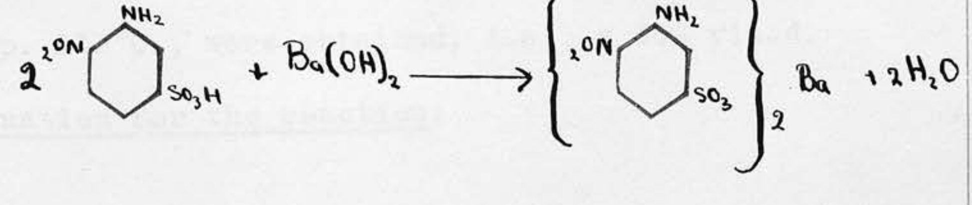
(11) Nitration of Metanilic Acid.

The sodium salt of metanilic acid was used for this experiment, as it was more readily available. The sodium salt of metanilic acid was first acetylated by heating with double the calculated quantity of acetic anhydride for 2 hours on the water-bath. With this treatment, acetylation occurred quite readily. For the purpose of nitration this semi-crystalline product was quite pure enough to use as the starting material.

This crude reaction product was dissolved in glacial acetic acid, and the theoretical amount of N_2O_5 was allowed to distil slowly into the well-stirred solution under external cooling. The mixture was allowed to stand for 2 hours and then poured on ice and allowed to stand overnight. A yellow solid separated, which was filtered off and dried on a porous plate. It was recrystallised from water, from which it was obtained in pale-yellow needles. These were moderately soluble in cold, rather more soluble in boiling water, difficultly soluble in alcohol, and almost insoluble in ether. The nitrosulphonic acid thus prepared was finally obtained in the form of its barium salt by the action of baryta.



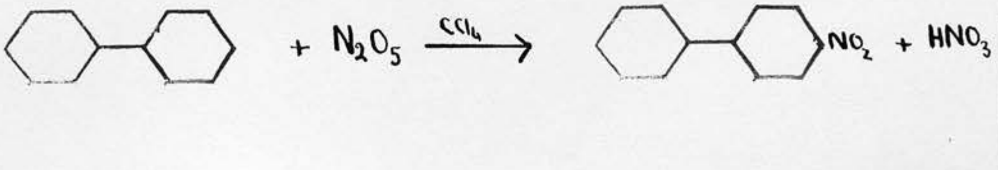




(12) Nitration of Diphenyl.

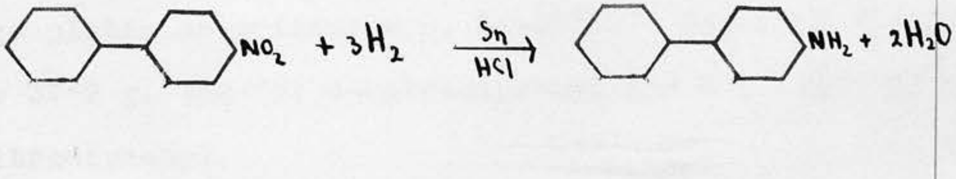
(a) Diphenyl (50 g.) was dissolved in carbon tetrachloride and the solution surrounded by an ice-salt freezing mixture. Into this solution under vigorous stirring the theoretical amount of N_2O_5 was slowly distilled (found by weighing the reaction vessel at frequent intervals until the required increase in weight was observed). A vigorous and instantaneous reaction took place as each drop of N_2O_5 fell into the solution. Care was taken that the N_2O_5 distilled very slowly into the reaction vessel, otherwise the temperature rose very rapidly. After the addition of the required amount of N_2O_5, the nitration mixture was poured into cold water and shaken up to remove nitric acid formed in the reaction. The carbon tetrachloride layer was then separated and the carbon tetrachloride removed on the steam-bath. A crop of pale-yellow, almost white, needle-like crystals was obtained. The crystals melted at 111-113°C. Upon recrystallisation from methyl alcohol, 62 g. of pure 4-nitrodiphenyl, m.p. 113°C., were obtained, i.e., a 96% yield.

Equation for the reaction:



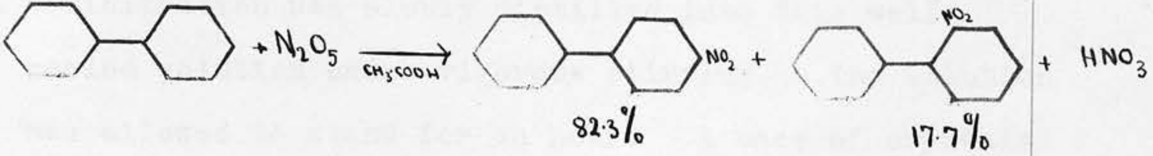
To prove its identity, the above product was reduced to the corresponding amine. Excess tin and some of the nitro-compound were placed in a R.B. flask fitted with an air condenser. Concentrated HCl was added in portions and the flask shaken. The temperature rose and the liquid boiled gently. The condenser was removed and the flask and contents were heated on the water-bath for an hour. The contents of the flask (a double salt of stannic chloride and the hydrochloride of 4-aminodiphenyl) were then treated with a 50% solution of NaOH until the stannic oxide first precipitated was nearly redissolved, and the liquid was strongly alkaline. The mixture was cooled during the addition of the NaOH. The contents of the flask were now steam-distilled, 4-aminodiphenyl being volatile in steam, and the distillate collected. Small, lustrous leaflets were separated from the distillate by filtration, m.p. 51°C.

Equation for the reaction:



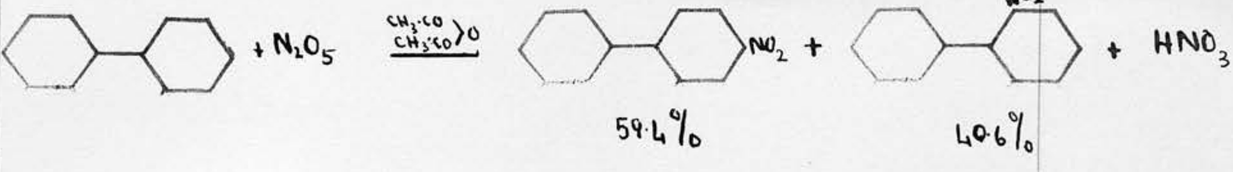
(b) Nitration in Glacial Acetic Acid. Diphenyl (35 g.) was dissolved in 70 g. glacial acetic acid and the solution cooled. To the well-stirred, cold solution the theoretical amount of N_2O_5 was added gradually, as described above. The solution darkened and a vigorous reaction set in. The N_2O_5 was added very slowly. On completion, the solution was cooled, and the crop of crystals obtained (30·2 g.) was separated by filtration. The filtrate was then poured into water and an oil was thrown out of solution. Part of the oil solidified and this was filtered off and proved to be 4-nitrodiphenyl. The residual oil was then heated in a current of steam to remove any unchanged diphenyl and any residual acid. It was then vacuum-distilled. A trace of diphenyl first distilled over, together with some moisture. The main bulk distilled over at 188-193°C. under 20 mm. pressure. This distillate was then dissolved in alcohol at 40°C. and the crystals of 4-nitrodiphenyl, which separated on cooling, were filtered off. On evaporation of the alcohol, 2-nitrodiphenyl crystallised in characteristic large plates or prisms, m.p. 35-37°C. Diphenyl (35 g.) gave 37·2 g. (82·3%) 4-nitrodiphenyl and 8 g. (17·7%) 2-nitrodiphenyl.

Equation for the reaction:



(c) Nitration in Acetic Anhydride. Diphenyl (40 g.) was dissolved in 100 c.c. acetic anhydride, and N_2O_5 (theoretical amount) was distilled into it. A violent reaction took place as each drop of N_2O_5 fell in, and despite efforts at cooling, the temperature rose rapidly. The reaction vessel was cooled overnight in a Frigidaire and the solid, which had separated out, was filtered off. The filtrate was then subjected to the same treatment as described above in the case of the nitration in glacial acetic acid. Diphenyl (40 g.) yielded 31 g. (59·4%) 4-nitrodiphenyl and 21 g. (40·6%) 2-nitrodiphenyl.

Equation for the Reaction:

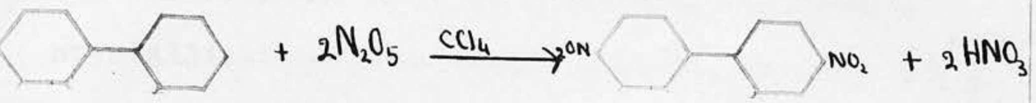


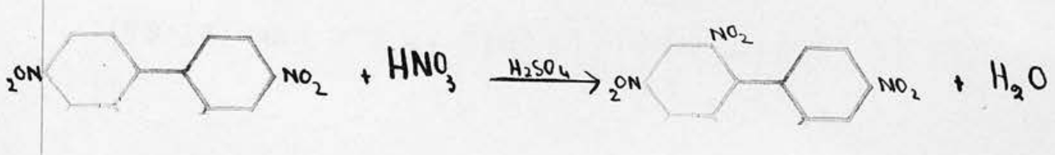
(13) Nitration of 4-Nitrodiphenyl in Carbon Tetrachloride Solution.

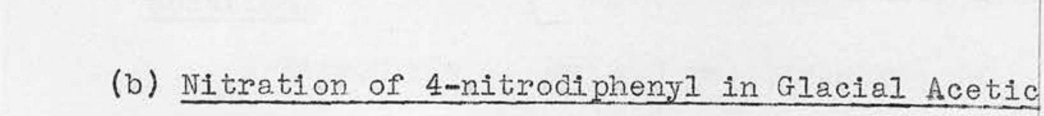
(a) Diphenyl (50 g.) was dissolved in carbon tetrachloride, and the theoretical amount of N_2O_5 for a dinitration was slowly distilled into this well-cooled solution under vigorous stirring. The solution was allowed to stand for an hour. A mass of crystals had formed in the nitration vessel. These were filtered from the mother liquor, washed with water and recrystallised from methyl alcohol. Pale-yellow needles of 4:4'-dinitrodiphenyl, m.p. 233°C., were obtained. On evaporation of the mother liquor, a further crop of these crystals was obtained. The total yield of 4:4'-dinitrodiphenyl was 96% of the theoretical. On treating a sample of these crystals with a mixture of sulphuric and nitric acids and heating, a trinitrodiphenyl, m.p. 176°C., was obtained in pale-yellow rhombic crystals. This is the 2:4:4'-trinitrodiphenyl.

The experiment was repeated. The amount of N_2O_5 theoretically required for a mononitration was added to 4-nitrodiphenyl dissolved in carbon tetrachloride. On treating the resultant solution as above, a 96% yield of 4:4'-dinitrodiphenyl was obtained. The residue was found to be unchanged 4-nitrodiphenyl.

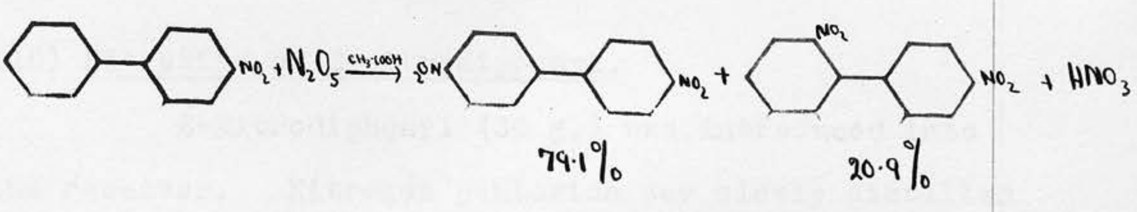
Equations for the reactions.







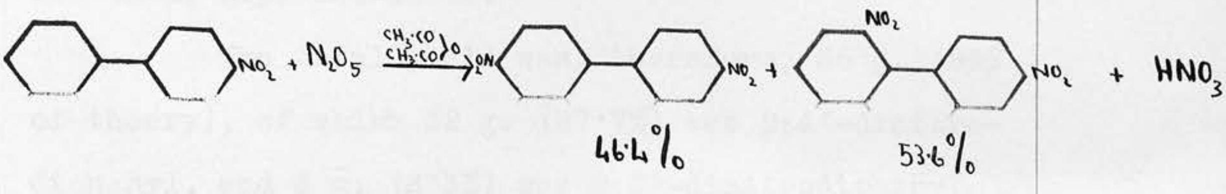
(b) Nitration of 4-nitrodiphenyl in Glacial Acetic Acid. 4-Nitrodiphenyl (20 g.) was dissolved in glacial acetic acid and the required amount of N_2O_5 was slowly distilled into the well-cooled vigorously stirred solution. A vigorous reaction took place. On the completion of the addition, the reaction mixture was allowed to cool, and crystals appeared. These were filtered off (15 g.) and recrystallised from methyl alcohol, m.p. 233°C. The filtrate from the crystals was poured into water. The solid precipitated was filtered off and, on undergoing fractional crystallisation from methyl alcohol, yielded 5·1 g. 4:4'-dinitrodiphenyl and 4·3 g. 2:4'-dinitrodiphenyl, m.p. 93-93·5°C. The 4:4'-dinitrodiphenyl was only sparingly soluble in the methyl alcohol. 4-Nitrodiphenyl (20 g.) yielded 20·1 g. 4:4'-dinitrodiphenyl (79·1%) and 4·3 g. 2:4'-dinitrodiphenyl (20·9%).



(14) Nitration of 4-nitrodiphenyl in Acetic Anhydride Solution.

4-Nitrodiphenyl (20 g.) was dissolved in acetic anhydride, and N_2O_5 was distilled into the well-cooled solution. An extremely vigorous reaction took place as each drop fell into the solution. When the amount of N_2O_5 theoretically required by the equation given below had been added, the reaction mixture was allowed to stand. 4:4'-Dinitrodiphenyl crystallised out and was filtered off. The mother liquor filtrate was poured into cold water, and the precipitated solid was fractionally crystallised from methyl alcohol. 4-Nitrodiphenyl (20 g.) yielded 10·4 g. (46·4%) 4:4'-dinitrodiphenyl and 14·0g.(53·6%) 2:4'-dinitrodiphenyl.

Equation for the reaction.



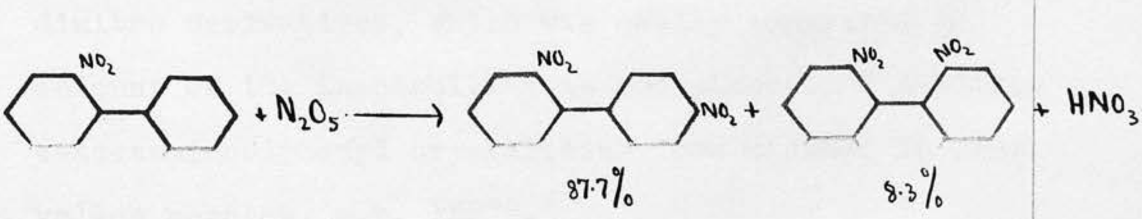
(15) Nitration of 2-nitrodiphenyl.

