A THESIS

entitled

PART I - CYCLIC POLY-YNES
PART II- ADDITION OF DINITROGEN TETROXIDE TO UNSATURATED ACIDS

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SUMMARY

This thesis is in two distinct parts. Part I describes an investigation of the oxidative coupling of ethynyl compounds, and the syntheses of certain cyclic conjugated α-diynes. Part II describes the investigation of the addition of dinitrogen tetroxide to long-chain unsaturated acids.

Part I is subdivided into three sections. Section I describes the preliminary investigation of the oxidative coupling reaction of ethynyl compounds, and its successful extension to reaction in homogeneous organic medium. Section II describes the use of a high-dilution modification of the conditions to provide the first cyclic poly-ynes, the properties and reactions of which are discussed. Section III discusses the possible syntheses of novel conjugated macrocycles by the oxidative coupling reaction, and describes one such macrocycle, from o-diethynylbenzene, and an investigation of its properties and reactions.

Part II describes an investigation of the addition products of the addition of dinitrogen tetroxide to long-chain unsaturated acids, in an attempt to confirm the reported findings, and to investigate the uses of the products.

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INTRODUCTION

Both academic and industrial fields admit the importance of acetylene and acetylenic compounds. On acetylene itself is based an entire chemical industry, a major contribution being the manufacture of plastics of the polyvinyl chloride type. Of late, interest in acetylenic compounds has gathered momentum; numerous applications of acetylenic intermediates in the synthesis of natural products have been reported, of which the polyenes, unsaturated fatty acids, penicillins, antibiotics, steroidal hormones, and the naturally-occurring insecticides provide diverse examples.[1] In 1950, Jones in his Tilden lecture[2] reviewed the use of acetylenic compounds in synthesis, and described a series of poly-ynes recently prepared at Manchester. The following years saw the rapid development of poly-yne chemistry, the highest member so far prepared being a fully conjugated octayne.[3] In the course of the study of these compounds, the characteristic ultraviolet absorption was identified. This new tool was of great help in identifying natural poly-ynes, within the next few years the structures of oenenanthotoxin,[4] cicutoxin,[4] mycomycin,[5-7] agrocybin,[8,9] and erythrogenic acid[10] were elucidated. Many more naturally-occurring acetylenic compounds will surely be discovered with this aid, and their syntheses will offer great scope for the acetylenic intermediate. A further impetus to the development of acetylenic chemistry was provided in the published work of Reppe[11,12] and his associates, which helped to overcome much of the technical difficulty associated with acetylene, and presented new practical routes to the aspiring explorer of acetylenic chemistry. A consequence of the increase in interest is the appearance of several text-books on the subject, of which must be mentioned those of Johnson[13,14] and Raphael[1], along with several excellent reviews of various aspects of acetylenic chemistry, including one on the naturally-occurring acetylenic compounds.[15]

In particular, the oxidative coupling reaction of terminal acetylenic compounds has been widely exploited since its discovery by Glaser in 1869.[16] Many diverse types[17-25] of acetylenic compound have been successfully submitted to the reaction, and a variety of conditions employed, covering solvent, pH, temperature, and time effects, all of which are adequately described in the literature.[1,11,25-28] However, a general shortcoming in acetylenic achievements was the lack of investigation of acetylenic compounds with a methylene chain separating the acetylenic linkage from the other functional group or groups. This has only been partly rectified[29] within the last few years. In particular, the oxidative coupling reaction had not been applied to $\alpha:\omega$-diynes, possibly because of the unsatisfactory aqueous-phase nature of the existing oxidative coupling reaction.

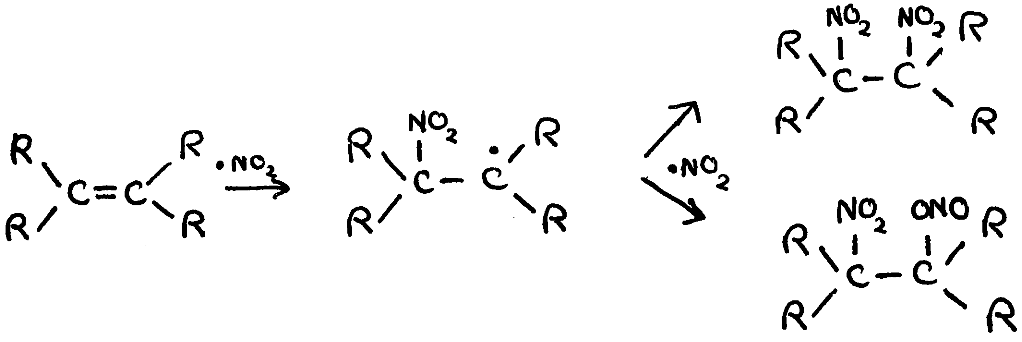
Since the formulation of Baeyer's strain theory in 1885, considerable attention has been paid to this theoretical aspect of the structure of all classes of cyclic compounds. The work of Prelog[30-33] and Blomquist[34-37] and their associates has shed much light on the requirements of cyclic hydrocarbons containing an acetylenic linkage. Since this present work was begun, further contributions have been made by Cram[38,39] and Sondheimer[40-44] and their associates, providing illuminating accounts of ring strain observations and their correlation with theory, using light absorption data as the main basis of argument.

The present work started in 1955 with the immediate aim of preparing cyclic polyacetylenic compounds. It was considered that a high-dilution coupling would be preferable to the conventional coupling procedure,[25] and Section I describes the successful extension of the oxidative coupling to reaction in an organic medium, and outlines the optimum conditions for this extension.

A fundamental improvement in the eyes of the organic chemist is the possibility of coupling such $\alpha:\omega$-diynes at varying dilutions to give cyclic compounds, such as cyclic α-diynes, possibly resulting from coupling at the highest-achieved dilution. Short-chain polymers might also be produced, and might have some application as synthetic intermediates. Some such successful attempts are described in Section II, and the properties and light absorption data of the cyclic compounds themselves are discussed. An investigation of the hydration of α-diynes is described, as little work had been done on that topic.

Section III deals with a synthesis of a novel conjugated cyclic system, rendered feasible by the high-dilution technique of oxidative coupling of terminal acetylenic linkages. The interesting properties and light absorption effects exhibited by this unusual system are discussed. The preparative route is dealt with in detail, as it contains several stages with unforeseen difficulties.

Part II describes a study of the addition of dinitrogen tetroxide to long-chain unsaturated systems. The addition of this reagent to carbon-carbon double bonds has been carefully studied by Levy.[45-49] The latter postulated an ionic mechanism of addition, but the recent experimental work of Schechter[50] had indicated a radical mechanism.



Since unsaturated fatty acids are commercially available, it was thought that addition of dinitrogen tetroxide might give products of commercial interest. Some additions to long-chain compounds have already been studied by Porter and Wood,[51,52] and by the active Russian[53-57] school of the present day. On this account, the study of the addition of dinitrogen tetroxide to several naturally-occurring fatty acids, and to their trans-isomers, was undertaken. Infrared spectroscopy proved to be invaluable in following the addition, although its use in this field had not previously been reported.

PART I

SECTION I

THE OXIDATIVE COUPLING REACTION OF ETHYNYL COMPOUNDS

Fig.1

HISTORY OF THE ACETYLENIC COUPLING REACTION

		Ref.	
1869	Glaser	16	Accidental discovery of the coupling reaction
1882	Baeyer	17	Use of potassium ferricyanide to effect coupling
1897	Noyes and Tucker	72	Use of cupric chloride to effect coupling
1910	Jositch and Orelkin	76	Action of I_2 on Grignard derivative of the acetylenic compound
1926	Straus and Kollek	26	Study of cupric chloride in effecting coupling
1926	Grignard and Perrichon	81	Coupling of Grignard derivative with acetylenic halide
1936	Danehy and Nieuwland	79	Coupling by action of cupric halides on Grignard derivative
1936 -39	Zal'kind _et_ _al_.	27-28 94-95	Conditions of coupling and proposed mechanism of reaction
1950	Schlubach and Wolf	73	Coupling of NaC≡CH in liquid NH_3 by action of $KMnO_4$
1952	Armitage _et_ _al_.	25	Improved method of coupling
1953	Milas and Mageli	70	Hydrogen peroxide in coupling of acetylenes
1953	Mkryan and Papazyan	98	Mechanism of the coupling reaction
1955	Reppe _et_ _al_.	12	Conditions and mechanism of coupling
1955	Raphael	1	Short survey of the coupling reaction
1956	Baxendale and Westcott	99	unpublished mechanism of coupling
1956	Eglinton and Galbraith	103	Cyclic poly-ynes
1957	Eglinton and Galbraith	192	A novel conjugated macrocycle
1957	Chodkiewicz	84	Extension to unsymmetrical coupling by double decomposition of an acetylenic halide and a cuprous derivative
1958	Klebanski _et_ _al_.	104	Rate and mechanism of the coupling reaction
1958	Kunichika and Oka	102	Review of the coupling reaction

HISTORICAL

In 1869 Glaser[16] observed that an ammoniacal alcoholic solution of the copper derivative of phenylacetylene underwent smooth aerial oxidation to give diphenyldiacetylene in good yield. This was the first reported instance of a

$$\mathrm{PhC{\equiv}CH} \xrightarrow[\substack{\mathrm{NH_3} \\ \mathrm{aq.\ alcohol}}]{\substack{\mathrm{CuCl} \\ \mathrm{NH_4Cl}}} \mathrm{PhC{\equiv}CCu} \xrightarrow{\mathrm{O_2}} \mathrm{PhC{\equiv}CC{\equiv}CPh}$$

reaction in which a compound containing a terminal acetylenic group was oxidatively coupled to give the conjugated α-diacetylene. This oxidative coupling reaction

$$\mathrm{RC{\equiv}CH} \xrightarrow{\mathrm{O_2}} \mathrm{RC{\equiv}CC{\equiv}CR}$$

of acetylenic compounds is one of a small class of reactions in which two molecules condense to give a symmetrical product.

Symmetrical Coupling

The Wurtz or Wurtz-Fittig reaction involves the action of sodium on two molecules of a halide, or different halides.

$$\mathrm{2RX + 2Na \longrightarrow R.R + 2NaX}$$

Olefins and paraffins corresponding to the alkyl halide are formed as by-products by dehydrohalogenation of the halide by the basic organosodium intermediates, and the postulation

$$RX + 2Na \longrightarrow RNa + NaX$$

$$RNa + RX \longrightarrow R.R + NaX$$

of free radical intermediates is now regarded as unnecessary.[58-60]

The Ullman reaction is employed in the symmetrical coupling of aryl halides. If less drastic conditions are desired, treatment of the arylmagnesium halide with an equimolecular quantity of cupric chloride[61] or other metallic halide,[62] furnishes the desired diaryl. Both couplings are thought to proceed via the free radical Ar•.

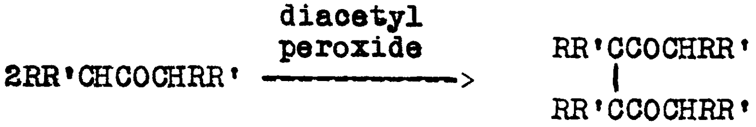
$$2ArX \xrightarrow[100^{\circ}]{Cu} CuX_2 + Ar.Ar$$

$$2ArMgX \xrightarrow{2CuCl_2} ArAr + 2MgXCl + 2CuCl$$

The Kolbe reaction produces long-chain paraffins by electrolysis of the potassium salts of fatty acids. The favoured explanation[63] is that hydrogen peroxide, liberated at the anode, oxidises the carboxylic anions to give the paraffin and carbon dioxide, with possible intermediate formation of an acyl peroxide, and liberation of acid radicals.

$$2RCOOK \longrightarrow R.R$$

A further example of symmetrical dimerisation occurs in the formation of an α-diketone from treatment of two moles of a ketene with diacetyl peroxide,[64] and the action of

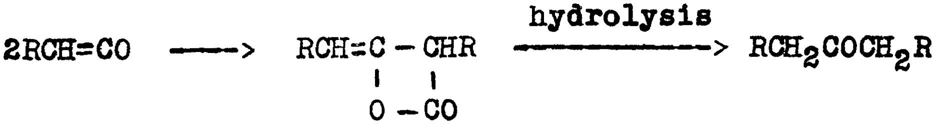


$$2RR'CHCOCHRR' \xrightarrow{\text{diacetyl peroxide}} \begin{array}{c} RR'CCOCHRR' \\ | \\ RR'CCOCHRR' \end{array}$$

zinc dust[65] and alkali on nitrobenzene leads to a symmetrical product, azobenzene.

$$PhNO_2 \xrightarrow[OH^-]{Zn} PhN{=}NPh$$

The formation of a symmetrical product from the direct coupling of two moles of a compound is also encountered in the self-condensation of ketenes.[66] This type of coupling,



$$2RCH{=}CO \longrightarrow \begin{array}{c} RCH{=}C - CHR \\ \;\;\;\;|\;\;\;\;\;\;\;\;\;| \\ \;\;\;\;O - CO \end{array} \xrightarrow{\text{hydrolysis}} RCH_2COCH_2R$$

and several other related instances, have produced cyclic symmetrical products by coupling of two moles of a bifunctional compound, and these instances are reviewed in the next section.

The mildness of the reaction conditions employed in the oxidative coupling of acetylenes (as compared to some others of the class), and the excellence of the yields, have led to a thorough investigation of the synthetic application of the coupling reaction of terminal acetylenic compounds.

Methods of Effecting the Coupling Reaction

The acetylenic compound itself readily undergoes coupling, and many oxidising agents are known to effect the reaction. The conventional reaction conditions[1,11,27,28] comprise air oxidation of the compound (in alcohol) with an aqueous solution of cuprous chloride and ammonium chloride, in either acid or alkaline conditions. Shaking of the above mixture in oxygen in a hydrogenation-type apparatus (ensuring intimate contact between the two phases) much improves the yields and shortens the reaction times.[24,25]

The cuprous derivative $RC{\equiv}CCu$ undergoes oxidation by air to give the diacetylenic compound. In addition to

$$2RC{\equiv}CCu + O_2 \longrightarrow RC{\equiv}CC{\equiv}CR + 2CuO$$

oxygen and air, the cuprous derivative has been successfully oxidised simply by heating,[67] or by the action of potassium ferricyanide,[17,68,69,74] hydrogen peroxide,[70] and cupric chloride.[26,71,72]

An interesting extension is the coupling of what is virtually the anion, in the observed coupling of the mono-sodium salt of acetylene in liquid ammonia, on treatment

$$2HC{\equiv}CNa + 2KMnO_4 \xrightarrow{\text{liq. } NH_3} HC{\equiv}CC{\equiv}CH + 2KNaMnO_4$$

with potassium permanganate[73].

The Grignard derivative of the acetylenic compound has also been successfully utilised in the oxidative coupling, and oxidation with iodine[75-78], cupric chloride[71,79] and cupric bromide[77,79,80], yields the diacetylenic compound, parallelling the previously described preparation of diaryls. The Grignard derivative may also be treated with an acetylenic halide, to give an unsymmetrical coupling, and Grignard[74,81] has explained

$$RC{\equiv}CMgX + IC{\equiv}CR' \longrightarrow RC{\equiv}CC{\equiv}CR + MgXI$$

the coupling of the halomagnesium acetylides by iodine as involving the above reaction.

$$a) \quad RC{\equiv}CMgX + I_2 \longrightarrow RC{\equiv}CI + MgXI$$

$$b) \quad RC{\equiv}CMgX + RC{\equiv}CI \longrightarrow RC{\equiv}CC{\equiv}CR + MgXI$$

The reaction between the Grignard derivative and the acetylenic halide generally requires the presence of small quantities of cobalt chloride[71] or cuprous chloride[72]. In the latter case traces of cuprous acetylide found at the end of the reaction suggest that the cuprous acetylide was an active participant in the reaction. Schlubach and Franzen have reported[71,83] an anomaly in the reaction with di-iodoacetylene, where the Grignard grouping is replaced by iodine.

$$2PhC{\equiv}CMgX + IC{\equiv}CI \longrightarrow 2PhC{\equiv}CI + XMgC{\equiv}CMgX$$

No evidence for the formation of $Ph(C{\equiv}C)_3Ph$ was obtained.

Non-symmetrical Coupling

Chodkiewicz[84] has recently extended the coupling reaction to a non-symmetrical coupling of wide scope. Conventional coupling of dissimilar acetylenic compounds leads to a

$$\mathrm{RC{\equiv}CH} \; + \; \mathrm{R'C{\equiv}CH} \; \xrightarrow[\mathrm{O_2}]{\mathrm{CuCl/NH_4Cl}} \; \begin{array}{l} \mathrm{RC{\equiv}CC{\equiv}CR} \\ \mathrm{RC{\equiv}CC{\equiv}CR'} \\ \mathrm{R'C{\equiv}CC{\equiv}CR'} \end{array}$$

mixture of three products,[85] the separation of which is usually extremely difficult. The new route parallels the previously mentioned discovery of the extension of the coupling to acetylenic Grignard derivatives, and involves the double decomposition of a cuprous acetylide and a halogenated acetylenic compound, leading to the non-symmetrical α-diyne. Bromides were the only halogen derivatives used in the investigation, as they were easily

$$\mathrm{RC{\equiv}CCu} \; + \; \mathrm{XC{\equiv}CR'} \; \longrightarrow \; \mathrm{RC{\equiv}CC{\equiv}CR'} \; + \; \mathrm{CuX}$$

prepared and the most reactive of the halogenated acetylenes. The reaction can be written as below, with cuprous ion as

$$\mathrm{RC{\equiv}CH} \; + \; \mathrm{R'C{\equiv}CBr} \; \xrightarrow[\mathrm{base}]{\mathrm{Cu}} \; \mathrm{RC{\equiv}CC{\equiv}CR'} \; + \; \mathrm{HBr}$$

a catalyst, in presence of a base for the removal of the hydrogen bromide liberated during the reaction. The reaction stops when all cuprous ion is converted to cupric, and introduction of a reducing agent, e.g., hydroxylamine, is necessary for the reaction to continue, and to prevent the normal oxidative coupling of the free acetylene by the cupric ion. A side reaction arises from the oxidisation of the bromide and gives the symmetrical coupling product

$$R'C\equiv CBr + 3Cu^{+} \longrightarrow R'C\equiv CCu + 2Cu^{++} + Br^{-} \longrightarrow R'C\equiv CC\equiv CR'$$

derived from the halogenated acetylenic component. This reaction might have application in the syntheses of symmetrical diynes where the cuprous derivative is slow to couple, and the proposed coupling would only involve addition of cuprous ion to the halogenated derivative. Chodkiewicz has made a full study of the reaction conditions, Various bases were employed, ethylamine furnishing the most satisfactory results. Use of a catalytic amount of cuprous salt favoured the suppression of the side reaction, which then only assumed importance if the cuprous derivative was slow to react.

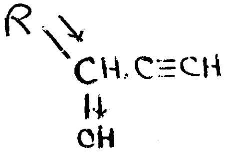
The synthetic importance of the oxidative coupling of acetylenic compounds lies in the advantage that not only acetylenic hydrocarbons, but many varied types of difunctional compound containing the acetylenic linkage, can be successfully submitted to the reaction. Thus in addition to hydrocarbons[16], nitro compounds[17], acids[10,18,19], esters[20-22], amines[23] and alcohols[24,25] have given the corresponding diynes smoothly and in high yield. This advantage, in addition to the discovery of several naturally-occurring poly-ynes[86], has made the oxidative coupling reaction of the greatest importance in the synthesis of these compounds, as the contributions of Bohlmann[87-90] and Sörensen[20,91-93] adequately testify.

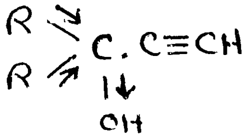
Mechanism of the Coupling Reaction

Considering the number of contributions to the literature on the coupling of terminal acetylenic compounds, it is surprising that so little investigation has been made of the mechanism of the coupling reaction. Straus and Kollek[26] made a study of the effect of varying the cupric ion concentration on the rate of reaction, and reported an increase in rate with increase of cupric ion concentration. Zalkind and his associates[27,28,94,95] studied the cuprous chloride/ ammonium chloride coupling, and considered the reaction to occur as : $2RC\equiv CH \longrightarrow RC\equiv CC\equiv CR + 2H$. They reported no evolution of hydrogen, or deposition of metallic copper, and concluded[27] that the reaction took place by a disproportionation resulting in the α-diyne and more hydrogenated products. Later they offered[28] the explanation of hydrogen removal by oxygen, and in an investigation[94] of the coupling of acetylenic alcohols, they proposed that the reaction took place through intermediate formation of free radicals, with subsequent condensation.

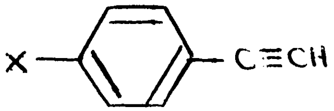
a) $RC\equiv CH \xrightarrow[\text{electron acceptor}]{O_2} RC\equiv C^{\bullet} + H^{+}$ b) $2RC\equiv C^{\bullet} \longrightarrow RC\equiv CC\equiv CR$

The poor yields noticed in the coupling of secondary alcohols were explained on the grounds that the formation of free radicals was retarded by the balancing of the supporting inductive effect of the alkyl group by the





electronegative effect of the hydroxyl group. In the case of the tertiary alcohols, the contributions of the two alkyl groups outweigh the effect of the hydroxyl group. By this mechanism they were able to explain the varying yields in the coupling of p-substituted phenylacetylenes.