2-Nitrodiphenyl (30 g.) was introduced into the receiver. Nitrogen pentoxide was slowly distilled into the solid orthonitrodiphenyl. A very vigorous reaction took place, nitrous fumes were evolved, the temperature rose and in a short time the 2-nitrodiphenyl melted. The melt was well stirred, and the addition of N_2O_5 continued until the amount required by the equation had been added (found by weighing the reaction vessel at frequent intervals). A green oil was obtained as the nitration product. This was thoroughly shaken up with water to remove the nitric acid formed in the reaction, and then extracted with ether. The ethereal extract rapidly yielded a crop of crystals melting over the range 85-94°C. On recrystallisation from methyl alcohol, 32 g. of very pale-yellow needles, melting sharply at 93-93·5°C., were obtained. These crystals were 2:4'-dinitrodiphenyl.

The ether and methyl alcohol mother liquors were concentrated and allowed to cool. Crystals were obtained. On repeating this treatment a further crop of crystals was obtained. On recrystallisation from ligroin, 3 g. crystals of 2:2'dinitrodiphenyl were obtained, m.p. 124-125°C.

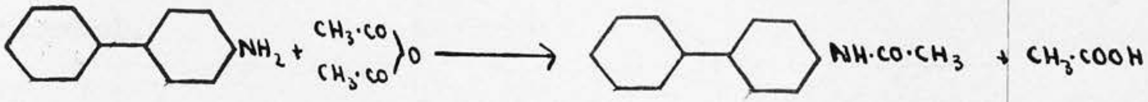
The total yield was, therefore, 35 g. (96% of theory), of which 32 g. (87·7%) was 2:4'-dinitrodiphenyl, and 3 g. (8·3%) was 2:2'-dinitrodiphenyl.

Equation for the Reaction.

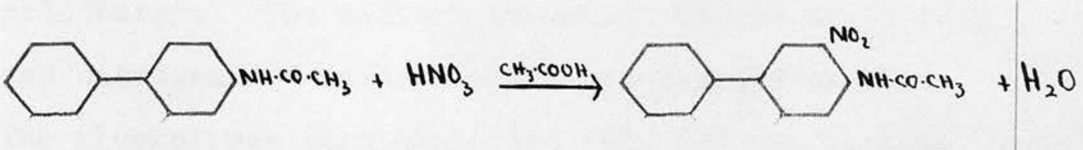


(16) Nitration of 3-Nitrodiphenyl in glacial acetic acid by means of Nitrogen Pentoxide.

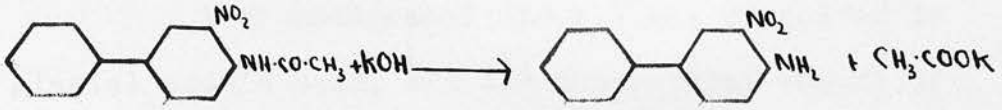
Preparation of 3-nitrodiphenyl. Para-aminodiphenyl (200 g.) was suspended in 200 c.c. benzene, and 121 g. acetic anhydride were added carefully. The suspension was cooled by running water. The mixture was allowed to stand for 15 minutes and was then filtered at the pump and well washed with cold water. It was dried (m.p. 171°C.) and did not need further purification:- p-acetaminodiphenyl



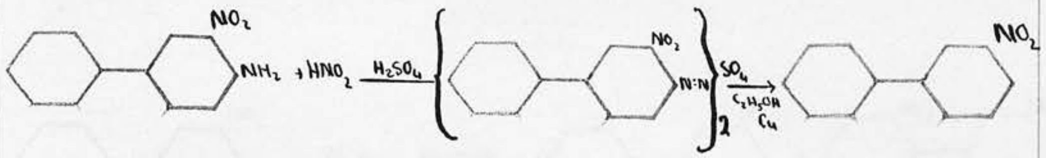
p-Acetaminodiphenyl (200 g.) was dissolved in 2 litres glacial acetic acid and warmed to 70°C. Fuming HNO_3 (200 g.), S.G. 1·51, diluted with an equal volume of glacial acetic acid, was allowed to drop into the stirred solution. The solution was kept at 70°C. for one hour. The 3-nitro-4-acetaminodiphenyl was thrown out of solution by pouring into water. The yellow precipitate contained a small amount of dinitro derivatives, which was easily separated on account of its insolubility in hot alcohol. 3-Nitro-4-acetaminodiphenyl crystallised from alcohol in fine yellow needles, m.p. 132°C.



The 3-nitro-4-acetaminodiphenyl was then boiled up with one litre alcohol, and a solution of 100 g. KOH in 125 c.c. water was added. The contents of the flask became deep-red in colour and went completely into solution. The heating was continued for 15-20 minutes, and the contents of the flask were then cooled rapidly. The precipitated 3-nitro-4-aminodiphenyl was filtered off and washed with 30% alcohol.



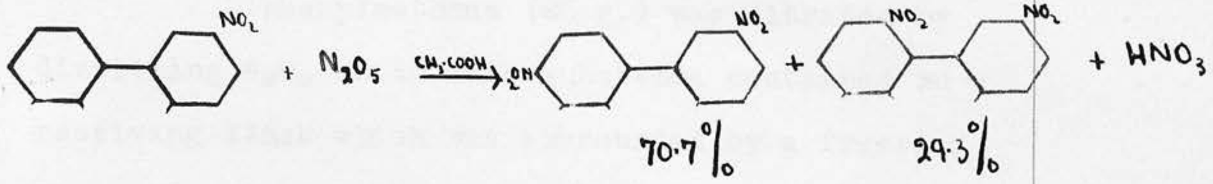
3-Nitro-4-aminodiphenyl (274 g.) was added to a mixture of 604 c.c. 95% alcohol and 90 c.c. H_2SO_4 (S.G. 1·84). The mixture was heated until solution was complete, cooled in ice-water, and vigorously stirred. A solution of sodium nitrite (145 c.c.) containing 100 g. sodium nitrite in 165 c.c. solution was allowed to flow in, drop by drop, during a period of 20 minutes. The reaction mixture was allowed to stand in the cold for 3 hours. Copper powder (8 g.) was next added in portions, and the flask placed in cold water. The mixture gradually warmed up to 40°C., and nitrogen and acetaldehyde were rapidly evolved. The alcohol was then distilled off, and the residue steam-distilled in a current of superheated steam, the flask containing the residue being held in an oil-bath above 200°C.



3-Nitrodiphenyl (15 g.) was dissolved in glacial acetic acid, and the theoretical amount of N_2O_5 (9 g.) was slowly distilled into the cooled, well stirred solution. On completion of the addition and cooling in an ice-salt freezing mixture, crystals separated and these, along with the solid thrown out of solution by pouring the acid mother liquor into water, were digested with 500 c.c. boiling methyl alcohol. The suspension was allowed to cool and the solid was separated. It was recrystallised from acetone in pale-yellow needles, m.p. 189°C. This was 3:4'-dinitrodiphenyl. The yield obtained was 13 g. (70·7%).

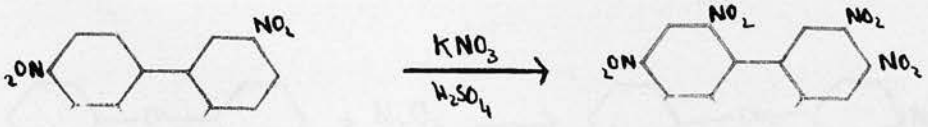
On evaporation of the methyl alcohol used for the digestion of the crude nitration product, 2:3'-dinitrodiphenyl was obtained. It crystallised from dilute acetic acid in white plates, m.p. 120°C. The yield obtained was 5·4 g. (29·3%).

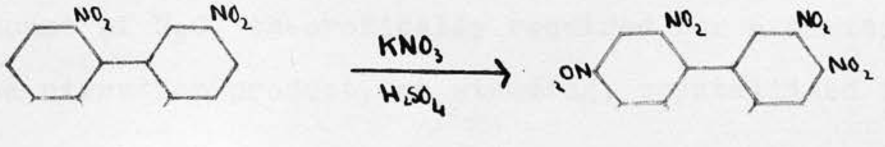
Equation for the reaction.



Identification of the compounds. These dinitrodiphenyls were identified by the preparation from them of the same tetranitrodiphenyl 2:4:3':4"-tetranitrodiphenyl. If either of the above were dissolved in 60 c.c. concentrated H_2SO_4 and 3 g. finely-ground KNO_3 gradually added, on keeping the solution overnight and then pouring on ice, a yellow solid was obtained. This was recrystallised from methyl alcohol in pale-yellow cubes, m.p. 173°C.

Equation for the Reaction.

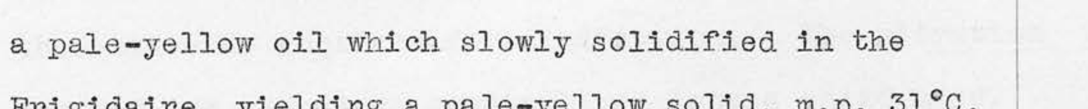




(17) The Nitration of Diphenylmethane by means of N_2O_5.

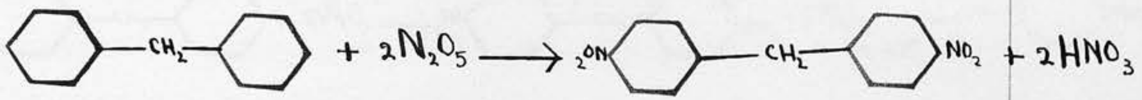
Diphenylmethane (25 g.) was nitrated by distilling N_2O_5 on to this substance contained in a receiving flask which was surrounded by a freezing mixture. A vigorous reaction took place, the diphenylmethane becoming liquid, and in order to maintain the temperature of the reaction ~~at a~~ sufficiently low to prevent decomposition of N_2O_5 , the distillation of that reagent was carried out extremely slowly. The nitration product consisted of a deep red-brown oil which was washed thoroughly with water to remove nitric acid formed in the reaction, and distilled under reduced pressure. The portion distilling at 200°C. under 12 mm. pressure was collected. The product was a pale-yellow oil which slowly solidified in the Frigidaire, yielding a pale-yellow solid, m.p. 31°C. The yield of 4-nitrodiphenylmethane was quantitative.

Equation for the Reaction.



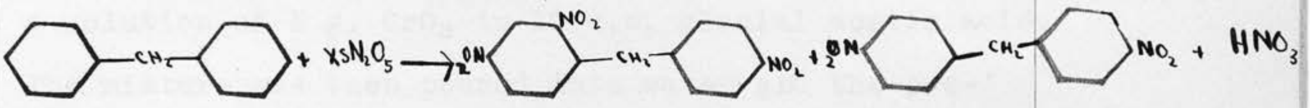
The above experiment was repeated, using the amount of N_2O_5 theoretically required for a dinitration. The nitration product, on standing, crystallised into a solid mass. This was thoroughly washed with water and, after drying, was recrystallised from benzene, being insoluble in solvents such as ether or alcohol. It crystallised in colourless needles, m.p. 183°C. This compound was 4:4'-dinitrodiphenylmethane. The yield was again practically quantitative.

Equation for the Reaction.



The nitration was repeated, 20 g. diphenylmethane being nitrated this time with 26·2 g. N_2O_5. This was a considerable excess over the weight theoretically required for dinitration. The nitration product, on standing, crystallised into a solid mass. This was washed thoroughly with water and then with ether to remove nitric acid and any traces of mononitro derivative. The undissolved dinitro compound was separated. It had a m.p. of 170°C. On recrystallisation from benzene, 12 g. pure 4:4'-dinitrodiphenylmethane, m.p. 183°C., were obtained. The ether and benzene solutions were evaporated down and yielded 13 g. of a substance which, on recrystallisation from benzene, melted at 107-109°C. On further recrystallisation from alcohol, yellow needles which melted sharply at

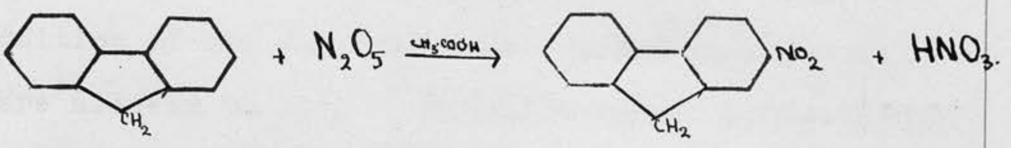
109-110°C. were obtained. This compound was 2:4:4'-trinitrodiphenylmethane. Dinitrodiphenylmethane (12 g.) and trinitrodiphenylmethane (13 g.) correspond to 17 g. diphenylmethane. Diphenylmethane (20 g.) was originally used. Hence, $\frac{17}{20} \times 100 = 85\%$ nitration must have taken place.



(18) The Nitration of Fluorene using Nitrogen Pentoxide.

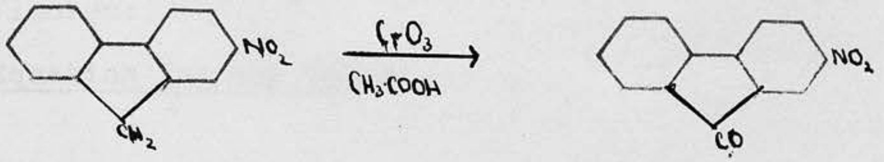
A cold saturated solution of fluorene in glacial acetic acid was prepared. Into this well-cooled, vigorously-stirred solution the amount of N_2O_5 theoretically required for mononitration was slowly distilled. A very vigorous reaction took place as each drop of the reagent fell into the solution. After the addition of N_2O_5 had been completed the reaction vessel was allowed to stand overnight. In the morning the yellow solid was filtered off and thoroughly washed with water. On recrystallisation from alcohol it melted at 154°C. The yield of 2-nitrofluorene was practically quantitative.

Equation for the Reaction.



To prove the identity of the compound, 1 g. of the 2-nitrofluorene was refluxed for 30 minutes with a solution of 5 g. CrO_3 in 10 c.c. glacial acetic acid. The mixture was then poured into water and the precipitated solid recrystallised from glacial acetic acid in sulphur-yellow crystals, m.p. 221°C. This compound was 2-nitrofluorenone.

Equation for the Reaction.