In the case of X = Me, high yields were obtained, but when X = NO_2, the expected effect of slowing down of the reaction with decrease in yield was observed.

However, recent investigations[25], following up an observation[28] that in aerial coupling, the rate increases with increase in the percentage of oxygen, have produced an improved method of shaking in oxygen, and the intimate contact gained between the two phases leads to very satisfactory coupling of secondary alcohols. These investigations also show the reaction to be applicable over a wide range of pH, only failing when the acetylenic starting material is attacked. The suggested reaction conditions employ pH = 5, mildly acid, but strong enough to prevent precipitation of the cuprous derivative.

The well-known[96] dimerisation of acetylene to give, amongst other products, vinylacetylene, also takes place in an acid solution of cuprous chloride and ammoniun chloride. Up to the present this process has been believed specific to acetylene itself, attempts[1] to extend it to ethynyl compounds in general having been unsuccessful. However, Weedon[97] has recently noticed appreciable formation of the ene-yne during oxidative coupling of terminal acetylenic compounds, and its formation, accompanied by the appearance of the characteristic intense ultraviolet absorption, is likely, as a competing side reaction.

Mkryan and Papazyan[98] proposed an explanation of the oxidative coupling based on the following scheme.

$$\begin{array}{lcl}
\mathrm{2CuCl + 2HCl + \tfrac{1}{2}O_2} & \longrightarrow & \mathrm{2CuCl_2 + H_2O} \\
\mathrm{2RC{\equiv}CH + 2CuCl} & \longrightarrow & \mathrm{2(RC{\equiv}CH.CuCl)} \\
\mathrm{2(RC{\equiv}CH.CuCl)} & \longrightarrow & \mathrm{2RC{\equiv}CCu + 2HCl} \\
\mathrm{2RC{\equiv}CCu + 2CuCl_2} & \longrightarrow & \mathrm{RC{\equiv}CC{\equiv}CR + 4CuCl} \\
\hline
\mathrm{2RC{\equiv}CH + \tfrac{1}{2}O_2} & \longrightarrow & \mathrm{RC{\equiv}CC{\equiv}CR + H_2O}
\end{array}$$

As proof of these contentions, they cited the failure of the reaction in absence of air, and its success, still in absence of air, with cupric chloride. This differed from the findings of Zal'kind,[94,95] and seemed to indicate that both coupling by air in cuprous chloride/ammonium chloride mixture, and coupling by the action of cupric chloride,[26] proceed by the same mechanism. Reppe published[12] a similar contribution to the mechanism in 1955, as follows.

$$2RC{\equiv}CH + 2CuCl + 2NH_4Cl \rightleftharpoons 2(RC{\equiv}CH.CuCl.NH_4Cl)$$

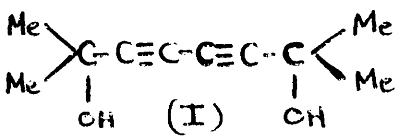
$$2CuCl + H_2O + \tfrac{1}{2}O_2 \longrightarrow 2Cu(OH)Cl$$

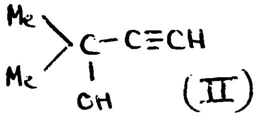
$$2(RC{\equiv}CH.CuCl.NH_4Cl + 2Cu(OH)Cl \longrightarrow (RC{\equiv}CC{\equiv}CR.2CuCl.2NH_4Cl) + 2CuCl + 2H_2O$$

$$(RC{\equiv}CC{\equiv}CR.2CuCl.2NH_4Cl) + 2RC{\equiv}CH \longrightarrow RC{\equiv}CC{\equiv}CR + 2(RC{\equiv}CH.CuCl.NH_4Cl)$$

The preceding sequences are somewhat cumbersome, and the series of complexes postulated may or may not have existence. However the reaction mechanism is but little clarified by these sequences, and the simpler radical mechanism seems preferable. The main points emerging from these investiga are that copper is shown to have a catalytic role in the coupling, and that the oxidising agent appears to be cupric ion. Reppe has also provided data on the rate of the cuprous chloride/ammonium chloride reaction. Recent work by Baxendale and Westcott[99] on the mechanism of the coupling reaction of terminal acetylenes has conclusively established that the oxidising agent in the commonly used cuprous chloride/ammonium chloride coupling is cupric ion, the behaviour of cuprous ion being essentially catalytic.

The dimer (I) was obtained simply by mixing (II) with copper sulphate in acetate buffer solution (pH = 6). They


(I)


(II)

considered that the reaction was autocatalytic, and that the cuprous ion concentration built up with time until it became stationary, when its removal by oxygen was balanced by its formation from the reduction of cupric ion by the acetylenic compound. The buffer was found to be necessary,

$$4RC\equiv CH + 2Cu^{++} \longrightarrow RC\equiv CC\equiv CR + 2RC\equiv CCu\downarrow + 4H^{+}$$

otherwise the developing acidity precipitated the cuprous derivative of the acetylenic compound.

The establishment of cupric ion as the oxidising agent in the coupling reaction provided the stimulus for the following investigations.

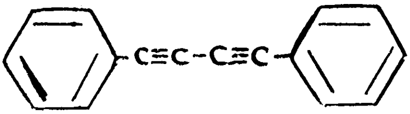
DISCUSSION

The main drawback to the aqueous oxidative coupling of ethynyl compounds is the frequent insolubility of the acetylenic component in the reaction medium, a feature which of necessity imposes long reaction times. Water-soluble ethynyl alcohols couple with reasonable rapidity, but the oxidative coupling of long-chain alkynes is often both slow and incomplete. This might explain why the coupling has only been recently applied to difunctional derivatives containing two ethynyl groups. It therefore seemed of value to find a method of extending the scope of the reaction, whereby ethynyl compounds might be coupled in homogeneous solution, preferably in a comparatively inert, easily removable solvent. This would present attractive new possibilities; firstly, such a manner of coupling would render possible a full kinetic study of reaction rates; secondly, it would be possible to study the coupling of α:ω-diynes in both <u>inter</u>- and <u>intra</u>-molecular fashion, leading in the first case to short- and medium-chain polymers, and in the second, to the hitherto unknown cyclic conjugated diynes, of which both the physical and chemical properties are likely to be of interest.

Coupling in Organic Medium

Cupric ion had been known to effect the oxidative coupling,[26] and its confirmation by Baxendale[99] as the oxidising agent in the commonly used cuprous chloride/ammonium chloride coupling simplified the problem, which now resolved itself into an attempt to react cupric ion and the acetylenic compound in an organic medium.

After some preliminary experiments, two model compounds which were readily available in satisfactory quantity and purity, were chosen. These were dimethylethynylcarbinol (I) and phenylacetylene (LII). Both compounds couple readily under the conventional conditions to yield the corresponding α-diynes, 2:7-dimethylocta-3:5-diyne-2:7-diol[100] (I) and



(IV)

diphenyldiacetylene (IV), which are colourless crystalline solids with satisfactory melting points. Following Baxendale's procedure, an experiment was devised wherein (II) was oxidatively coupled with cupric sulphate in a buffered aqueous solution with cuprous chloride as catalyst. The reaction yielded the α-diyne (I) in 58% yield, along with the cuprous acetylide (V). The temperature of the reaction

$Me_2C(OH)C{\equiv}CCu$ (V)

was that of the steam-bath, the time allowed being two to three hours. According to Baxendale's mechanism, the maximum possible yield is 50%, the remaining 50% being uncoupled (V). This seems to suggest that the Baxendale equation does not represent the complete reaction, but that oxidation by air, or oxygen, or some other oxidising agent has caused the coupling of part of the cuprous salt (V), giving rise to further diyne (I) and regenerating cupric ion:

$$2RC{\equiv}CCu + 4H^{+} + O_2 \longrightarrow RC{\equiv}CC{\equiv}CR + 2Cu^{++} + 2H_2O$$

Thus the combined equations give the overall relation :

$$4RC{\equiv}CH + O_2 \xrightarrow{Cu^{++}} 2RC{\equiv}CC{\equiv}CR + 2H_2O$$

with a recommended concentration of $\frac{1}{2}$ mole of cupric ion per mole of acetylenic compound. With (II), in the absence of the buffer, it was found that no reaction took place, the liberated acid entirely inhibiting the reaction. However on substituting copper acetate for copper sulphate, no buffer was necessary, as the liberated acetic acid did not hinder the reaction. The use of pyridine as reaction medium proved much more successful, as no cuprous derivative separated from the solution. The experiment was repeated omitting the catalyst and no deterioration in the yield was found. Thus no buffer or catalyst is necessary, and the reaction seems to take place in both aqueous and organic media quite freely. The successful prevention of precipitation of the cuprous derivative renders coupling in organic medium extremely attractive. The coupling was also successfully applied to the preformed cuprous derivative (VI) of phenylacetylene.

$$PhC{\equiv}CCu \quad (VI)$$

The reaction was performed in pyridine solution, as for the

$$2PhC{\equiv}CCu \xrightarrow{2Cu^{++}} PhC{\equiv}CC{\equiv}CPh + 4Cu^{+}$$

free acetylenic compounds, and supports the postulate of Baxendale[99] as to the course of the reaction.

A series of experiments was conducted with a wide variety of cupric salts[101] and solvents in order to determine the optimum conditions for the coupling reaction. Cupric salts were almost all successful in bringing about the coupling, except in cases where the cupric ion is too strongly complexed to allow of participation in the reaction, e.g., cupric salicylate, and the ethylene-diamine complex with cupric ion. A number of attempts were made with salts of other metals with an easily removable electron in the outer shell, e.g., ferric and cobaltic salts, but no success has so far been achieved in either aqueous or organic medium. Compounds which might be expected to effect the oxidative coupling are the cobalt naphthenates, noted in the paint industry as oxygen carriers, but results so far have been inconclusive.