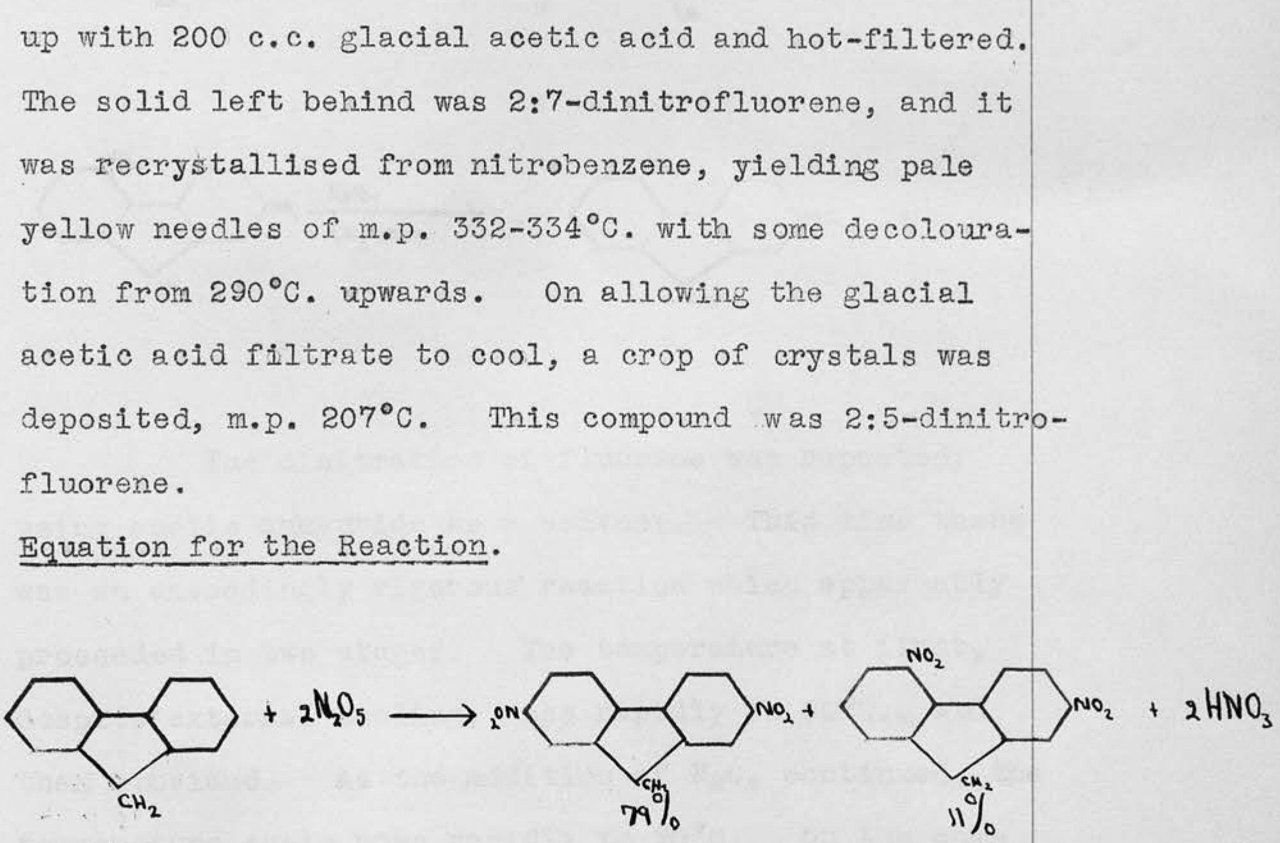


Upon repeating the above experiment, this time using acetic anhydride as the solvent, a quantitative yield of 2-nitrofluorenone was again obtained.

(19) Dinitration of Fluorene.

Fluorene (20 g.) was dissolved in 100 c.c. glacial acetic acid and the amount of N_2O_5 required theoretically for a dinitration was slowly distilled into the solution. Despite external cooling, there was a considerable rise in temperature. After the addition of the N_2O_5 the reaction vessel and contents were allowed to cool. A yellow solid crystallised out. After standing for some time, this solid was filtered off and thoroughly washed with water. The crude nitration product, consisting of a mixture of 2:5-dinitrofluorene and 2:7-dinitrofluorene, was boiled up with 200 c.c. glacial acetic acid and hot-filtered. The solid left behind was 2:7-dinitrofluorene, and it was recrystallised from nitrobenzene, yielding pale yellow needles of m.p. 332-334°C. with some decolouration from 290°C. upwards. On allowing the glacial acetic acid filtrate to cool, a crop of crystals was deposited, m.p. 207°C. This compound was 2:5-dinitrofluorene.

Equation for the Reaction.

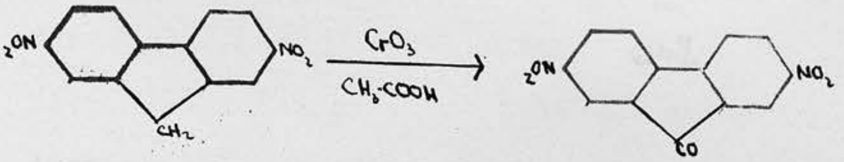


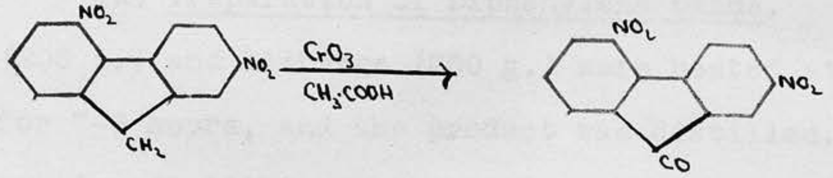
The total nitration yield was 90% of the theoretical and consisted of 79% 2:7-dinitrofluorene and 11% 2:5-dinitrofluorene.

To prove the identity of these compounds they were subjected to oxidation by means of CrO_3 and

and glacial acetic acid, as in the case of the mononitrofluorene described above, yielding 2:5-dinitrofluorenone, m.p. 241°C, and 2:7-dinitrofluorenone, m.p. 292°C., respectively.

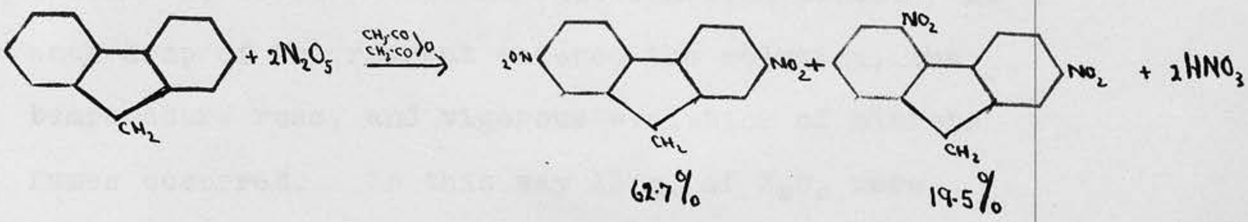
Equations for the Reactions.





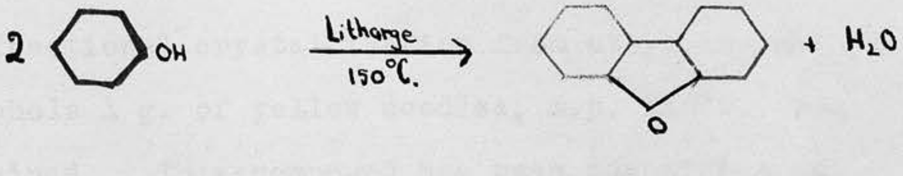
The dinitration of fluorene was repeated, using acetic anhydride as a solvent. This time there was an exceedingly vigorous reaction which apparently proceeded in two stages. The temperature at first, despite external cooling, rose rapidly to 50°C., and then subsided. As the addition of N_2O_5 continued, the temperature again rose rapidly to 90°C. On the completion of the addition, the solution was allowed to cool, when it deposited a crop of crystals which were treated as in the preceding instance. From this, a crude yield of 82·2%, there was separated, as above, 62·7% 2:7-dinitrofluorene and 19·5% 2:5-dinitrofluorene.

Equation for the Reaction.



(20) Nitration of Diphenylene Oxide by means of Nitrogen Pentoxide.

(a) Preparation of Diphenylene Oxide. Phenol (200 g.) and litharge (300 g.) were heated at 150°C. for 7-8 hours, and the product was distilled. The portion distilling above 185°C. was collected, shaken up with warm dilute sodium hydroxide solution, cooled, washed with water and recrystallised from dilute alcohol. Colourless plates (30 g.) of diphenylene oxide, m.p. 87°C., were obtained.

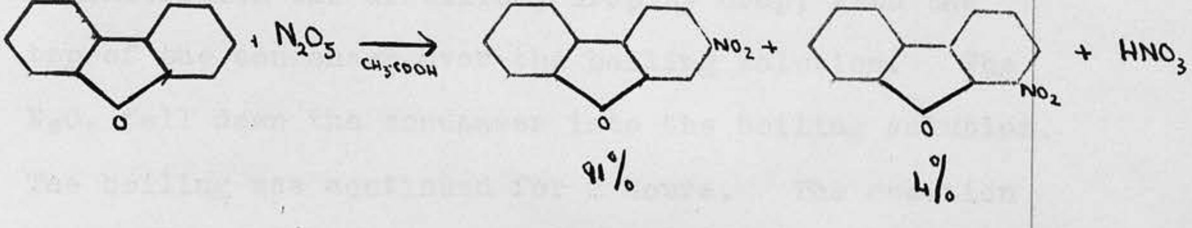


(b) Nitration of Diphenylene Oxide. Diphenylene oxide (20 g.) was dissolved in 80 c.c. glacial acetic acid, and the amount of N_2O_5, theoretically required for a mononitration, was slowly distilled into the well-stirred cold solution. Slow addition was essential, since a violent reaction took place. As each drop of the reagent entered the solution, the temperature rose, and vigorous evolution of nitrous fumes occurred. In this way 13 g. of N_2O_5 were distilled, drop by drop, into the solution. On completion of the addition, the reaction vessel was warmed on the water-bath and allowed to cool, when a solid crystallised out. The solid was filtered off and purified by boiling up with alcohol in which it is only slightly soluble, even when hot. It was then recrystallised from glacial acetic acid. Yellowish needles (23 g.) with a silky lustre were obtained. These were crystals of pure 2-nitrodiphenylene oxide, m.p. 181-182°C.

On dilution with water, the original glacial acetic acid filtrate yielded a semi-solid oil. This was separated and allowed to stand, when it solidified. By fractional crystallisation from ethyl and methyl alcohols 1 g. of yellow needles, m.p. 110°C., was obtained. This compound has been identified as 1-nitrodiphenylene oxide.

The total nitration yield was 95% of theory, consisting of 91% 2-nitrodiphenylene oxide and 4% 1-nitrodiphylene oxide.

Equation for the Reaction.



(21) Nitration of Benzanthrone.

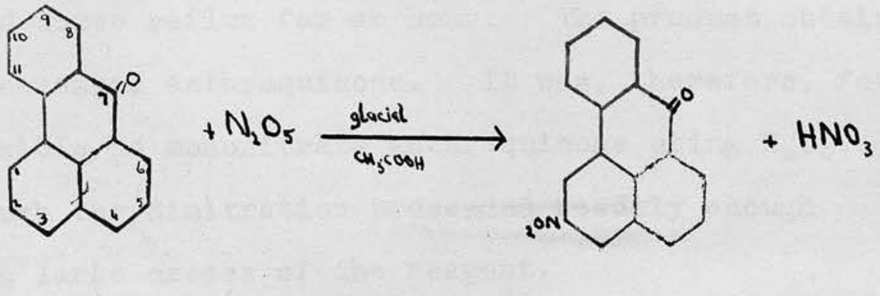
I. Formation of 3-nitrobenzanthrone. Benzanthrone (100 parts) was placed in 850 parts nitrobenzene, and 66 parts of nitric acid added at room temperature. The benzanthrone dissolved with a red colour. The mixture was heated at 40-50°C. for 2-3 hours and allowed to cool, diluted with alcohol, filtered and washed with alcohol. The crude product melted at 238°C. Recrystallised from glacial acetic acid and toluene, it melted at 248-9°C.

It was found to be impossible to prepare 3-nitrobenzanthrone in this way, using N_2O_5 as the nitrating agent, since even at temperatures of about 0°C. in dilute carbon tetrachloride solution, nitrobenzene reacted with N_2O_5 to give a quantitative yield of m-dinitrobenzene. With nitrobenzene as a solvent, therefore, m-dinitrobenzene was formed in preference to nitrobenzanthrone.

II. Formation of 2-nitrobenzanthrone. Benzanthrone (20 g.) was boiled with 300 c.c. glacial acetic acid, and the calculated quantity of N_2O_5 required for a mononitration was distilled, drop by drop, into the top of the condenser over the boiling solution. The N_2O_5 fell down the condenser into the boiling solution. The boiling was continued for 2 hours. The reaction vessel was then allowed to cool, when a crop of crystals appeared in the mixture. This was filtered off and amounted to 18 g. The product was recrystallised from acetic acid. The melting point of this final product was 305-7°C. and it was, therefore, 2-nitrobenzanthrone. The yield was 75·3% of the theoretical.

The mother liquor from the first filtration, on pouring into water, yielded a very impure substance melting over the range 140-170°C. It was, therefore, probably impure benzanthrone.

Equation for the Reaction.



(22) Nitration of Anthraquinone.

The mononitration of anthraquinone was attempted, using N_2O_5 as the nitrating agent. The theoretical amount of N_2O_5 for a mononitration was slowly distilled into a solution of anthraquinone in boiling glacial acetic acid. On cooling the reaction vessel and filtering off the crystalline product, the latter was found to be unchanged anthraquinone. The experiment was repeated, this time N_2O_5 being added to a solution of anthraquinone in sulphuric acid at 80°C. Unchanged anthraquinone was again found to be the resulting compound. A large excess of N_2O_5 was then distilled on to solid anthraquinone and the mixture heated for an hour. In this case, however, dinitration occurred, the product consisting of a mixture of the 1:8-, 1:7-, 1:5- and 1:6- dinitroanthraquinones.

In view of this last result, the experiment was repeated, this time adding N_2O_5 to the solid anthraquinone until the amount required by the equation for mononitration had been added. The mixture was boiled under reflux for an hour. The product obtained was unchanged anthraquinone. It was, therefore, found impossible to mononitrate anthraquinone using N_2O_5, although the dinitration proceeded readily enough with a large excess of the reagent.

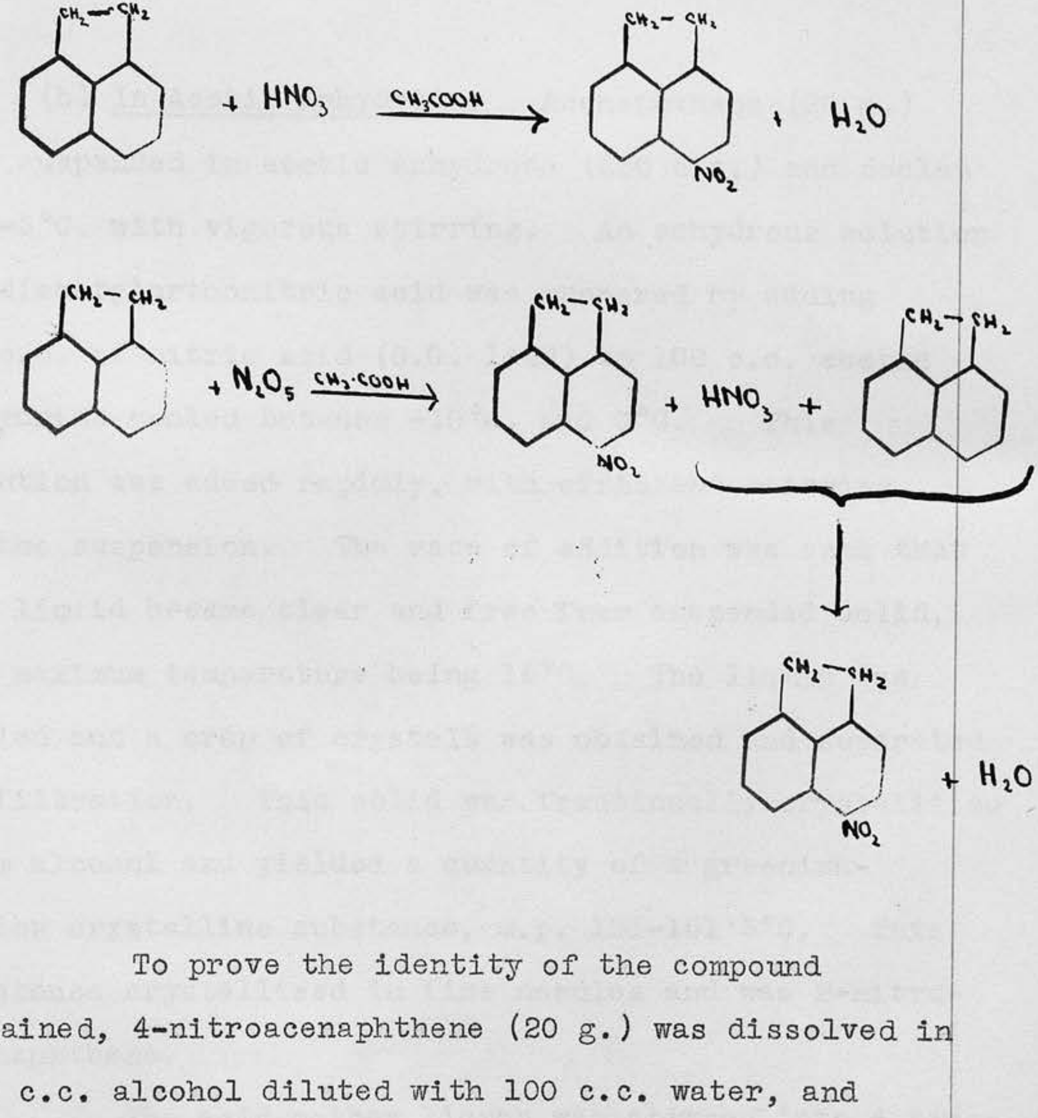
(23) Nitration of Acenaphthene.

(cf. Morgan, J.S.C.I., 1930, 49, 413 T)

(a) In Acetic Acid. Acenaphthene (25 g.) was partially dissolved in 200 c.c. glacial acetic acid. The residual acenaphthene was kept in suspension by mechanical stirring. The suspension was heated until the acenaphthene went completely into solution, which was then rapidly cooled, with stirring, to 10°C. The acenaphthene separated from the solution as a fine crystalline mass which readily underwent nitration. Nitric acid (25 c.c.), S.G. 1·42, was added, drop by drop, to this fine crystalline mass, and the temperature was maintained at 10°C. 4-Nitroacenaphthene separated as a yellow crystalline mass from the reaction mixture. This was filtered off, washed with water to remove acid and recrystallised from alcohol. It crystallised in fine, yellow needles, m.p. 106°C. The yield was 87·5%.

The above experiment was repeated, this time slowly distilling the amount of N_2O_5 theoretically required for a mononitration, into the well-cooled suspension (-5° - 0°C.). The product consisted of some dinitroacenaphthene as well as 4-nitroacenaphthene. The experiment was carried out once more with N_2O_5. This time, only half the amount of N_2O_5 theoretically required for a mononitration was slowly distilled into the well-cooled suspension. The yield of 4-nitroacenaphthene was quantitative.

Equations for the Reaction.



To prove the identity of the compound obtained, 4-nitroacenaphthene (20 g.) was dissolved in 200 c.c. alcohol diluted with 100 c.c. water, and crystalline sodium hydrosulphite (50 g.) was added in two portions. The mixture was boiled until the yellow colour disappeared (about 20 minutes). After distilling off the alcohol, hot water (100 c.c.) and concentrated hydrochloric acid (100 c.c.) were added, and the residue was boiled repeatedly with further addition of HCl. On addition of ammonia to the combined filtrates, 4-aminoacenaphthene separated out. It was recrystallised from light petroleum and melted at 108°C. The yield was 70%.

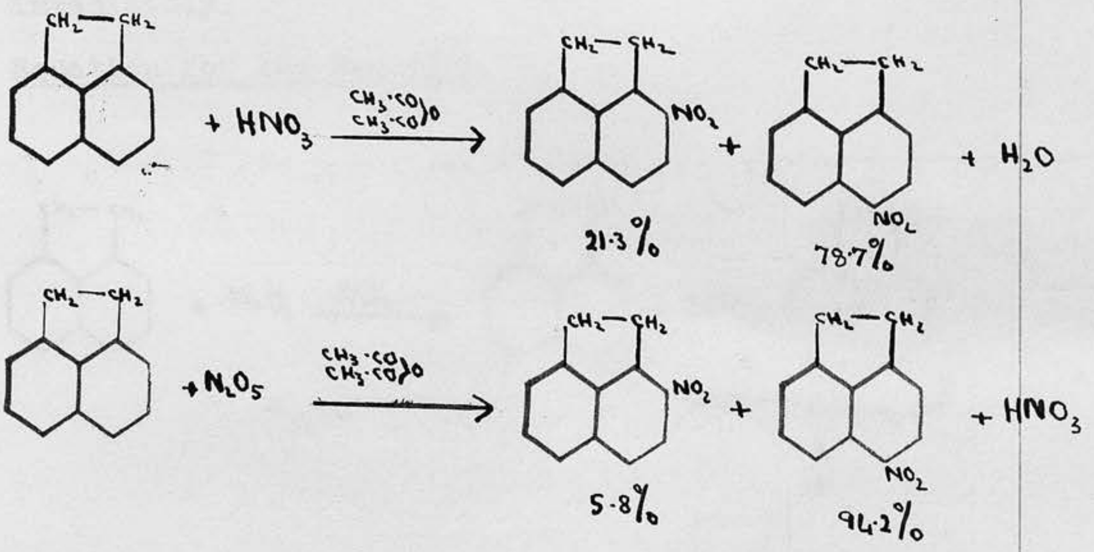
(b) <u>In Acetic Anhydride</u>. Acenaphthene (20 g.) was suspended in acetic anhydrode (250 c.c.) and cooled to -5°C. with vigorous stirring. An anhydrous solution of diacetylorthonitric acid was prepared by adding 10 c.c. of nitric acid (S.G. 1·42) to 100 c.c. acetic anhydride cooled between -10°C. and 0°C. This solution was added rapidly, with efficient stirring, to the suspension. The rate of addition was such that the liquid became clear and free from suspended solid, the maximum temperature being 16°C. The liquid was cooled and a crop of crystals was obtained and separated by filtration. This solid was fractionally crystallised from alcohol and yielded a quantity of a greenish-yellow crystalline substance, m.p. 151-151·5°C. This substance crystallised in fine needles and was 2-nitroacenaphthene.

The acid mother liquor was stirred into 4 times its volume of cold water and deposited a precipitate of crude 4-nitroacenaphthene. The alcohol filtrates from the fractional recrystallisations yielded a further quantity of 4-nitroacenaphthene . This, along with the crude precipitate, was recrystallised from alcohol, and 4-nitroacenaphthene was obtained in the pure state in fine yellow needles, m.p. 106°C. The total yield of nitroacenaphthenes was quantitative and consisted of 21·3% 2-nitroacenaphthene and 78·7% 4-nitroacenaphthene.

The experiment was repeated, this time distilling half the quantity of N_2O_5 required for a mononitration very slowly into a suspension of acenaphthene in acetic anhydride maintained below 0°C. The product obtained was treated as above, when a quantitative yield of mononitroacenaphthenes was obtained, consisting of 94·2% 4-nitroacenaphthene and 5·8% 2-nitroacenaphthene.

If the nitration of acenaphthene was carried out in the following manner a large yield of a molecular compound of acenaphthene and 4-nitroacenaphthene could be obtained. Nitric acid (3 c.c.), S.G. 1·42, was cooled to -10°C. and mixed with acetic anhydride (30 c.c.) at the same temperature. This mixture was added to 10 g. acenaphthene dissolved in 150-200 c.c. acetic anhydride. The mixed solution was stirred vigorously and cooled in an ice-salt-concentrated hydrochloric acid freezing mixture to -20°C. At this low temperature a solid separated (yield 30-35% of acenaphthene used) and, after recrystallisation from alcohol or dilute acetic acid, was identified as 4-nitroacenaphthene, m.p. 104°C. The filtrate was added to a large excess of ice-water. A yellow precipitate (m.p. 67°C.), after recrystallisation from alcohol, melted at 68°C. The yield was 65-70%. This product was a molecular compound between acenaphthene and 4-nitroacenaphthene.

Equations for the Reactions.

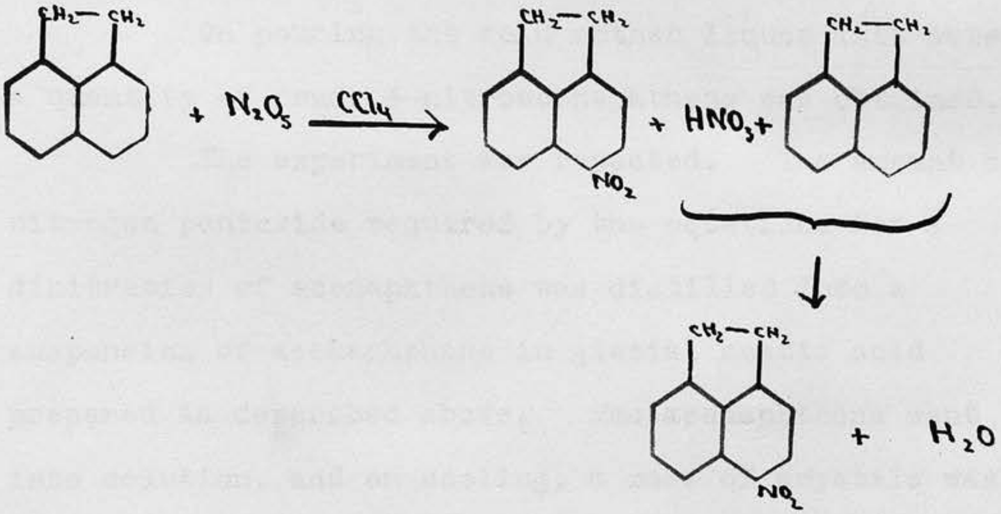


An additional distinction between the two isomeric mononitroacenaphthenes was in their colour reactions with sulphuric acid. Orthonitroacenaphthene, m.p. 151·5°C., with cold concentrated sulphuric acid, gave a grey-blue colour which gradually deepened through purple to red, whilst paranitroacenaphthene, m.p. 106°C., gave a deep-crimson colour immediately.

The nitration of acenaphthene was repeated in carbon tetrachloride solution, using N_2O_5 as the nitrating agent. In this case, exceedingly slow addition of the reagent, with strong cooling, was imperative, as the reaction was very vigorous and if the addition of N_2O_5 was rapid a great deal of charring took place. A quantitative yield of 4-nitroacenaphthene, m.p. 106°C., was obtained.

An attempt was made to carry out the nitration of acenaphthene by means of a mixture of nitric and sulphuric acids, but the acenaphthene charred immediately.

Equation for the Reaction.



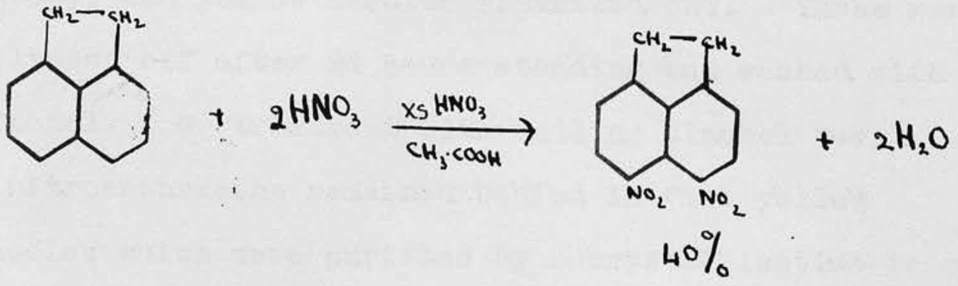
(24) Dinitration of Acenaphthene.

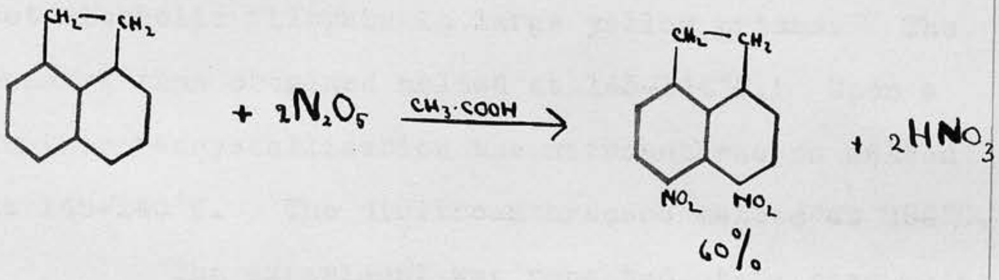
Acenaphthene (25 g.) was dissolved in 200 c.c. glacial acetic acid and, on cooling rapidly with constant stirring, very fine crystals separated. Concentrated nitric acid (100 c.c.), S.G. 1·42, was added. On heating, the acenaphthene went into solution with a reddish-yellow colour. The temperature was kept at 80°C. for 20 minutes, and then the reaction vessel and contents were cooled so that the evolution of red nitrous gases was very marked. On cooling, a thick dark-yellow mass of crystals was obtained. These were filtered off, washed with glacial acetic acid, dried, boiled with ½ litre of ligroin and finally crystallised from toluene. The product was 4:5-dinitroacenaphthene, m.p. 222-224°C., with sintering at 210°C. The yield of dinitroacenaphthene obtained in this way was 40·3% of the theoretical.

On pouring the acid mother liquor into water a quantity of crude 4-nitroacenaphthene was obtained.

The experiment was repeated. The amount of nitrogen pentoxide required by the equations for a dinitration of acenaphthene was distilled into a suspension of acenaphthene in glacial acetic acid prepared as described above. The acenaphthene went into solution, and on cooling, a mass of crystals was deposited. These were separated and treated as above. The product isolated was identified as 4:5-dinitroacenaphthene and was obtained in a yield of 60%. A 35% yield of 4-nitroacenaphthene was obtained.

Equation for the Reaction.