Optimum Conditions

From the results of the above experiments, the optimum conditions may be summarised as follows ;

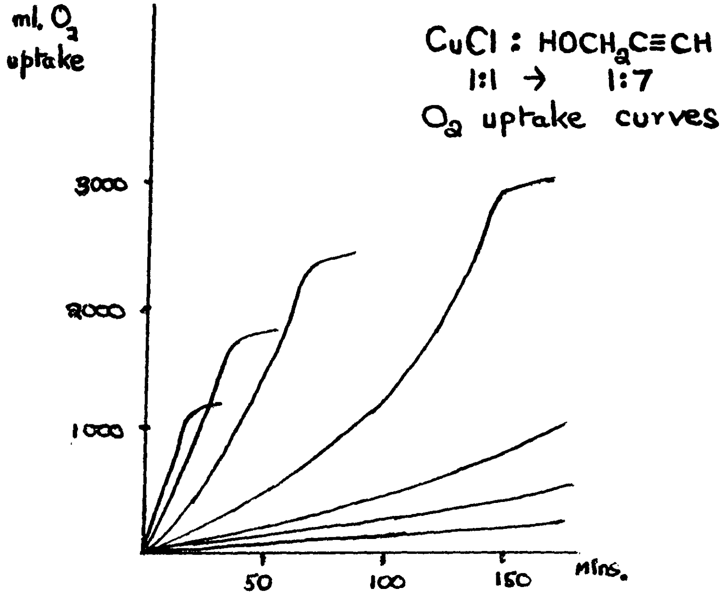
Cupric acetate is the most convenient and satisfactory reagent, as only acetic acid is produced to contaminate the product. The benzoate, butyrate, stearate and naphthenate are all successful in promoting the coupling, but chromatography would be required for removal of the organic acids, and in the case of the naphthenate, hydrocarbon impurities present serious problems in separation. While pyridine is a reasonably good solvent for cupric acetate, the addition of methanol greatly increases the solubility. Ether may be added if it is desired to lower the reflux temperature to 40-60°.

Catalytic Coupling

An important extension has been the coupling with a catalytic amount of cupric ion. Since the overall equation makes no mention of copper concentration, the cupric ion may be assumed to have a catalytic value, i.e., formation of the cuprous derivative as an intermediate. It should theoretically be possible to carry out the coupling employing a catalytic amount of cupric ion. This has been realised with a solution of (II) in pyridine:methanol:ether containing an essentially catalytic quantity of cupric ion (in the form of cupric acetate). Refluxing of the solution caused a colour change to green, while passage of oxygen effected the return to the original blue. Continued reversal of these states was carried out over a lengthy period of time, and the pure diyne (I) was isolated in 81% yield. It may be possible to extend the coupling reaction to other metal ions. Since the reaction involves the reduction of the cupric ion to cuprous, it might be expected that ions such as cobaltic and ferric would be capable of bringing about the reaction, as they are easily reduced to the corresponding cobaltous and ferrous states. From the periodic table, silver and gold must also be considered, but these are unlikely to be of practical importance on account of their high cost. However, copper does have a unique position in the periodic table, and may prove to be the only agent for this coupling.

Rate of Reaction

The effect of the concentration of cupric ion on the speed and yield of the oxidative coupling reaction deserves investigation, the only previous relevant work being that of Straus and Kollek,[26] on the effect of cupric chloride on the coupling of cuprous acetylide. Similar studies using cuprous chloride have been made by Reppe.[12] Oxidative coupling of propargyl alcohol in admixture at 0° with cuprous chloride/ammonium chloride solution gave the result that relatively large quantities of cuprous chloride were required to effect the coupling, as measured by the fall in the uptake of oxygen on keeping the cuprous chloride



concentration constant, and increasing that of propargyl alcohol. However it was noticed that the reaction was strongly accelerated by addition of small amounts of cupric acetate to the reacting solution. The rate of coupling was similarly[26] found to increase with increase in cupric ion concentration. The cuprous chloride/ammonium chloride coupling reaction has the disadvantage of long reaction times, due to its non-homogeneity, although the recent refinements[24,25] have reduced these as much as possible. The temperatures used in the Baxendale[99] aqueous coupling were ca. 80°, and it was found that some time was required for these couplings also, possibly due to the tendency of the precipitated cuprous derivative to continue to couple to the diyne. In contrast, the couplings in organic medium went extremely quickly at that temperature, being more or less complete after thirty minutes or less. The reaction was observed as a blue/green colour change, the blue colour of the cupric ion/pyridine complex being discharged as the cupric ion underwent reduction to the cuprous state. On standing in air, however, the original blue colour returned, presumably by air re-oxidation of the cuprous state, Relative speeds of coupling were in the following order ;-

$PhC\equiv CH > Me_2C(OH)C\equiv CH > CH_3(CH_2)_3C\equiv CH$

Kunichika and Oka[102] have reviewed the oxidative coupling of acetylenic compounds, and they provide a fairly comprehensive summary of compounds submitted to the reaction, the oxidising agent used, the yield, and the time of reaction.

Since the publication[103] of our preliminary findings, Klebanski[104] and his associates have reported an investigation into the mechanism and rate of the oxidative coupling reaction. They have investigated the coupling of (II) and other ethynyl compounds, both by the action of cuprous chloride/ammonium chloride/oxygen, and also by the action of cupric ion in aqueous alkaline (usually ammoniacal) solution. They postulate a three-stage process in which a) is the rate-determining process. Oxidation of the anion is regarded as the only reasonable explanation of the formation of the radicals, and evidence in favour of a) is as follows.

a) $RC\equiv CH \rightleftharpoons RC\equiv C^- + H^+$

b) $RC\equiv C^- + Cu^{++} \longrightarrow RC\equiv C^\bullet + Cu^+$

c) $2RC\equiv C^\bullet \longrightarrow RC\equiv CC\equiv CR$

Appearance of $RC\equiv C^-$ in the conventional cuprous chloride/ammonium chloride/oxygen coupling is facilitated by the formation of the complex ion $(RC\equiv CCuCl.NH_4Cl)^-$, as is evident from the drop in pH on admitting the ethynyl compound to the solution. In alkaline solution with cupric ion, ionisation is believed to go through formation of unstable copper acetylides. The ease of coupling of ethynyl compounds is shown to vary inversely as the pK of the corresponding carboxylic acid, an indication of the importance of the mobility of the hydrogen ion in causing reaction, and evidence for the rate-determining nature of a). In the reaction employing cupric ion, alkali is necessary to achieve reaction, as parallelled by Baxendale's requirement of a buffer. In the conventional coupling with cuprous chloride/ammonium chloride, the developing acidity is neutralised by the oxidation of cuprous ion to cupric, and

$$2Cu^+ + \tfrac{1}{2}O_2 + H_2O \longrightarrow 2Cu^{++} + 2OH^-$$

the reaction may then proceed as in the given sequence, with an overall relation as follows below, in exact agreement

$$2RC\equiv CH + 2Cu^{++} \longrightarrow RC\equiv CC\equiv CR + 2Cu^+ + 2H^+$$

with our previous postulate.[103] These authors have shown the reaction to be bimolecular, and polarographic investigation has shown that there is no build-up of intermediates in the solution, confirming the postulate of a much faster second stage. The speed of the reaction in the ammoniacal cupric ion coupling has been shown to vary with pH, rising to a maximum at the maximum degree of dissociation of the ammonia base. Addition of ammonium salts, depressing the dissociation of $[NH_4OH]$, has been shown to reduce the speed of the reaction. The order of speed of reaction for several different types of ethynyl compound was found to be as shown below.

$$PhC{\equiv}CH > PhCH(OH)C{\equiv}CH > MeCH(OH)C{\equiv}CH \approx Ph_2C(OH)C{\equiv}CH$$
$$> Me_2C(OH)C{\equiv}CH > HO(CH_2)_2C{\equiv}CH > CH_3(CH_2)_3C{\equiv}CH$$

No success in employing other oxidising agents has been achieved, in accordance with our findings[105], although Schlubach's[73] successful oxidation of the sodium salt of the ethynyl compound with permanganate has been known for some time, as has the coupling of the Grignard reagent of an ethynyl compound by the action of iodine[74]. They consider that copper may have an almost specific effect in this reaction, and mention that copper is known[106-108] to give up an electron to any species of ion, with the formation of a free radical. No evidence of the capacity of $RC{\equiv}CH$ to yield a free radical is to hand, but Favorsky[67] has obtained the diyne from heating the cuprous salt of $Me_3C.C{\equiv}CH$, and they themselves have caused the cuprous salt of phenylacetylene to react with isopropylbenzene to produce phenylacetylene, indicating the intermediate formation of $PhC\equiv C^{\cdot}$. They offer no direct proof of the existence of free radicals in the aqueous reaction medium, but consider the formation of mixed diynes[1,85] as main products in the coupling of dissimilar acetylenic compounds is best explained on the basis of combination of free radicals. Quantitative formation of final products in all of the couplings investigated leads the authors to postulate the third stage as an uncomplicated speedy recombination of the free radicals, and there seems to be little objection to this argument.

PART I

SECTION II

CYCLIC α-DIYNES

Fig.2

HISTORY OF THE PREPARATION OF CYCLIC ACETYLENES

		Ref.	
1929	Lespieau	110	The first reported cyclic acetylene
1933	Domnin	109	The first carbocyclic acetylene
1953	Blomquist *et al.*	37	Synthesis of *cyclo*öctyne
1955	Reppe *et al.*	12	Preparation of a heterocyclic unconjugated diyne
1956	Cram and Cordon	38	Paracyclophane system with an acetylenic linkage
1956	Cram and Allinger	39	Synthesis of an unconjugated cyclic diyne
1956	Epsztein and Marszak	111	Cyclic acyloins containing an acetylenic linkage
1956	Eglinton and Galbraith	103	Cyclic conjugated diynes
1956-57	Sondheimer *et al.*	40-44	Cyclic poly-ynes
1957	Eglinton and Galbraith	192	A novel conjugated macrocycle

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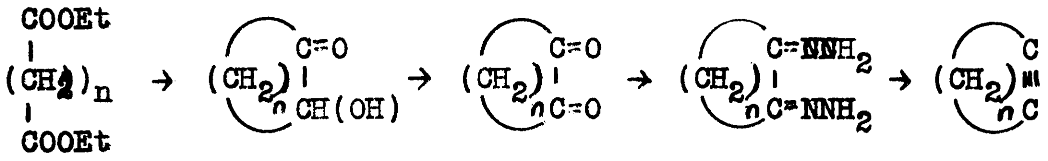
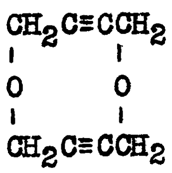
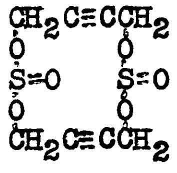
HISTORICAL

Medium-size carbocyclic compounds containing an acetylenic linkage, first reported[109] in 1933, are now well known,[30-37] *cyclo*öctyne[37] being the smallest ring so far obtained. These compounds are of interest for several reasons, notably the correlations which may be drawn between the degree of ring strain, the proximity of the acetylenic linkage to the other functional groups, and their physical and chemical properties. The method of synthesis[30,34] given below involves, in each case, ring closure of an α;ω-diester to give the acyloin, which is converted to the acetylene *via* the diketone and dihydrazone.