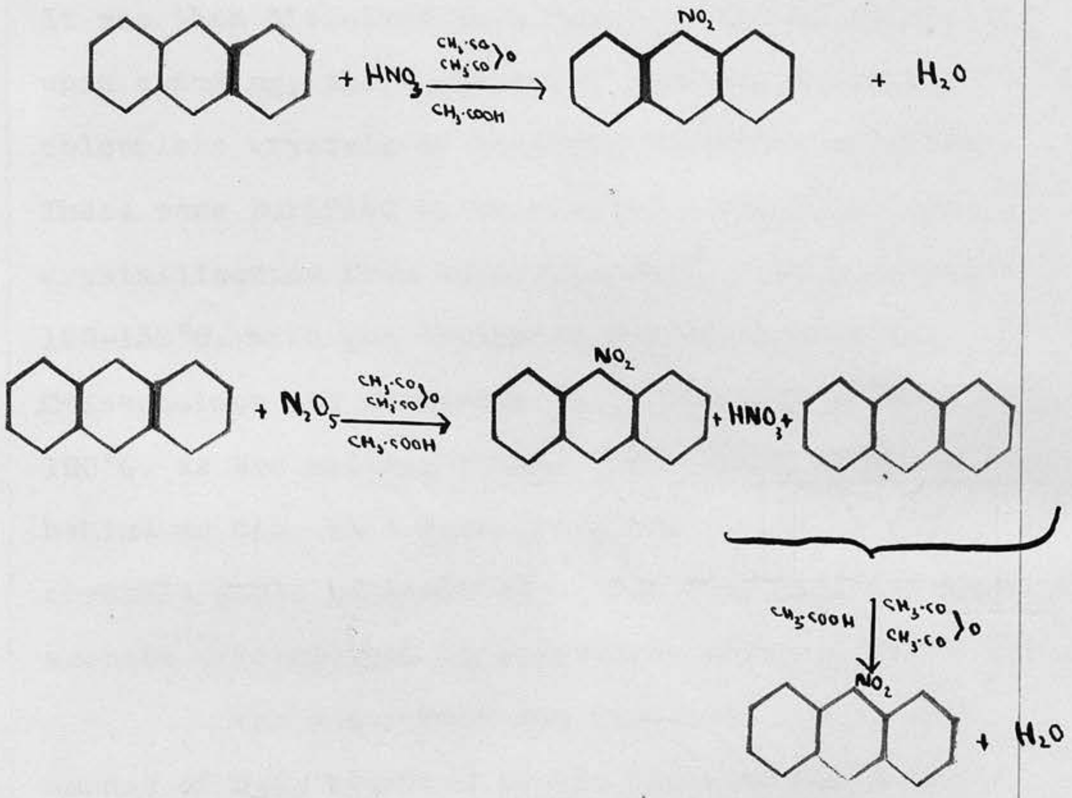


(25) Nitration of Anthracene.

(a) Nitration in presence of acetic anhydride and glacial acetic acid. Finely-powdered anthracene (10 g.) was suspended in 40 c.c. glacial acetic acid. The suspension was cooled in ice. A mixture of 10 c.c. nitric acid (S.G. 1·5), 6 c.c. acetic anhydride and 15 c.c. glacial acetic acid was prepared and cooled. This mixture was added to the suspension slowly from a dropping funnel. The temperature was allowed to rise to 15-20°C. and maintained within that range. The anthracene slowly dissolved. Before all the nitric acid was added the liquid began to deposit a fine colourless precipitate which gradually became a thick crystalline mush. This pasty mass became more watery, and yellow needles separated out. These were filtered off after 24 hours standing and washed with alcohol. On treatment with boiling alcohol the dinitroanthracene remained behind in fine yellow needles which were purified by recrystallisation from xylene, whilst 9-nitroanthracene crystallised from the hot alcoholic filtrate in large yellow prisms. The product thus obtained melted at 143-144°C. Upon a further recrystallisation the nitroanthracene melted at 145-146°C. The dinitroanthracene melted at 294°C.

The experiment was repeated, this time using the amount of N_2O_5 theoretically required for a mononitration (mixed with the acetic anhydride and acetic acid). The product, however, consisted mainly of the dinitroanthracene. Upon repeating the experiment with half the quantity of N_2O_5 required for a mononitration, a quantitative yield of 9-nitroanthracene was obtained.

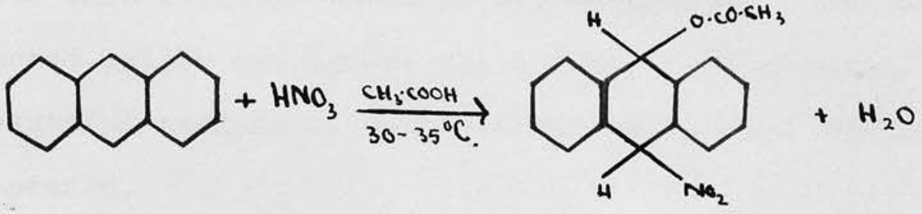
Equations for the Reactions.

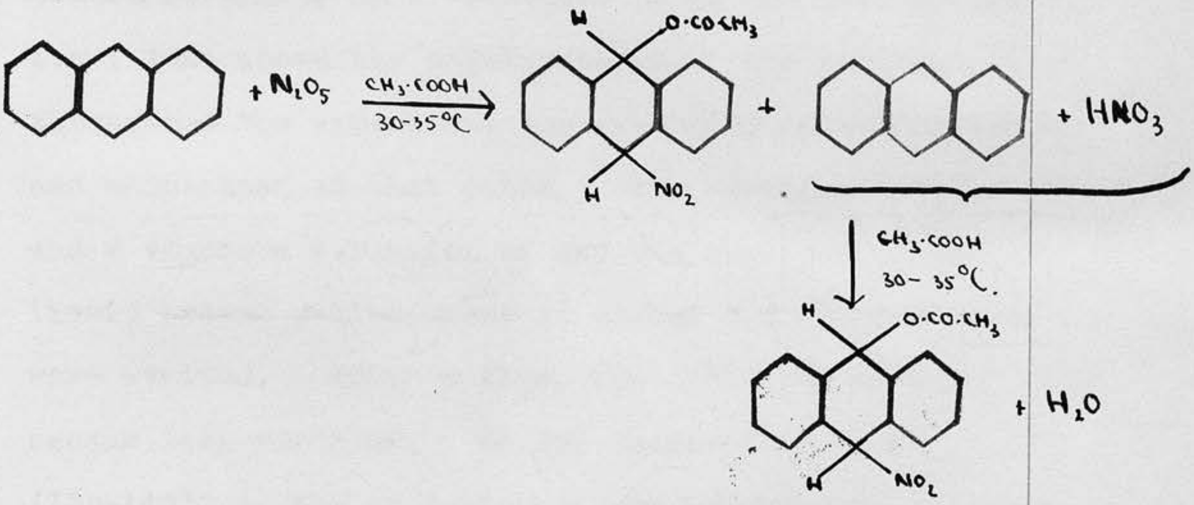


(b) Nitration in presence of glacial acetic acid. Nitric acid (20 c.c.), S.G. 1·4, was allowed to drop slowly into a suspension of 50 g. finely-powdered anthracene in 200 c.c. glacial acetic acid. This corresponded to one molecular weight equivalent. The temperature was maintained at 30-35°C., by cooling with water. Within 15 minutes a clear deep-yellow solution was obtained. This solution was poured into cold water in a thin stream. The yellowish semi-solid mass which separated was repeatedly kneaded thoroughly with water, washed and finally dried overnight in vacuo. It was then dissolved in a small amount of ether, and upon standing, there separated from the solution colourless crystals of dihydronitroanthranylacetate. These were purified by washing with ether and recrystallisation from methyl alcohol. They melted at 129-130°C. with gas evolution and decomposition. Meisenheimer and Connerade (A., 1903, <u>330</u>, 158) quote 120°C. as the melting point. The ether solution left behind an oil, on evaporation, from which no more crystals could be isolated. The dihydronitroanthranylacetate crystallised in colourless prisms; yield 45%.

The experiment was repeated. Half the amount of N_2O_5 required by the equation for a mononitration was slowly distilled into a suspension of 50 g. finely-powdered anthracene in 200 c.c. glacial acetic acid. The temperature was maintained at 30-35°C. by external cooling. The anthracene dissolved to give a yellow solution. This solution was treated as above and the resulting product, crystalline colourless prisms, melted at 129-130°C. The yield in this case was 75%.

Equations for the Reaction.

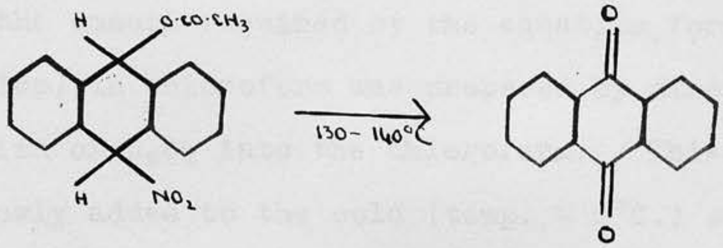




Meisenheimer and Connerade (loc. cit.) identified the compound by the action of concentrated hydrochloric acid upon a solution in glacial acetic acid. This reaction yielded the dihydrochloronitroanthracene, m.p. 164°C. However, upon repeating this experiment by dissolving the dihydronitroanthranylacetate in glacial acetic acid and adding two drops of hydrochloric acid, a different result was obtained. The colourless solution became yellow in colour and, on cooling, long needles of 9-nitroanthrancene, m.p. 145°C., crystallised out.

An alcoholic solution of the dihydronitroanthranylacetate was prepared and HCl gas was passed into this solution until it was saturated. The solution turned yellow and became quite warm. On cooling, beautiful needles of 9-nitroanthracene, m.p. 145°C., appeared.

The dihydronitroanthranylacetate (1 g.)was heated carefully in a test-tube in an oil bath at 130°C., i.e., just above the melting point. The temperature throughout the experiment was gradually raised to 140°C. and maintained at that point. The substance melted and a vigorous evolution of gas was observed. The liquid became yellow-brown in colour and nitrous gases were evolved. After a time, the evolution of gas became less vigorous. As the temperature rose (135-140°C.), the evolution of gas became more vigorous once again and now acetic acid fumes appeared. The heating was continued until the evolution of gases ceased. During this period solid had begun to be deposited on the walls of the tube. Gradually the entire liquid became a solid, greasy mass. This was allowed to cool and recrystallised from xylene. It crystallised in fine, yellow needles, m.p. 286°C. A mixed melting point with anthraquinone (m.p. 286°C.) was taken and remained at 286°C. This final product was, therefore, anthraquinone as had been suspected. The reaction apparently consisted in the splitting off of nitric and acetic acids and the subsequent oxidation by the nitric acid at the temperature of the oil-bath of the anthracene formed (140°C.).



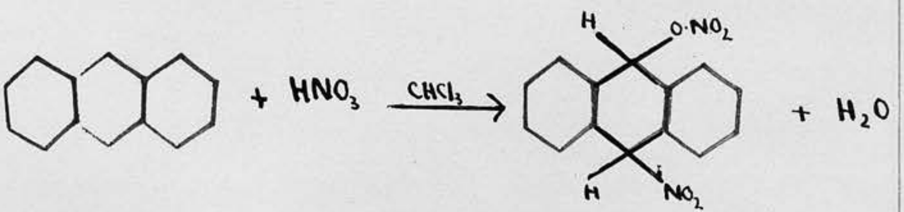
(c) Nitration in an Inert Solvent:- Chloroform.
Anthracene (10 g.) was dissolved in 150 c.c. boiling chloroform and quickly cooled to 0°C. In this way the crystals deposited were obtained in a fine state of sub-division. Nitric acid (S.G. 1·4), 10 c.c., was introduced in small portions with efficient stirring. The anthracene went quickly into solution, imparting a yellow colour to the solution. On further stirring, white leaflets separated out in the solution. After a short time a little water was added, and the crystals filtered off at the pump. They were thoroughly washed with water, alcohol and ether and then dried in vacuo. The yield of dihydronitroanthranylnitrate was 110% of the anthracene used.

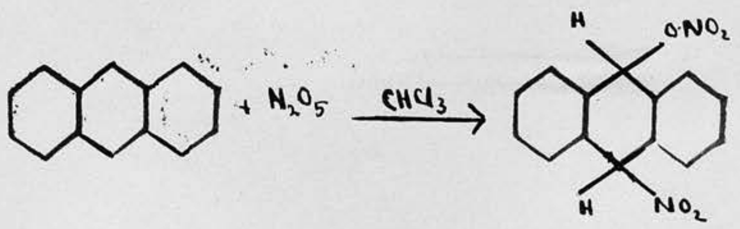
After drying the leaflets in vacuo overnight over sulphuric acid, the original colourless leaflets had become yellow, but the melting point had not changed.

The melting point was 79-80°C. and the melting of the substance was accompanied by vigorous decomposition and evolution of red nitrous fumes.

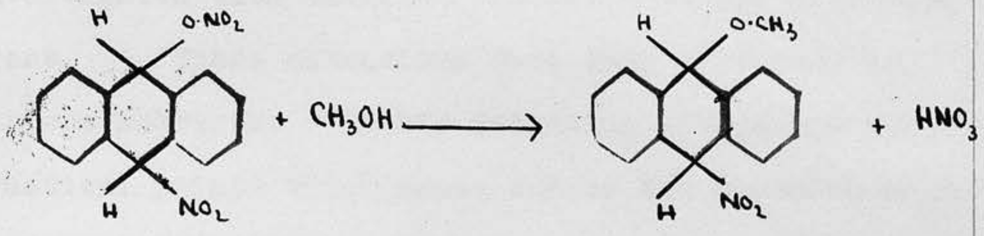
The experiment was repeated. A solution of N_2O_5 (the amount required by the equation for a mono-nitration) in chloroform was prepared by direct distillation of N_2O_5 into the chloroform. This solution was slowly added to the cold (temp. = 0°C.) suspension of anthracene in chloroform. The resulting solution was yellowish in colour and, on standing, deposited the colourless leaflets of dihydronitroanthranylnitrate as described above. These leaflets were subjected to the same treatment as above, and were obtained in quantitative yield, m.p. 79-80°C., with vigorous decomposition.

Equations for the Reactions.





This compound was identified by boiling with methyl alcohol, when the product obtained was dihydronitroanthranylmethylether, m.p. 180°C. which crystallised from the hot solution in colourless needles.

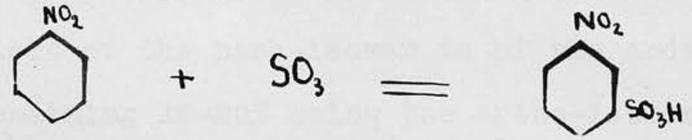


SUMMARY Of EXPERIMENTAL WORK And

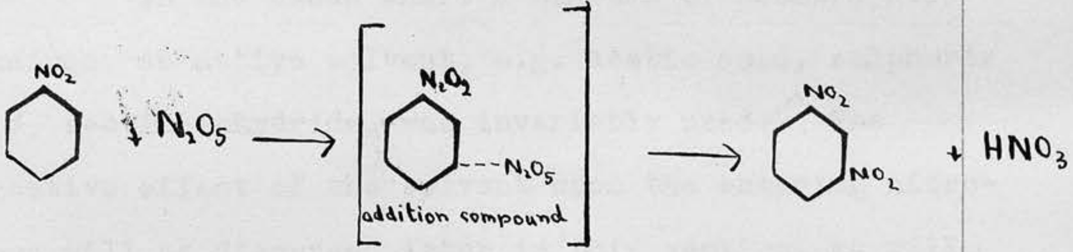
DISCUSSION Of RESULTS.

A large number of nitrations have been investigated with nitrogen pentoxide as the nitrating agent. These nitrations have been performed in various solvents. In the following discussion the practical points which arose out of the research will be detailed first.