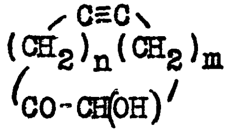


At the commencement of this work in 1955, the only cyclic compounds reported containing more than one acetylenic linkage were the heterocycle described by Lespieau,[110] and the



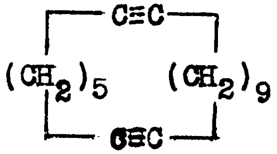


cyclic dimeric supphite ester of but-2-yne-1:4-diol of Reppe,[12] formed in quantitative yield in the attempted formation of the dichloride by mixing equimolecular amounts of but-2-yne-1:4-diol and thionyl chloride. Subsequently Epzstein and Marszak[111] have reported the preparation of the mixture of



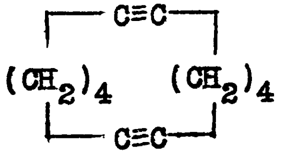
n = 5 ; n = 9
m = 9   m = 5

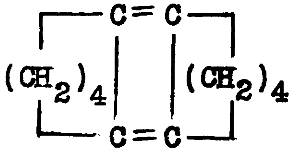
acyloins having the acetylenic linkage already present in the ring, and by means of the reaction scheme previously outlined, a 1:8-diyne appears to be obtainable from both



compounds.

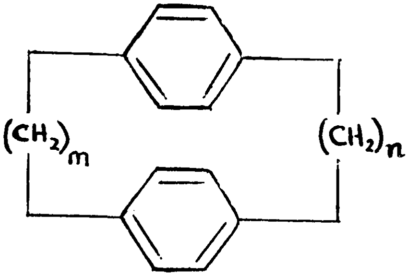
Cram[39] had already explored this possibility with his preparation of *cyclo*dodeca-1:7-diyne, from an ester containing a pre-introduced acetylenic linkage, in an effort





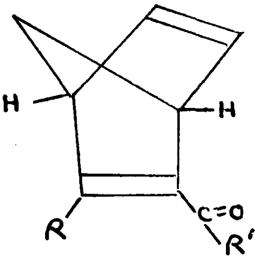
to find evidence for a *cyclo*butadiene structure. Light absorption data however showed only $C\equiv C$ end absorption.

This followed his studies on the paracyclophanes,[112-116] in which regular ultraviolet spectra were obtained only up to

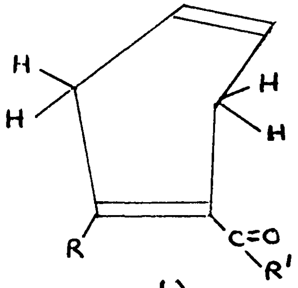


m = n = 4. The spectrum of any smaller cycle exhibited differences due to interaction between the π electrons of the benzene rings when the methylene chain no longer sufficiently separates them. His efforts to prepare cyclodeca-1:6-diyne were however in vain.

A similar effect is thought to cause the anomalous spectra of 1:4-dihydrobenzene derivatives[117-122] of type a) and b),



a)



b)

in which the distance between the unsaturated groupings is of the same order. The anomalies are attributed to either a direct spacial electronic interaction[120] across the centre of the six-membered ring, or strong hyperconjugation[118] of the cyclomethylene groups. The first was considered unlikely, in view of the directional properties of the π electron orbitals, and the comparatively large distance (*ca*. 2.5A) across the *cyclo*hexadiene ring. The application of such an argument to account for the ultraviolet absorption anomalies in triptycene[121], and the reassignment of the ultraviolet absorption bands in these substituted *cyclo*hexadienes[122], constitute evidence in its favour.

DISCUSSION

Whereas *cyclo*öctyne is the smallest cyclic acetylenic compound so far prepared,[37] and *cyclo*heptyne seems most unlikely from consideration of molecular models, it is obvious that a larger ring will be required to contain the rigid, linear six-carbon α-diyne unit. The obvious route to such a system is the oxidative coupling of α:ω-diethynyl compounds of type (VII). The conventional coupling of such compounds would be expected to give poly-ynes such as (VIII) and (IX), and continued coupling would yield polymeric poly-yne chains. In homogeneous solution however, complete coupling under high-dilution conditions, would favour the formation of cyclic products,[123] ranging from the monomeric cyclic α-diyne (X), *via* the dimer (XI), to macrocycles of type (XII).

$HC{\equiv}C(CH_2)_nC{\equiv}CH$

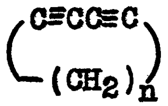
(VII)

$HC{\equiv}C(CH_2)_nC{\equiv}CC{\equiv}C(CH_2)_nC{\equiv}CH$

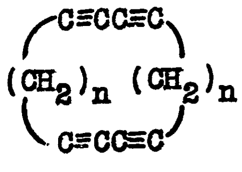
(VIII)

$HC{\equiv}C(CH_2)_nC{\equiv}CC{\equiv}C(CH_2)_nC{\equiv}CC{\equiv}C(CH_2)_nC{\equiv}CC{\equiv}C(CH_2)_nC{\equiv}CH$

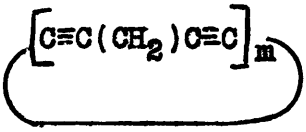
(IX)



(X)



(XI)

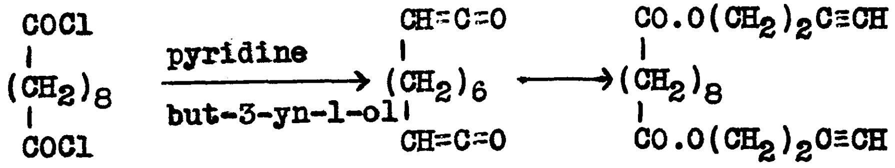


(XII)

The higher the dilution, the more favoured is the formation of cycles of lower molecular weight. From a study of "Catalin" models, it might be expected that a twelve-carbon *cyclo*alkadiyne (X, n = 8) is likely to be the smallest reasonably stable ring. With decreasing ring size, the ring-strain should increase, and would be expected to influence the light absorption, particularly the ultraviolet region. In addition to the interest in the physical properties, the chemical behaviour of such systems seems equally worthy of study, especially hydration and hydrogenation reactions, possibly in a transannular fashion. The preparation of highly conjugated cyclic poly-ynes, (and the corresponding polyenes), would appear to be a natural extension of the desired preparation of the simple cyclic alkadiynes.

Synthesis of Cyclic α-Diynes

In our own work, several long-chain α:ω-diynes have been submitted to our newly-developed organic-phase coupling reaction. The first such compound was the crystalline ester (XIII), available in good yield by condensation[124] of sebacoyl chloride with but-3-yn-1-ol in pyridine, presumably *via*

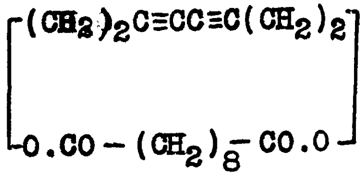


$$\begin{array}{c}\mathrm{COCl}\\ |\\ \mathrm{(CH_2)_8}\\ |\\ \mathrm{COCl}\end{array} \xrightarrow[\text{but-3-yn-1-ol}]{\text{pyridine}} \begin{array}{c}\mathrm{CH{=}C{=}O}\\ |\\ \mathrm{(CH_2)_6}\\ |\\ \mathrm{CH{=}C{=}O}\end{array} \longrightarrow \begin{array}{c}\mathrm{CO.O(CH_2)_2C{\equiv}CH}\\ |\\ \mathrm{(CH_2)_8}\\ |\\ \mathrm{CO.O(CH_2)_2O{\equiv}CH}\end{array}$$

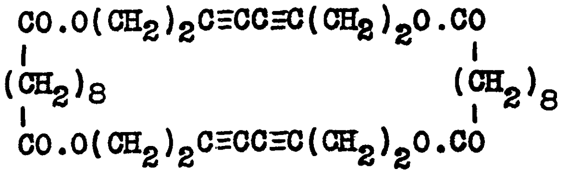
(XIII)

the ketene[66]. This compound was chosen because of the ready availability of the starting materials, and because consideration of the "Catalin" model of the cyclised product (XIV) indicated that it should be strainless. In addition, it was thought that the presence of the ester groups might render the ethynyl groups more reactive, as the simple aliphatic ethynyl hydrocarbons were found to be relatively slow to couple. The faster the rate of coupling, the more effective is the high-dilution addition.

When (XIII) was treated with cupric ion under high-dilution conditions of addition, it coupled rapidly, and after isolation by chromatography or sublimation, the pure cyclic monomer (XIV) was obtained in 47% yield, along with small quantities (1-2%) of the cyclic dimer (XV) when a lower dilution was employed. Polymeric material was also produced. The coupling appeared to be virtually complete, from the absence of the ethynyl band in the infrared spectrum of the ether-soluble product, and it seems that the dilution achieved has almost suppressed the formation of larger macrocycles.



(XIV)



(XV)

The monomer, the cyclic ester of sebacic acid and octa-3:5-

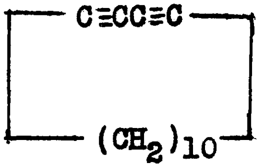
diyne-1:8-diol (XIV), was characterised by analysis, light absorption, hydrogenation, and molecular weight data. The infrared spectrum indicated absence of ethynyl groupings, and had bands due to disubstituted $C\equiv C$, the ultraviolet spectrum exhibited the typical three α-diyne maxima. On hydrogenation, the compound took up four moles of hydrogen. The dimer (XV) was characterised by the same criteria, the infrared spectrum being more or less identical with that of (XIV), and the ultraviolet spectrum showing the same low-intensity maxima. (XIII), when submitted to the conventional coupling procedure with cuprous chloride and ammonium chloride at room temperature, with addition of dioxane to facilitate solution, gave mainly unchanged starting material, and some polymeric, ether-insoluble residues. Use of higher temperatures achieved only slow coupling to acyclic material.

Thus the first cyclic α-diyne had been prepared, but it was felt that the real objective should now be attempted, namely the preparation of a simple carbocyclic diyne containing no other functional groups. The α:ω-diyne chosen for oxidative coupling was tetradeca-1:13-diyne (VII, n = 10). This diethynyl compound was chosen as it was considered that a fourteen-membered carbon ring would be sufficiently stable to allow of characterisation, and the commercially available decamethylene dibromide provided an easy route for its synthesis. Condensation of decamethylene dibromide with two moles of sodium acetylide in liquid ammonia[125-127] yielded (VII, n = 10) in 57% yield. This compound

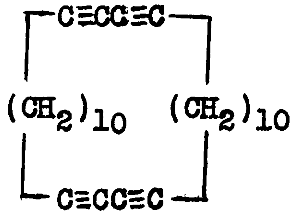
$$\mathrm{Br(CH_2)_{10}Br + 2NaC{\equiv}CH \xrightarrow[\text{liq.}NH_3]{\text{r.t./pressure}} HC{\equiv}C(CH_2)_{10}C{\equiv}CH}$$

m.p. 33-34°
(VII, n = 10)

had previously been prepared by bromination and dehydrobromination of tetradeca-1:13-diene, but was reported[128] as a liquid, and must have been impure. Cyclisation was carried out without the use of the high-dilution apparatus as (VII, n = 10) is very slow to couple, and the product was isolated and chromatographed on alumina to give the cyclic monomer and dimer, *cyclo*tetradeca-1:3-diyne (X, n = 10) and *cyclo*octacosa-1:3:15:17-tetrayne (XI, n = 10).