It is well known that in sulphonation experiments, sulphonation with sulphuric acid yields in most cases a mixture of isomers. On the other hand, sulphonations performed with sulphur trioxide, the anhydride of sulphuric acid, in many cases yield 100% of one isomer (Lauer, J. prakt. Ch., 1935, <u>143</u>, 127). One of the main objects in carrying out this research was to find whether similar results could be obtained in nitrations with nitrogen pentoxide, the anhydride of nitric acid. In the case of nitration with nitrogen pentoxide, however, a complication arises which is not present in the sulphonation experiments with sulphur trioxide. The reaction between sulphur trioxide and an organic compound consists merely in the addition of the sulphur trioxide to the compound, e.g., with nitrobenzene:



After the addition of one molecule of nitrogen pentoxide a molecule of nitric acid is obtained which itself may react with the substance which is being nitrated, e.g., with nitrobenzene:



This nitric acid which is liberated in the course of the reaction may then react upon the original nitrobenzene to produce a further quantity of dinitrobenzene. Unfortunately, however, nitric acid in its reactions upon organic substances generally produces a mixture of isomers. This fact, that a by-product of the main nitrating reaction has a nitrating effect, no doubt will influence the distribution of isomers in the resultant nitration product.

In spite of these considerations, however, several instances were obtained where a single isomer resulted. In most of the other cases investigated, the yields of one isomer were overwhelmingly larger than the yields of the other. In many cases, quantitative yields of the para-isomer are obtained, whilst in others the yield of the para-isomer is of the order of 80-90%, the remaining 10-20% being the ortho-isomer. It is a significant fact that in all cases where only one isomer was obtained, an inert solvent was used. The commonest inert solvent used was dry carbon tetrachloride. Another solvent in which similar results could be obtained was chloroform.

In the cases where a mixture of isomers was obtained, an active solvent, e.g. acetic acid, sulphuric acid, acetic anhydride, was invariably used. The directive effect of the solvent upon the entering nitro-group will be discussed later in this section, as will be the nature of the action of the nitrogen pentoxide.

Substances which on interaction with nitrogen pentoxide, in carbon tetrachloride solution, yielded the para-nitro isomer alone, include bromobenzene, diphenyl, 4-nitrodiphenyl, fluorene, acenaphthene, diphenylmethane and α-methylnaphthalene. Benzene gave a quantitative yield of nitrobenzene, whilst nitrobenzene gave a quantitative yield of m-dinitrobenzene. The total yields in all these cases were practically quantitative, and in many instances there was marked increase in the total yield of nitro-product as compared to that obtained in the usual nitration by means of a mixed acid.

Compound.	Nitrating Reagents and Total Yields.	
Benzene	N_2O_5 in CCl_4	HNO_3 - H_2SO_4
	Quantitative yield of nitrobenzene.	80% nitrobenzene.
Phenol	N_2O_5 in CCl_4	HNO_3 - H_2SO_4
	Quantitative yield of Picric Acid.	50-60% Picric Acid.
Diphenyl	N_2O_5 in CCl_4	HNO_3
	96% nitrodiphenyl	80% nitrodiphenyls
α-methylnaphthalene	N_2O_5 in CCl_4	HNO_3 - $CH_3 \cdot COOH$
	100% crude yield 75% yield pure 4-nitro-1-methylnaphthalene.	50-60% crude 30% yield pure 4-nitro-1-methylnaphthalene.
Fluorene	N_2O_5 - $CH_3 \cdot COOH$	HNO_3 - $CH_3 \cdot COOH$
	90-95% dinitrofluorenes.	70-80% dinitrofluorenes.
Acenaphthene	N_2O_5 in CCl_4 or $CH_3 \cdot COOH$	HNO_3 - $CH_3 \cdot COOH$
	Quantitative yield of 4-nitroacenaphthene.	87% yield 4-nitroacenaphthene.
Diphenylene Oxide	N_2O_5 - $CH_3 \cdot COOH$	HNO_3 - $CH_3 \cdot COOH$
	95% nitrodiphenylene oxide.	80% nitrodiphenylene oxide.

In other solvents, notably glacial acetic acid, these compounds and many others gave an 80-90% yield of the para-nitro compound on nitration with nitrogen pentoxide.

Nitrogen pentoxide in these reactions shows itself to be an excellent preparative reagent. In cases where the single para-nitro isomer is required, the use of nitrogen pentoxide as the nitrating agent offers itself as an excellent means of preparing the desired compound, thus obviating in many instances long and difficult separations of ortho- and para-isomers. This is particularly the case with bromobenzene, toluene, diphenyl, substituted diphenyls, diphenylmethane and substituted diphenylmethanes. Nitrogen pentoxide is a very vigorous reagent, and many nitrations with it can be carried out at low temperatures (0°C and below 0°C) and in very dilute solution. Benzene, for example, is quantitatively nitrated by nitrogen pentoxide in very dilute carbon tetrachloride or chloroform solution at temperatures below 0°C, and m-dinitrobenzene is also formed by the addition of another equivalent of the reagent even at these low temperatures. Indeed, the fact that most nitrations in which nitrogen pentoxide is used as the nitrating agent may be carried out at temperatures below 0°C favours para substitution. It is well known that the use of higher temperatures favours ortho-substitution. Thus, nitrogen pentoxide, by enabling the nitrations to be carried out at very low temperatures, aids para-substitution.

In view of the results given above and quoted in the tables (pp.116-122), the view is tentatively put forward that nitrogen pentoxide itself nitrates solely in the para-position, whilst the presence of the ortho isomer in small yield in nitrations in active solvents is traced to the by-product nitric acid. In many nitrations carried out in inert solvents no trace of an ortho-substituted isomer could be found. It is suggested that the nitric acid produced as a by-product in the primary nitration by the pentoxide is not present in sufficient concentration in the inert solvent to bring about further nitration. On the other hand, in the presence of an active solvent, e.g. acetic anhydride, the nitric acid is present <u>in a sufficiently active form</u> to effect further nitration. This secondary nitration by the nitric acid, as in ordinary mixed acid nitrations, produces a mixture of the ortho- and para-isomers. This interpretation, along with the similar behaviour of sulphur trioxide, gives a reasonable explanation of the experimental facts.

Another point of practical and preparative importance lies in the fact that by the use of nitrogen pentoxide troublesome oxidation effects are avoided. Again the use of nitrogen pentoxide, by allowing the nitrations to be carried out at very low temperatures, avoids this difficulty which is often encountered in nitrations with nitric acid. Oxidation effects are more marked at the higher temperatures required for most nitric acid nitrations. Another point in favour of the use of nitrogen pentoxide as the nitrating reagent lies in its ability to accomplish nitration, dinitration, and in some cases (e.g., phenol) quantitative trinitration, without the use of sulphuric acid and external heating. Again, as in many reactions one molecule of nitrogen pentoxide produces one molecule of nitro compound, a nitration reaction may be stopped at any stage required, by making use of solutions of known concentration of nitrogen pentoxide in dry carbon tetrachloride.

The commonest methods of introducing a nitro-group into an organic compound are those involving interaction between that compound and nitric acid, either by itself or as one constituent of a mixture of acids, e.g., HNO_3 - H_2SO_4 or HNO_3 - $CH_3 \cdot COOH$. As detailed in the Introduction to this thesis, considerable uncertainty exists as to the actual nitrating agent in such mixtures. In the case of nitration by nitric acid alone, the nature of the mechanism of the nitration reaction itself has been the cause of considerable controversy, and no explanation exists which accounts for all the experimental data to the complete satisfaction of chemists.

By the use of nitrogen pentoxide in an inert solvent, e.g. carbon tetrachloride, as the nitrating reagent, one of these major difficulties is removed. There can be no doubt as to what is the actual nitrating agent. It must be the nitrogen pentoxide. Hence, by the use of this reagent, theoretical deductions may be made from the experimental facts with a greater degree of safety and certainty than hitherto. In this connection it may be mentioned that whilst in nitrations by nitric acid, water is the resultant by-product of the reaction, in the case of nitrations by nitrogen pentoxide, nitric acid is the by-product.

$$R{\cdot}H + HNO_3 \longrightarrow R{\cdot}NO_2 + H_2O$$
$$R{\cdot}H + N_2O_5 \longrightarrow R{\cdot}NO_2 + HNO_3$$

The question of the effect on the reaction of the chemically produced water which by its dilution of the nitric acid may considerably affect the course of the reaction, does not arise in connection with nitrations with nitrogen pentoxide.

In reference to the influence of water upon these nitrations, it is of interest to note that Morgan and co-workers (J.S.C.I., 1924, <u>43</u>, 343 T; 1925, <u>44</u>, 16 T, 408 T, 493 T, 513 T; 1928, <u>47</u>, 16 T; 1930, <u>49</u>, 413 T) claim that the appearance of 2-nitroacenaphthene in a nitration of acenaphthene suspended in acetic anhydride by means of a mixture of 10 c.c. HNO_3 (S.G. 1·42) and 100 c.c. acetic anhydride, is due to the anhydrous nature of the nitration. But in a nitration of acenaphthene in dry carbon tetrachloride by nitrogen pentoxide, it may also be said that the nitration is carried out under anhydrous conditions. This nitration gave a quantitative yield of 4-nitroacenaphthene. This result demonstrates that the formation of 2-nitroacenaphthene in Morgan's experiment is not due to the absence of water butto the presence of acetic anhydride as an active solvent. This acetic anhydride undoubtedly will form, with the nitric acid, diacetylorthonitric acid or acetyl nitrate, which, as Pictet (loc. cit.) has shown, are reagents which tend to nitrate in the ortho-position. This is borne out by the fact that in a nitration by nitrogen pentoxide in acetic anhydride, 2-nitroacenaphthene was formed. The nitric acid produced in these nitrations is present, in many cases, in such a low concentration that it has no secondary effect upon the reaction.

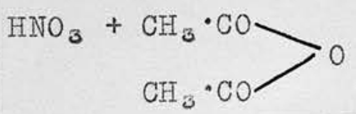
Several workers in this field put forward the hypothesis that in nitrations with a HNO_3 -H_2SO_4 mixture, nitrogen pentoxide was responsible for the nitration - Klemenc (Z. anorg. allgem. Chem., 1924, <u>141</u>, 231); Schaarschmidt (Z. angew. Chem., 1926, <u>39</u>, 1457). If this were the case, the results obtained in nitrations with such a mixture should be comparable to those obtained in nitrations with nitrogen pentoxide. For the purposes of comparison a table has been drawn up showing the results obtained in nitrations with various nitration mixtures (p.116).

On studying the results detailed in the table given below, a strong parallelism is at once noticed. In general, the results of nitrations with similar nitrating reagents show a great similarity. In nitrations with nitrogen pentoxide in carbon tetrachloride, the yield of para-nitro compounds is by far the predominant feature. By using glacial acetic acid as solvent, the formation of an ortho-nitro compound is observed in many cases. In the cases where acetic anhydride has been used as the solvent, the yield of the ortho-nitro compound is increased, and in one case (4-nitrodiphenyl) the yield of the 2:4'-dinitrodiphenyl exceeds the yield of the 4:4'-dinitro isomer. These results are undoubtedly traceable to the formation and activity of diacetylorthonitric acid and acetyl nitrate. These compounds, as has been shown by Pictet and Genequard (Ber., 1902, <u>35</u>, 2526), nitrate preferentially in the ortho-position (cf. benzoyl nitrate which Francis (Ber., 1906, <u>39</u>, 3801) has shown to possess the same marked tendency to nitrate in the ortho-position). The formation of such compounds cannot be doubted in solutions containing nitric acid anhydride and glacial acetic acid or acetic anhydride. In nitrations in such media it is probable that two separate nitration reactions are proceeding simultaneously:

(a) primary nitration by the nitrogen pentoxide which is responsible for the formation of the para-nitro isomer.

(b) secondary nitration by the diacetylorthonitric acid or acetyl nitrate produced by interaction of the nitrogen pentoxide and the active solvent. This secondary nitration is responsible for the formation of the ortho-nitro isomer.

The nitric acid produced as by-product in the primary nitration may not interact with the compound to be nitrated; may interact, giving a mixture of ortho and para isomers as in the ordinary nitrations; or may interact with the active solvent to produce a further quantity of the organic nitrating substance, which in turn tends to increase the yield of the ortho-nitro compound. These considerations lead to a general discussion of the question of what is the actual nitrating agent in any given nitration reaction. For the purposes of comparison (cf. Table) this will be limited to the following cases.

Reagents Added.	Nitrating Agent.
N_2O_5 in CCl_4	N_2O_5 By-product HNO_3
HNO_3	HNO_3 By-product H_2O.
HNO_3 + H_2SO_4	Possibilities: $H^+ \cdot NO_3^-$, $HO \cdot NO_2$, N_2O_5 , nitrosulphonic acid.
HNO_3 + $CH_3 \cdot COOH$ glacial	Possibilities: HNO_3 , diacetylorthonitric acid, acetyl nitrate.
 $HNO_3 + \begin{matrix} CH_3 \cdot CO \\ CH_3 \cdot CO \end{matrix} \Big> O$	Possibilities: HNO_3 , diacetylorthonitric acid, acetyl nitrate.

In the table given below an attempt has been made to compare the results obtained in nitrations of organic compounds with different nitrating reagents. The table is only of limited value, however, as the conditions under which the nitrations have been carried out are by no means standard. Many authors do not give their experimental conditions at all. Some nitrations are carried out under the influence of heat, others are carried out below 0°C. The actual experiments carried out in the course of this work were performed under the standard conditions described in the experimental section. Again, some authors quote their yields as percentages of the products isolated, others as percentages of the theoretical yield calculated from the starting material. Bearing this in mind, however, it is possible to draw certain conclusions from a comparison of the results given in the table. Products given below without a reference number are the ones obtained in the course of this work.

Products of Nitrations with Different Reagents.

Compound	HNO_3 H_2SO_4	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\left.\begin{matrix}CH_2\cdot CO\\CH_3\cdot CO\end{matrix}\right>O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\left.\begin{matrix}CH_3\cdot CO\\CH_3\cdot CO\end{matrix}\right>O$	Other Reagents.
Benzene	nitrobenzene	nitrobenzene	nitrobenzene	nitrobenzene	nitrobenzene	nitrobenzene	nitrobenzene	Diacetylorthonitric Acid. nitrobenzene (1)
Nitrobenzene	98·58% HNO_3 4·8% o- 93·5% m- 1·7% p- 97·6% HNO_3 6·8% o- 91·8% m- 1·4% p- (2)	100% m-	-	-	6·4% o- 93·2% m- 0·25% p- (2)			$SO_2\cdot O\cdot SO_2\cdot O\cdot NO_2)_2$ m- only (3)
Bromobenzene	30·6% o- 69·4% p- (3)	100% p- (4)	-	-	37·6% o- 62·1% p- (4)	33·8% o- 66·2% p- (3)	-	N_2O_4 5% o- 95% p- (5) Nitric Acid + Nitrosulphuric Acid. p- only (4)

Products of Nitrations with Different Reagents.