(X, n = 10)



(XI, n = 10)

*Cyclo*tetradeca-1:3-diyne (X, n = 10) was obtained as a viscous, colourless liquid, readily solidifying at 18° as large prisms, reddening rapidly on standing with simultaneous appearance of carbonyl absorption at 1735cm.$^{-1}$ Its structure

Fig.3

CYCLIC POLY-YNES

	Name	Formula	Ring size	m.p.	Yield
1)	cyclotetradeca-1:3-diyne	$C_{14}H_{10}$	C_{14}	18°	20-40%
2)	cycloöctacosa-1:3:15:17-tetrayne	$C_{28}H_{20}$	C_{28}	101-102°	10-30%
3)	cyclic ester of sebacic acid and octa-3:5-diyne-1:8-diol	$C_{18}H_{24}O_4$	20	55-56°	63%
4)	cyclic diester of sebacic acid and octa-3:5-diyne-1:8-diol	$C_{36}H_{48}O_8$	40	109-110°	ca. 2%
5)	cyclic diester of terephthalic acid and dodeca-5:7-diyne-1:12-diol	$C_{40}H_{40}O_8$	44	210-211°	35%
6)	cyclic ester of terephthalic acid and dodeca-5:7-diyne-1:12-diol	$C_{20}H_{20}O_4$	22	145-148°	<1%†

† - no analytical data

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followed from analysis, light absorption, and the identity of the fully hydrogenated hydrocarbon with a genuine sample of *cyclo*tetradecane.[129] The infrared spectrum showed the absence of ethynyl groups and the presence of disubstituted C≡C (band at 2260cm.$^{-1}$), the ultraviolet showing the three low-intensity maxima typical of α-diynes.[24,25,130-133]

From the later fractions, the dimer, *cyclo*öctacosa-1:3:15:17-tetrayne (XI, n = 10), was isolated as a solid m.p. 101-102°, and its structure was established by analytical, molecular weight and light absorption data, and hydrogenation to the fully saturated *cyclo*öctacosane.[129] The infrared spectrum was almost identical with that of the monomer, and the ultraviolet spectrum exhibited the expected three maxima in the region 225-255mμ. Exposure to light and/or air resulted in the appearance of a brightly coloured surface film. The polyacetylenic compounds of the first described series appear more stable than those of the carbocyclic series, although after exposure to air and/or light, similar brightly-coloured films are found on the surfaces of the crystals.

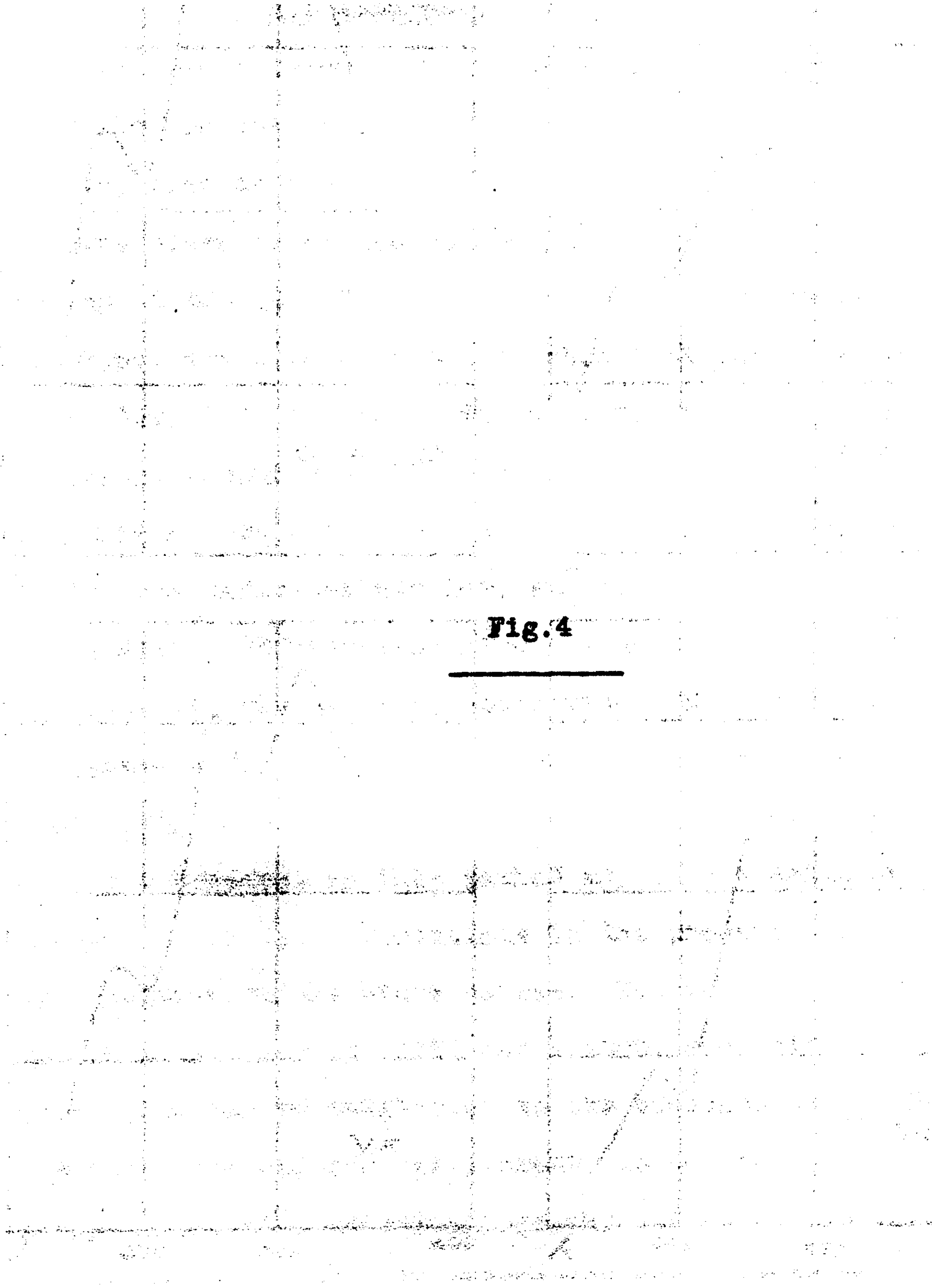
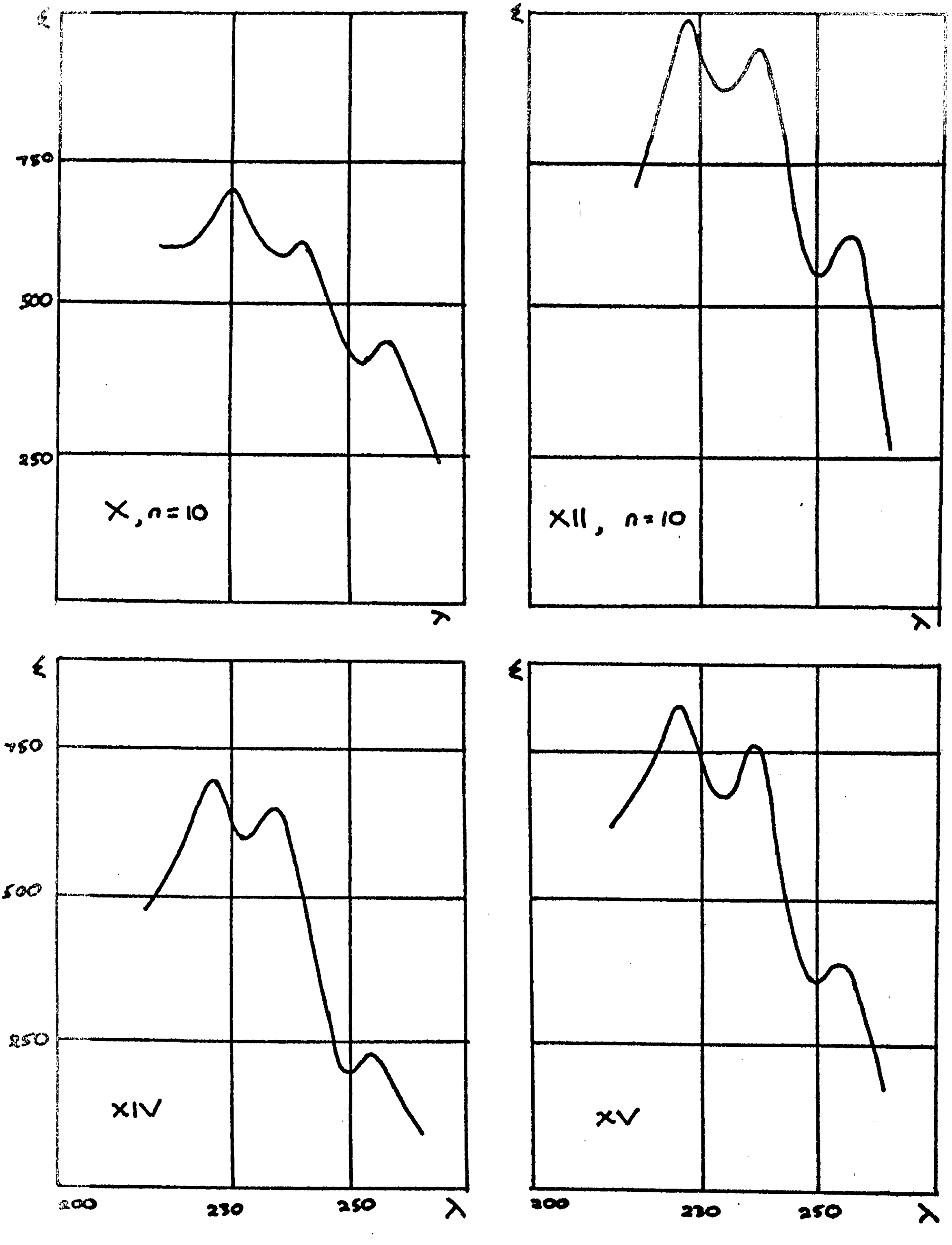


Fig.4

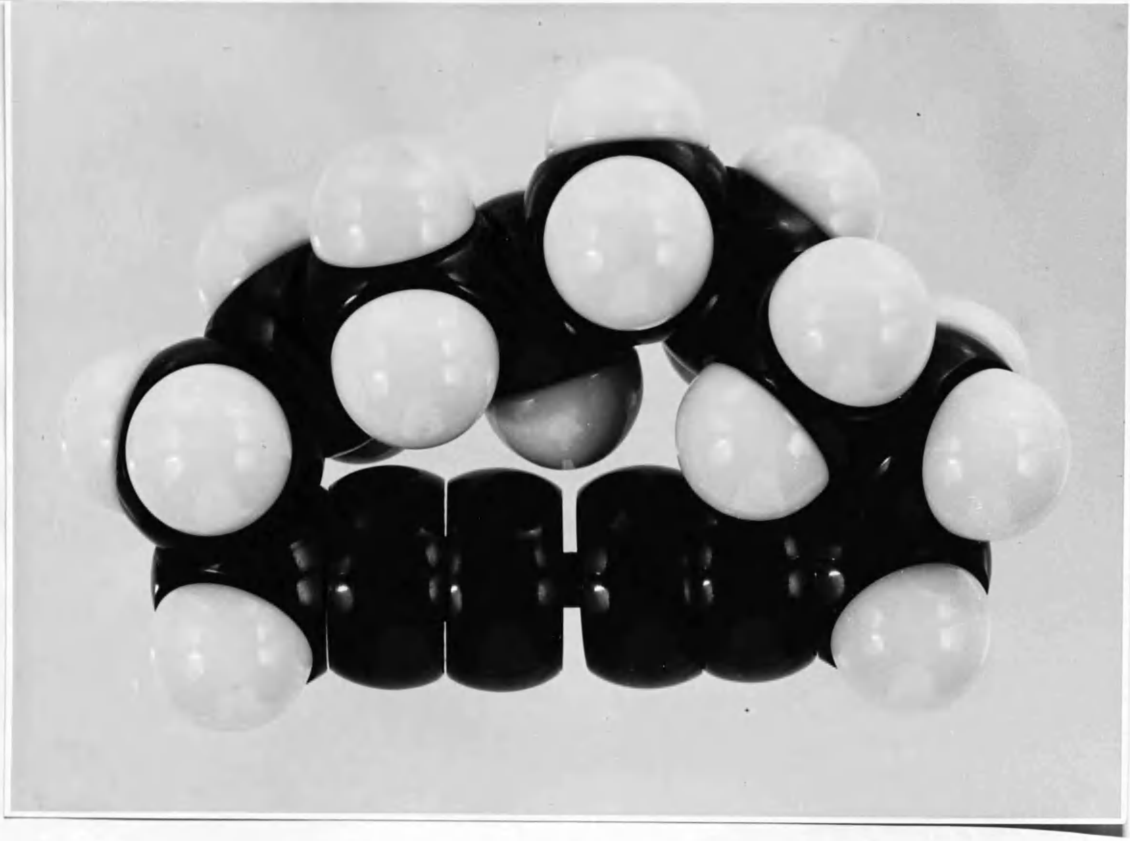


U.V. Spectra of the Cyclic Poly-ynes

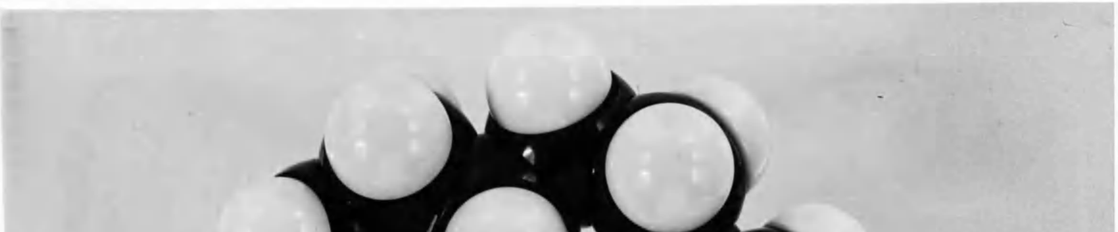
Light Absorption of Cyclic α-Diynes

The light absorption of the cyclic α-diynes should be a valuable indication of molecular abnormalities, e.g., ring strain, transannular interaction, etc. α-Diynes are stated[24,25] to have ultraviolet absorption maxima at λ 226, 238, and 254 mμ (ε 300-400, 300-400, and 180-240 respectively). Thus tetraynes would be expected to absorb at these maxima with ε *ca*. 700, 700, and 400. The ultraviolet data of the poly-ynes prepared are listed in table 1, along with comparable data for other poly-ynes. The ε values of these maxima are unfortunately low, and impurities brought about by oxidation or hydration have strong absorption which may markedly affect the diyne absorption. Ene-ynes are now available on the preparative scale[97], using conditions very similar to those of the oxidative coupling reaction, and α-diynes prepared by this method may be contaminated by traces of ene-yne. Variations in the present work may be attributable to the above causes. The reported[103] value for the first maximum of (XIV) was > 1000, and this unusually high value may be attributed to the presence of *ca*. 5% of ene-yne. The ene-yne, if present, is not easily removed by recrystallisation of chromatography and no ε value of < 1000 was obtained. In subsequent experiments material of lower ε has resulted, and careful chromatography and

Fig.5



X , n = 10 "Catalin" model



XIV , "Catalin" model

Table I

Poly-yne	λ	ε per $C\equiv CC\equiv C$	λ	ε per $C\equiv CC\equiv C$	λ	ε per $C\equiv CC\equiv C$	Ref.
$MeC\equiv CC\equiv CMe$	227	360	236	330	250	160	25
$BuC\equiv CC\equiv CH$	230	300	238	300	251	200	25
$BuC\equiv CC\equiv CBu$	228	440	240	390	254	240	25
$HC\equiv C(CH_2)_2C\equiv CC\equiv C(CH_2)_2C\equiv CH$	226	530	240	460	254	300	43
$HC\equiv C(CH_2)_3C\equiv CC\equiv C(CH_2)_3C\equiv CH$	226	540	240	510	254	440	43
$HC\equiv C(CH_2)_2C\equiv CC\equiv C(CH_2)_{23}C\equiv CH$	229	530	240	440	254	290	43
$\lfloor (CH_2)_3C\equiv CC\equiv C(CH_2)_3C\equiv CC\equiv C \rfloor$	226	300	238	290	263	180	43
$\lfloor (CH_2)_4C\equiv CC\equiv C(CH_2)_4C\equiv CC\equiv C \rfloor$	227	340	239	330	254	230	42
$\lfloor (CH_2)_5C\equiv CC\equiv C(CH_2)_5C\equiv CC\equiv C \rfloor$	227	280	239	300	254	180	43
(X, n = 10)	230	690	242	600	257	440	
(XI, n = 10)	226	490	238	470	254	320	
XIV	226	680	238	550	254	220	
XV	225	420	240	380	254	190	
$HOCH_2C\equiv CC\equiv CCH_2OH$	232	410	244	440	258	260	25
$AcOCH_2C\equiv CC\equiv CCH_2OAc$	233	700	244	670	258	480	130
$HO(CH_2)_2C\equiv CC\equiv C(CH_2)_2OH$	229	450	240	490	254	330	130

crystallisation have failed to lower the ε value, which remains fairly high, although there are several reported instances of poly-ynes with $\varepsilon > 400$ per α-diyne unit (see table 1). The effect of substituents on C_1 and C_6 in hexa-2:4-diyne[130] is to increase ε to values between 500 and 1000, and a study of the variation of the intensities of the maxima with different substituents revealed that the intensities were in the following order :-

$OH < OAc < OTs < Cl < Br < I$.

The value of ε for the first maximum of hexa-2:4-diyne-1:6-diacetate is 700, and although substitution on C_1 and C_8 of octa-3:5-diyne did not have such a marked effect[130] on the intensities of the maxima, the values for (XIV) do not appear unreasonable. (X, n = 10), the only compound which might possibly be subject to ring strain (from a study of a "Catalin" model), has all three maxima shifted to slightly higher wave-length, but this may not be significant, considering the simplicity with which the compound decomposes.

Ring strain and possible interactions might also affect the infrared absorption of the lactone groups in the heterocycles (XIV), (XV), and (XVII) (to be described later). However, infrared evidence has shown that the carbonyl frequency is practically unaffected by ring closure of the open-chain diesters, and the compounds are thought to be strainless, as indicated by consideration of their "Catalin" molecular models. The ν data are summarised in table II.

Table II

Compound	ν	$\Delta\nu_{\frac{1}{2}}$	ε per C=O
(XIII)	1745	18	430
(XIV)	1742	18	490
(XV)	1743	------------	
(XVI)	1726	16	570
(XVII)	1727	------------	
acetone	1719	18	250

(Taken with Unicam S.P. 100 spectrophotometer with NaCl prism in CCl_4 solution).

The α-diyne unit is less satisfactory for infrared observation as its intensity is very weak and easily masked by overtones and combination bands in aromatic or oxygenated substances. The cyclic compounds seem to exhibit normal absorption, and their C≡C stretching absorptions are compared with those of other α-diynes in table III.

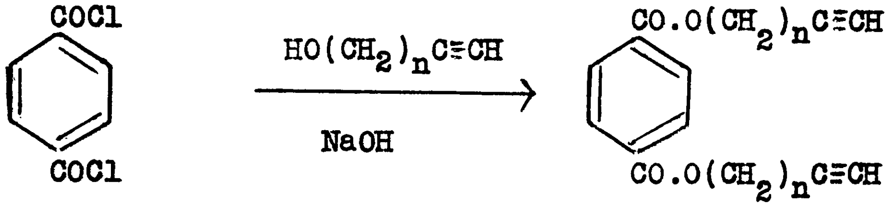
Table III

Compound	ν_1	ν_2	Solvent
(XIV)	2256	2150	CCl_4
(XI)n = 10	2252	2140	nujol
PhC≡CC≡CPh	2222	2132	nujol
$Me_2C(OH)C{\equiv}CC{\equiv}CC(OH)Me_2$	2251	2123	nujol
$HOCH_2CH_2C{\equiv}CC{\equiv}CCH_2CH_2OH$	2174	2120	nujol
$AcOCH_2CH_2C{\equiv}CC{\equiv}CCH_2CH_2OAc$	2260	2150	CCl_4
$PhC{\equiv}CC{\equiv}CC(OH)Me_2$	2235	2132	CCl_4
$CH_2{=}CHCN$	2228		CCl_4

(Taken with the Unicam S.P. 100 spectrophotometer with NaCl prism). ν C≡N = 2228cm.$^{-1}$ [134]

Further Cyclisations

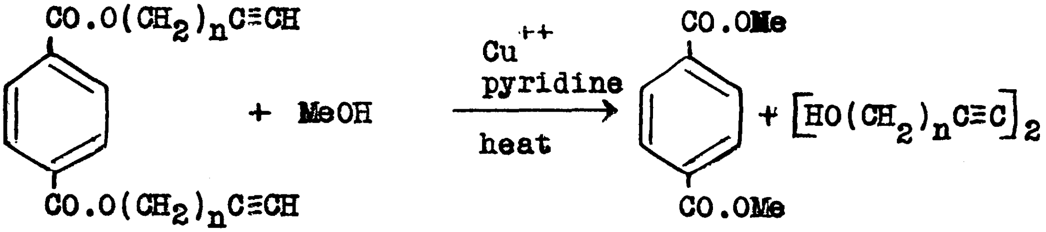
A further series of terminal diethynyl compounds was prepared in order to investigate any effects arising from ring strain, or from interactions between the α-diyne unit and an aromatic nucleus, in the derived cyclic compounds.