Compound	HNO_3 H_2SO_4	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\left.\begin{array}{l}CH_3\cdot CO\\CH_3\cdot CO\end{array}\right>O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\left.\begin{array}{l}CH_3\cdot CO\\CH_3\cdot CO\end{array}\right>O$	Other Reagents.
Toluene	40% o- 60% p- (7)	20-30% o- 70-80% p-	-	-	58% o- 3·9% m- 38·1% p- (8)	-	-	Acetyl nitrate in CCl_4 or acetic anhydride. 88% o- 12% p- (9) Ferric nitrate in acetic anhydride. o- exclusively (10)
Phenol and bromo-phenols	50-60% Picric Acid	100% Picric Acid	Picric Acid	Picric Acid	Mixture of bromonitro-phenols (11)			-
p-dichloro-benzene	94% 1:4-dichloro-2-nitro-benzene (12) 83% 1:4-dichloro-nitro-benzene (13)	100% 1:4-dichloro-2-nitro-benzene	100% 1:4-dichloro-2-nitro-benzene	-	-	-	-	-

Compound.	Products of Nitrations with Different Reagents.							
	HNO_3 H_2SO_4	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\left.\begin{array}{l}CH_3\cdot CO\\ CH_3\cdot CO\end{array}\right>O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\left.\begin{array}{l}CH_3\cdot CO\\ CH_3\cdot CO\end{array}\right>O$	Other Reagents
1:4-dichloro-2-nitro-benzene	13·1% 1:4-dichloro-2:6-dinitro + 26·2% 1:4-dichloro-2:3-dinitro-benzene + 45·6% molecular compound (14)	-	-	-	-	-	-	<u>N_2O_5 in H_2SO_4</u> 44% 30% 26%
2-chloro-4-nitro-toluene	85% 2-chloro-4:5-dinitro-toluene + 12% 2-chloro-4:6-dinitro-toluene (15)	<u>N_2O_5 alone</u> 81·3% -	-	-	-	-	-	-

Products of Nitrations with Different Reagents.

Compound.	HNO_3 H_2SO_4	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\begin{matrix}CH_3\cdot CO\\CH_3\cdot CO\end{matrix}>O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\begin{matrix}CH_3\cdot CO\\CH_3\cdot CO\end{matrix}>O$	Other Reagents.
Diphenyl	-	96% 4- ~~82·3% 4-~~	17·7% 2- 82·3% 4-	40·6% 2- 59·4% 4-	25·9-28·8% 2- 46·3-51·8% 4- (16)	-	-	$\underline{N_2O_4}$ 4- exclusively (17)
4-Nitrodiphenyl	-	96% 4:4'-	20·9% 2:4'- 79·1% 4:4'-	53·6% 2:4'- 46·4% 4:4'-	37% 2:4'- 63% 2:4'- (13)	-	-	$\underline{N_2O_4}$ 2:4'- 4:4'- (17)
2-Nitrodiphenyl	-	-	8·3% 2:2'- 87·7% 2:4'-	-	39% 2:2'- 61% 2:4'- (18)	-	-	-
3-Nitrodiphenyl	-	-	29·3% 2:3'- 70·7% 3:4'-	-	27·1-32·6% 2:3'- 59·8-65·5% 3:4'- (19) (20)	-	-	-

Compound.	HNO_3 H_2SO_4	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\begin{matrix}CH_3\cdot CO\\CH_3\cdot CO\end{matrix}>O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\begin{matrix}CH_3\cdot CO\\CH_3\cdot CO\end{matrix}>O$	Other Reagents.
Fluorene	-	100% 2-	-	100% 2-	-	96% 2- (21)		$\underline{N_2O_4}$ 70% 2- (17)
2-nitro-fluorene	20% 2:5- 65% 2:7-	-	11% 2:5- 79% 2:7-	19·5% 2:5- 62·7 2:7-	20% 2:5- 53% 2:7-	22% 2:5- 60% 2:7- (22)	-	2:5- 2:7- (17)
Di-phenylene Oxide	-	-	91% 2- 4% 1-	-	-	80% 2- trace 1- (23)	-	-
Acenaph-thene	-	100% 4-	100% 4-	94·2% 4- 5·8% 2-	-	87·5% 4- (24) (25)	21·3% 2- 78·7% 4- (26)	$\underline{N_2O_4}$ 90-95% 4- (17)

Products of Nitrations with different Reagents.

Products of Nitrations with different Reagents.

Compound.	HNO_3 H_2SO_4	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\left.\begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\right\rangle O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\left.\begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\right\rangle O$	Other Reagents.
m-nitrotoluene	55% 3:4- 25% 2:3- 20% 2:5- (27)	-	-	-	-	-	-	$\underline{HNO_3}$ anhydrous + $\underline{H_2SO_4}$ 81% 3:4:6- 18·1% 2:3:4-
	63·1% 3:4:6- 30·3% 2:3:4- 6·6% 2:3:6- (28)							$\underline{N_2O_5}$ + $\underline{H_2SO_4}$ 95·8% 3:4:6- 4·2% 2:3:4-
Diphenylmethane	-	4- 4:4'- 2:4:4'- successively	-	-	1 part 2:4' 4-5 parts 4:4'- (29)			$\underline{N_2O_4}$ No interaction (17)
α-methylnaphthalene		76% 4-	-	-	-	30% isolated pure. 50-60% 4- (30)	-	-

Compound.	Products of Nitrations with different Reagents.							
	HNO_3 $H2SO_4$	N_2O_5 CCl_4	N_2O_5 $CH_3\cdot COOH$	N_2O_5 $\left.\begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\right>O$	HNO_3	HNO_3 $CH_3\cdot COOH$	HNO_3 $\left.\begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\right>O$	Other Reagents.
Benzanthrone	Mixture of 2-and 3-		75·3% 2-	-	-	2-	-	<u>HNO_3 in nitrobenzene</u> 3- (31)
Anthracene	-	Dihydronitroanthranylnitrate	Dihydronitroanthranylacetate	N_2O_5 + $CH_3\cdot COOH$ + $\left.\begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\right>O$ nitroanthracene	HNO_3 + $CHCl_3$ Dihydronitroanthranylnitrate (32)	dihydronitroanthranylacetate (32)	HNO_3 + $CH_3\cdot COOH$ + $\left.\begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\right>O$ (32)	<u>N_2O_4</u> dihydronitreanthranylnitrate (32)
Quinoline and Pyridina	HNO_3 fuming + H_2SO_4 fuming 300 g. Quinoline 200 g. ananitro- + 150 g. orthonitro- (33)	Addition Compounds (4)						

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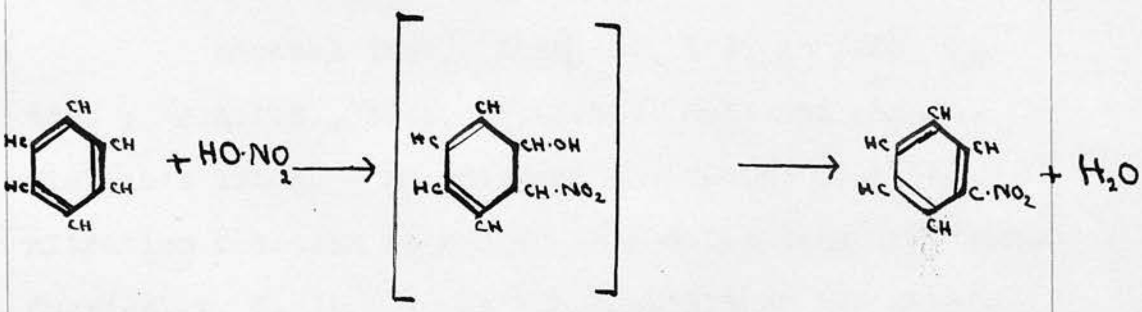
If we consider the yield of para-nitro compound we find a striking similarity running throughout the whole series of results. The yields of the para-isomer decrease throughout the following series of nitration media: N_2O_5 in $CCl_4 > N_2O_5$ in $CH_3\cdot COOH > HNO_3 + H_2SO_4 > HNO_3 > HNO_3 + CH_3\cdot COOH > N_2O_5 + \begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\!\!>O >$ $HNO_3 + \begin{matrix}CH_3\cdot CO\\ CH_3\cdot CO\end{matrix}\!\!>O$. This is borne out in the cases of bromobenzene, toluene, diphenyl, substituted diphenyls, fluorene and acenaphthene.

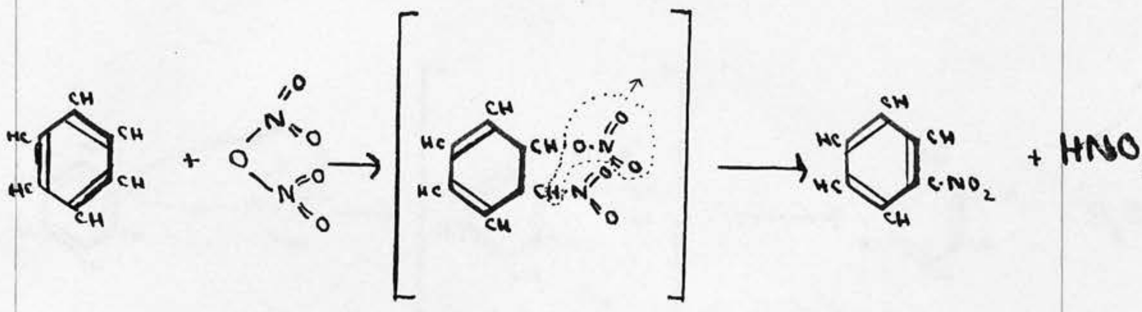
From the results obtained it is improbable that in nitration mixtures, e.g. $H_2SO_4 - HNO_3$, the N_2O_5 produced in the dehydration of nitric acid by sulphuric acid (cf. Introduction, p. 28) can be solely responsible for the nitration reaction, although it is no doubt responsible in some degree for this nitration. The possibility that nitrosulphonic acid, $HO\cdot SO_2\cdot NO_2$, may be responsible for the nitration is considered unlikely by Varma and Kulkarni (J.A.C.S., 1925, 47, 143). For example, nitrosulphonic acid by itself had no effect on benzene. A mixture of nitrosulphonic acid and sulphuric acid and benzene blackened on heating, but no nitrobenzene was formed. However, when a 46% solution of nitrosulphonic acid in fuming nitric acid was used, a good yield of nitrobenzene was obtained. From these results and many others, Varma concluded that nitrosulphonic acid functioned because of its dehydrating action, in which respect it was more efficacious than sulphuric acid. In this connection it is of interest to note that when bromobenzene is nitrated by means of nitrogen pentoxide in carbon tetrachloride solution, a quantitative yield of p-bromonitrobenzene is obtained. With nitrosulphonic acid in fuming nitric acid Varma obtained only p-bromonitrobenzene, but in the nitration of bromobenzene with a mixture of HNO_3 (cold conc.) + H_2SO_4 , 69·4% p-bromonitrobenzene and 30·6% o-bromonitrobenzene are obtained. It is probable that nitrosulphonic acid, being a more efficient dehydrating agent than sulphuric acid, is able to liberate nitrogen pentoxide from the fuming nitric acid, and that this nitrogen pentoxide then accomplishes the para-nitration.

In view of the results detailed in the table (pp. 116-122), it seems reasonable to conclude that nitrogen pentoxide nitrates solely in the para-position or in cases where the group already present in meta-directing in the meta-position; e.g., nitrobenzene yields 100% m-dinitrobenzene. In other words, nitric acid anhydride in its own direct action upon an organic compound, like sulphuric acid anhydride, tends to produce only one isomer. The formation of other isomers in nitrations with nitrogen pentoxide may be attributed to the presence of either nitric acid which is produced as a by-product to the primary nitration, or organic nitrates or mixed anhydrides formed by the interaction of the nitric acid anhydride and an active solvent.

As pointed out in the Introduction to this thesis, differing viewpoints exist as to the precise nature of the nitration mechanism. Reddelien (J. prakt. Chem., 1915, 91. 220) and Wieland (Ber., 1919, 52, 898; 1920, 53, 201 ; 1921, 54, 1770) advanced the hypothesis that in nitration reactions, nitric acid did not act as an electrolyte, i.e. H^+ NO_3^- , but added to either end of a double bond as $HO + NO_2$. This primary addition was followed by a splitting off of one molecule of water from the nitroalcohol to yield the nitro compound. He represented the nitration of benzene as follows:-

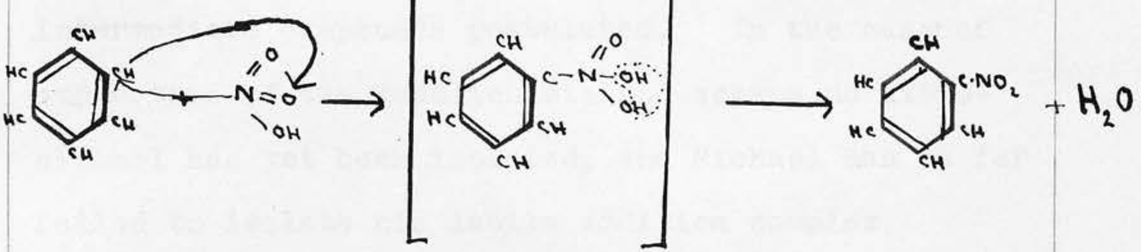


If nitrogen pentoxide reacted in this manner, i.e., by addition to either end of a double bond with a subsequent splitting off of one molecule of nitric acid, the nitration of benzene could be represented as follows:

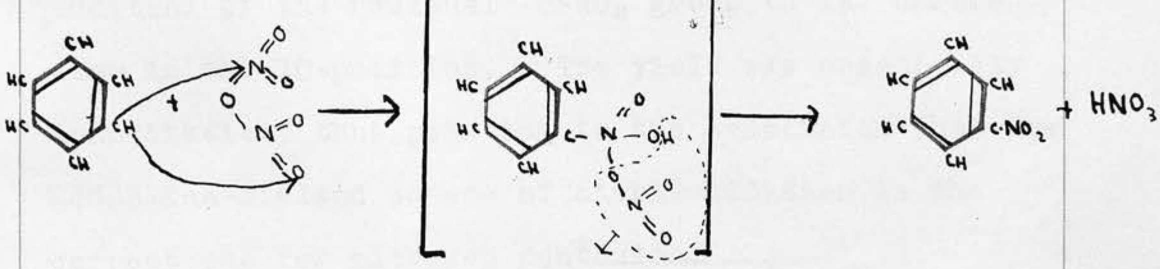


An unstable derivative of dihydrobenzene must first be formed and then this unstable complex splits off a molecule of nitric acid to give the required nitro-compound.

Michael (Ber., 1896, 29, 1795 ; 1901, 34, 4030 ; J.A.C.S., 1935, 57, 1268) does not support Wieland's ideas. He proposed the theory that the nitration reaction resembled an aldolisation (cf. Introduction, p. 6.). He stipulated that the nitric acid did not add to either end of an ethylenic double bond, but that the chemical potential of the nitrogen atom in the nitric acid for the aryl group and that of an unsaturated oxygen atom for hydrogen, were the dominating motive forces in the nitration. Hence Michael's scheme for the nitration of benzene can be represented as follows:

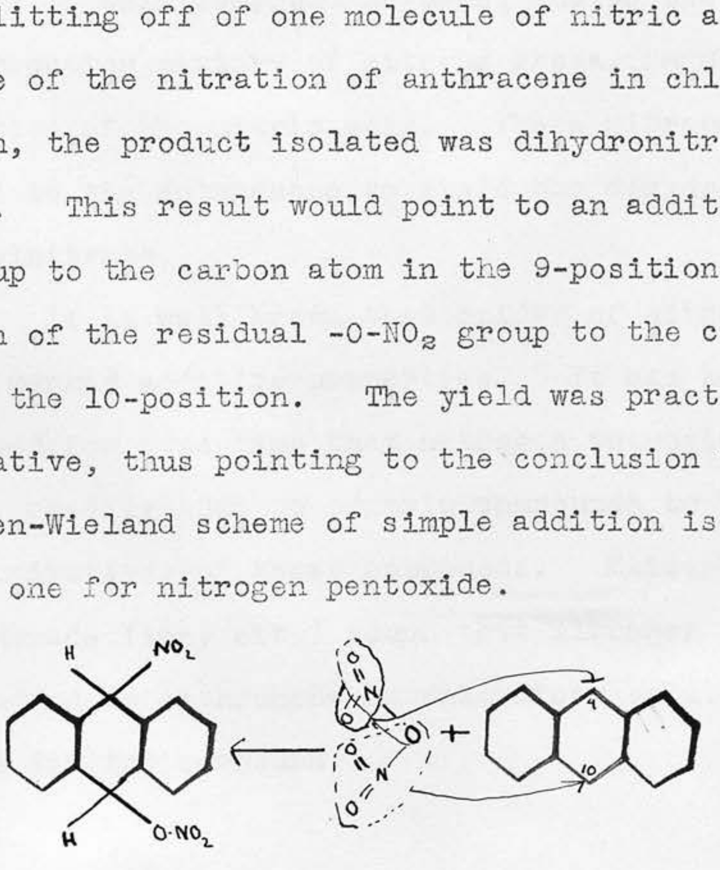


Application of Michael's theory to nitrations with nitrogen pentoxide necessitates a strong chemical attraction between the aryl group and a nitrogen atom of the pentoxide, and also between an unsaturated oxygen atom of the pentoxide and a hydrogen atom from the nucleus:

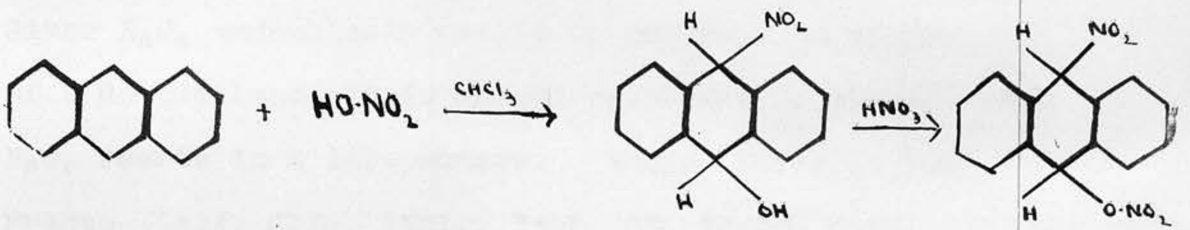


It is difficult to prove which of these mechanisms is the correct one, owing to the inability of the workers in this field to isolate the unstable intermediate compounds postulated. In the case of supporters of the Reddlien-Wieland scheme no nitro-alcohol has yet been isolated, and Michael has so far failed to isolate his labile addition complex.

While the work carried out in this research does not prove the correctness of one or the other of these hypotheses, the results obtained in particular cases lend substance to the suggestion that nitrogen pentoxide nitrations involve a simple addition of the reagent to an ethylenic linkage, or to unsaturated carbon atoms in the substance to be nitrated, followed by a splitting off of one molecule of nitric acid. In the case of the nitration of anthracene in chloroform solution, the product isolated was dihydronitroanthranylnitrate. This result would point to an addition of an NO_2 group to the carbon atom in the 9-position and an addition of the residual $-O-NO_2$ group to the carbon atom in the 10-position. The yield was practically quantitative, thus pointing to the conclusion that the Reddelien-Wieland scheme of simple addition is the correct one for nitrogen pentoxide.

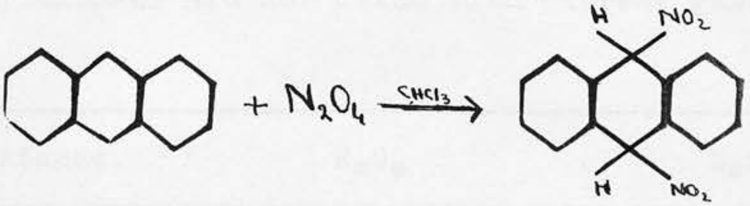


In the case of a nitration with nitric acid, the same product, dihydronitroanthranylnitrate, is isolated, (Meisenheimer and Connerade, Ann., 1903, 330, 160). This result can be explained by the Reddelien-Wieland scheme through the primary formation of a nitro-alcohol which undergoes esterification in the presence of the nitric acid to give the dihydronitroanthranylnitrate.



Michael, on the other hand, would explain the formation of this compound as being due to the presence in the reaction mixture of nitrous gases, formed by the deoxidation of the nitric acid. These nitrous gases then add to the anthracene to yield the dihydronitroanthranylnitrate.

It is well known that oxides of nitrogen exhibit marked additive properties. It has been recognised for some time that nitrogen tetroxide, for example, readily adds to organic compounds to yield nitro derivatives of these compounds. Meisenheimer and Connerade (loc. cit.) found that nitrogen tetroxide, N_2O_4 , added to anthracene in chloroform solution to give the dinitro compound.



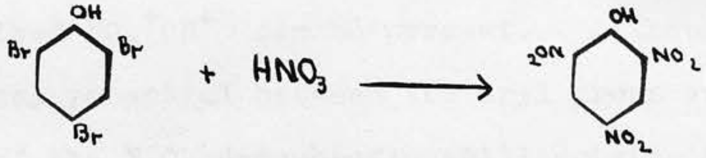
In view of the similarity of the results obtained in reactions with N_2O_4 and N_2O_5 it is not unlikely that the actual mechanisms of the nitration reactions of these two compounds are similar in nature. Since N_2O_4 undoubtedly reacts by addition to either end of a double bond, it is not unreasonable to suggest that N_2O_5 reacts in a like manner. Monté, Martello and Franco (Gazz. Chim. Ital., 1936, 66, 31-38) have investigated the reactions between N_2O_4 in the gaseous and the liquid states towards acenaphthene, fluorene, diphenyl and diphenylmethane. Acenaphthene dissolved in ether yielded with N_2O_4 90-95% 4-nitroacenaphthene, and on further nitration 4:5-dinitroacenaphthene; fluorene gave 70% 2-nitrofluorene, and on further nitration in glacial acetic acid solution at 90-95°C. a mixture of 2:5- and 2:7-dinitrofluorenes. Diphenyl dissolved in ligroin reacted with gaseous N_2O_4 at 90-95°C. to give a theoretical yield of 4-nitrodiphenyl, and with liquid N_2O_4 at room temperature to give a theoretical yield of 4-nitrodiphenyl. On further nitration in glacial acetic acid solution, diphenyl gave a mixture of 2:4'-dinitrodiphenyl and 4:4'-dinitrodiphenyl.

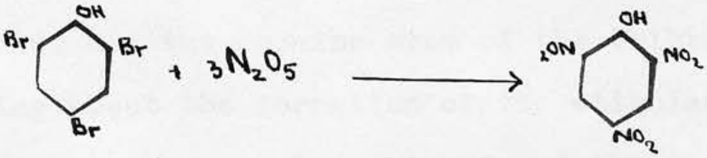
Diphenylmethane did not react with nitrous gases.

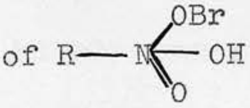
Substance.	N_2O_4	N_2O_5
Diphenyl	in ligroin: 4-nitrodiphenyl	in carbon tetrachloride: 4-nitrodiphenyl
4-nitrodiphenyl	in glacial acetic acid: 2:4'-dinitrodiphenyl + 4:4'-dinitrodiphenyl	in glacial acetic acid: 79·1% 4:4'-dinitrodiphenyl + 17·7% 2:4'-dinitrodiphenyl
Fluorene	70% 2-nitrofluorene	100% 2-nitrofluorene.
2-nitrofluorene	2:5-dinitrofluorene + 2:7-dinitrofluorene	11% 2:5$^+$-dinitrofluorene + 79% 2:7-dinitrofluorene
Diphenylmethane	-	CCl_4 4-nitrodiphenylmethane
Acenaphthene	in ether: 90-95% 4-nitroacenaphthene	in CCl_4: 100% 4-nitroacenaphthene
4-nitroacenaphthene	in ether: 4:5-dinitroacenaphthene	in CCl_4 4:5-dinitroacenaphthene.

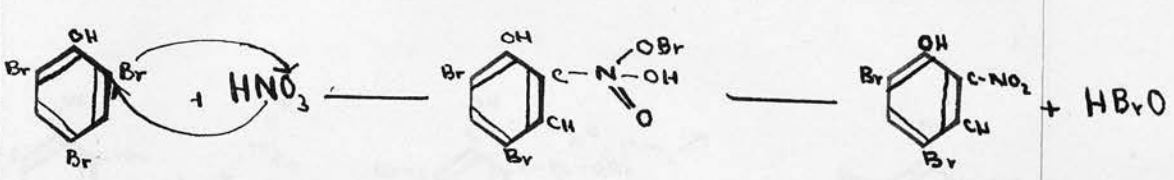
In view of the striking similarity of these results it seems feasible to suppose that the reactions in the two instances follow the same course, viz: by addition at either end of a double bond with subsequent splitting off of some part of the resultant labile complex molecule.

An illustration of the value of the use of nitrogen pentoxide in theoretical considerations is found in the replacement of bromine in certain compounds by the nitro group.

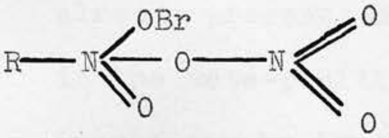




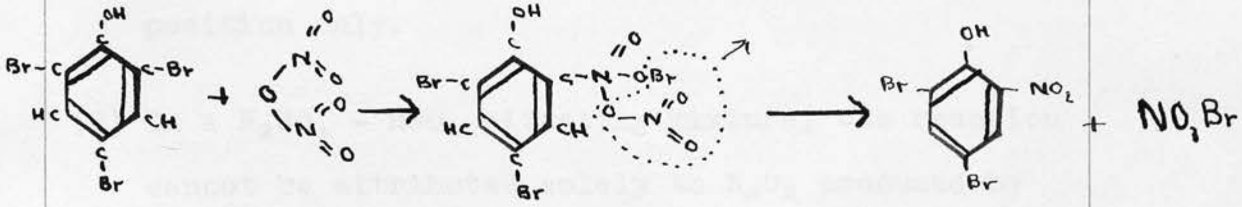
According to Hodgson and Elliot (J., 1936, 1762) there are three stages in the reaction: (a) the action of nitric acid as $NO_2{}^{+}OH^{-}$; (b) the formation of  $R-\overset{OBr}{\underset{O}{N}}-OH$ as described by Michael; (c) the subsequent splitting off of hypobromous acid.



The same reaction, however, takes place with N_2O_5 as the nitrating reagent, picric acid again being the product. In this case, however, the arguments of Hodgson and Elliot (loc. cit.) cannot apply, as no polarised $NO_2^+OH^-$ can be present. Although the chemical potential between the aryl group and a nitrogen atom of the N_2O_5 undoubtedly still exists, it is extremely doubtful if there is sufficient chemical affinity between an unsaturated oxygen atom of the pentoxide and the bromine atom of the tribromphenol to bring about the formation of the stipulated intermediate unstable complex which is of the form



. In order to complete the replacement reaction, this unstable intermediate complex must split off NO_3Br. Such a reaction seems highly improbable. Consequently this mechanism does not seem to be applicable. According to Hodgson and Elliot (loc. cit.) and Michael (loc. cit.), the reaction would be represented thus:



When all the considerations detailed above are examined together they tend to prove the correctness of the Reddelien-Wieland scheme as far as nitrations by means of nitrogen pentoxide are concerned.

As a result of the work carried out in this research it is possible to draw the following conclusions with regard to nitrations with nitrogen pentoxide:

(1) It is probable that nitrogen pentoxide itself nitrates only in one position. In most cases this is the para-position. Where a meta-directing group is already present, nitrogen pentoxide nitrates solely in the meta-position. The presence of an ortho-isomer may be traced to the presence of nitric acid in the reacting mixture. The nitric acid is produced as a by-product to the main nitration reaction by the pentoxide. In cases where the ortho-isomer is predominant, the active solvents, such as acetic anhydride, undoubtedly play a large part in the

reaction through the formation of diacetylorthonitric acid or acetyl nitrate. These substances show a marked tendency to nitrate in the ortho-position only.

(2) In a H_2SO_4 - HNO_3 nitrating mixture, the reaction cannot be attributed solely to N_2O_5 produced by dehydration of the nitric acid by the sulphuric acid, as the results obtained in nitrations where N_2O_5 is the only possible nitrating agent are not comparable to those obtained with an HNO_3 - H_2SO_4 mixture.

(3) The results obtained tend to demonstrate that the Reddelien-Wieland hypothesis of the nitration mechanism, involving addition at either end of a double bond with subsequent breaking down of the complex formed, is quite applicable to nitrations with nitrogen pentoxide.

(4) Many practical advantages accrue from the use of nitrogen pentoxide. Increased total yields of nitro-compounds are obtained. In many instances, only one isomer is obtained, and in other cases the yield of the one isomer is so overwhelmingly greater than that of the other, that many long and difficult separations in trying to isolate that isomer in a state of purity may be avoided.
Again, the use of nitrogen pentoxide enables rapid

and quantitative nitrations to take place in many instances at temperatures below 0°C. In these cases where an inert solvent is used and under the conditions specified in the Experimental Section of this work, theoretical deductions may be made from the experimental data with a greater degree of certainty than is the case when an active solvent is used, as in many ordinary nitrations. By enabling nitration to take place at a low temperature, the yield of any ortho-isomer is decreased and oxidation effects are avoided. By the use of dry carbon tetrachloride solutions of the reagent, of known concentration, nitrations may be fairly accurately stopped at any stage desired. A 33% solution of nitrogen pentoxide is easily prepared, may be kept for long periods, and is much more easily handled than is the nitrogen pentoxide itself.

SUMMARY.

The reactions between nitrogen pentoxide and various organic compounds in different solvents have been examined. The results obtained in these nitrations have been compared to the results obtained by previous workers using different nitrating reagents (cf. Table, pp. 116-122). The practical advantages of the use of nitrogen pentoxide have been noted, and theoretical conclusions have been drawn from the results obtained as to the nature of its nitrating mechanism

In conclusion, the author wishes to express his indebtedness to Dr Neil Campbell for his advice and constant interest throughout the course of this work, and to make grateful acknowledgment to the Department of Scientific and Industrial Research for a Maintenance Allowance for the years 1935-37.