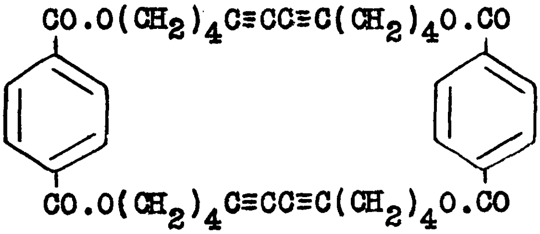
(XVI, n = 1,2, and 4

The above series of diethynyl diesters of terephthalic acid were prepared from the readily available terephthaloyl chloride and propargyl alcohol, but-3-yn-1-ol, and hex-5-yn-1-ol. The latter was prepared from 2-hydroxymethyltetrahydropyran by literature methods.[29,135] A Schotten-Baumann reaction on the solid acid chloride gave the solid esters directly, attempts to prepare them by Brewster's[136] method resulted in very low yields. These substances were found to possess characteristic ultraviolet absorption, λ 242, 285, and 295 mμ, (ε 21,000, 1800, and 1500 respectively). Any electronic effects arising from approach of the α-diyne system to the benzene ring might be expected to affect the light absorption, by analogy with the work of Cram[112-116] on the paracyclophanes.

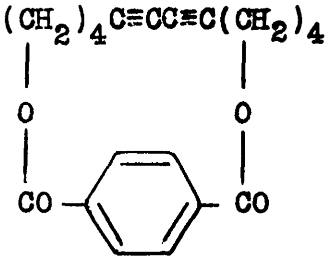
The oxidative coupling reactions had to be done in the absence of methanol, as ester interchange took place in each case to give dimethyl terephthalate and the acetylenic alcohol, which then coupled to give the diyne-diol. It is less probable that the cyclic compound was first formed and then hydrolysed to the diester and the diyne-diol.



In the case of (XVI, n = 4), 100% of the theoretical quantity of dimethyl terephthalate and 33% of dodeca-5:7-diyne-1:12-diol were isolated. When the pure starting materials were resubmitted to the oxidative coupling reaction in pyridine:ether alone, (XVI, n = 4) was found to couple only very slowly, and a lower dilution had to be employed for the coupling. No identifiable products have been obtained from the oxidative coupling of (XVI, n = 1,2) under high-dilution conditions, although the cupric ion was reduced to the cuprous state, and infrared evidence indicated removal of the ethynyl grouping. It is possible that the cyclic compounds, on formation, underwent spontaneous decomposition, being too unstable to exist under the existing conditions. It is possible that the buffering effect of the C_4 methylene chain in the case of (XVL, n = 4) confers stability on the cyclic poly-ynes formed from it, shielding them from the influence of the ester groups, which ultraviolet evidence indicates to be appreciable.[130] In the case of (XVl, n = 4) two products were isolated. The first proved to be the cyclic dimer (XV11), the cyclic diester of terephthalic acid and dodeca-5:7-diyne-1:12-diol; the second, of which only a few crystals were obtained, has been tentatively formulated as the monomer (XV111).



(XV11)



(XV111)

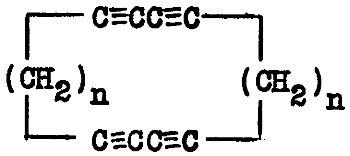
The lower-melting solid was thought to be the monomer (XV111), infrared evidence supporting the cyclic structure, and the ultraviolet spectrum had the expected maxima at λ 244, 286, and 294 mμ, and two others at λ 250 and 256 mμ. Lack of material prevented further characterisation. The dimer was obtained after chromatography in 35% yield, proof of its structure following from light absorption, analytical, and molecular weight measurements. The ultraviolet spectrum adequately supported the dimeric structure, the intensities of the peaks being doubled (corresponding to two -O.COCO.O- units) in every case. No abnormalities were noticed, indicating a ring system free from strain or electronic interactions, and the compound appeared quite stable. Small quantities of a hydroxyl-containing solid were also isolated, and could have resulted from the splitting of one of the ester linkages in the coupled molecule. It would be of interest to repeat the cyclisation using as high a dilution as possible, in an attempt to isolate further quantities of the cyclic monomer, whose properties, especially the ultraviolet absorption, would appear to hold more interest than those of the stable dimer.

One further α:ω-diyne was submitted to the oxidative coupling reaction. This was hepta-1:6-diyne diethyl-4:4-dicarboxylate(XlX).^{29} This reaction might be expected to yield the cyclic dimer under high-dilution coupling, giving a substituted C_{14} tetrayne. Recently Sondheimer and his associates have described^{43} the parent C_{14} tetrayne (Xl, n=3) from the oxidative coupling of hepta-1:6-diyne in aqueous solution. This dimer has the highest maximum in the ultraviolet region shifted to longer wavelength, and they ascribe this effect to interaction of the adjacent parallel α-diyne rods. (XlX) was slow to couple, and appeared to yield unstable products. Room temperature coupling conditions (cf. Bohlmann and Pollitt[137]) were applied, and though the ethynyl band at ca. 3300cm.$^{-1}$ finally disappeared from the infrared spectrum after one month, no stable product could be isolated. Chromatography on alumina afforded a red oil which appeared, from light absorption evidence, to have the properties of a cyclic poly-yne, but which was unstable, and polymerised on standing, and during attempted hydrogenation, although 70% of the theoretical uptake of hydrogen was achieved.

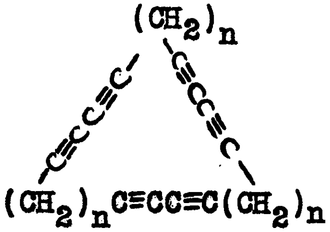
It now appears that about the same time as the present investigations were in progress, Sondheimer et al.[40-44] were following similar lines of study. Subsequent to our reported[103] extension of the oxidative coupling to reaction in organic medium, they have employed[44] our reagent in the cyclisation of short-chain α:ω-diynes of type (VII) to give a surprising series of compounds. In general, they have found the α:ω-diyne (VII) to give, as well as the cyclic tetrayne (XI), a homologous series of cyclic compounds extending as far as the cyclic hexamer with n = 5, which possesses a fifty-four membered ring, considerably larger than the largest carbocyclic ring previously reported.[123, 138] It should be noticed that the larger systems, though flexible, must take up roughly the shapes shown in the next diagram. Sondheimer[43] has postulated that for the symmetrical tetrayne (XI), electronic interaction between the α-diyne

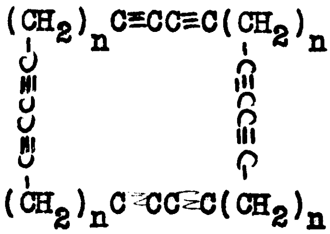
$HC{\equiv}C(CH_2)_nC{\equiv}CH$

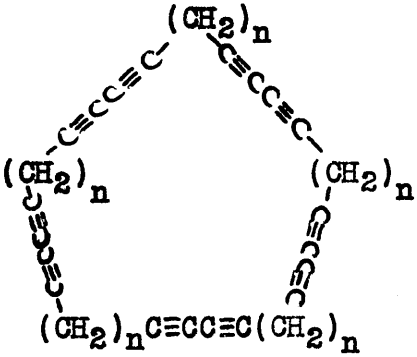
(VII)

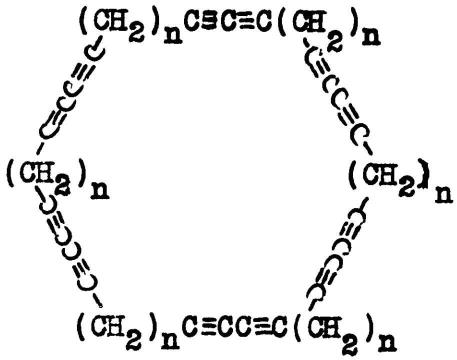


(XI)

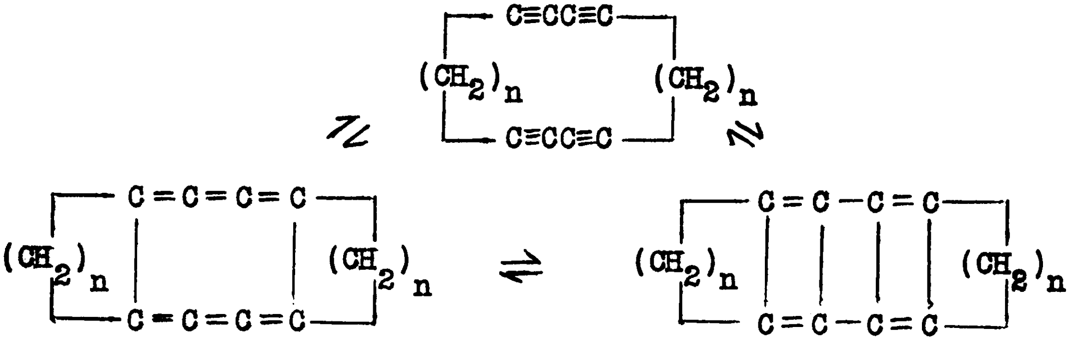




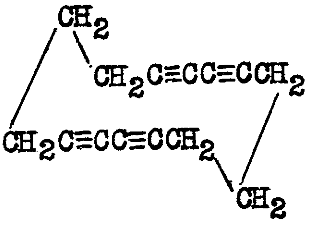




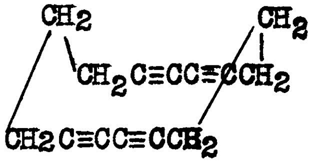
rods when the methylene chains no longer adequately separate them might give rise to anomalies in the ultraviolet spectra of the compounds. In the cases where n = 4,5, it was found that no such effects were observed, but with n = 3 the ultraviolet spectrum exhibits a bathochromic shift of the highest maximum,[43] the first purely aliphatic case of such non-classical interaction between adjacent unsaturated systems. The attempt to prepare (XI, n = 2) was unsuccessful.[43] The light absorption of the series of tetraynes excludes the possibility of existence in the



forms shown, considered plausible by Cram[39], as they would require little decrease in entropy for the transformation. The cyclic tetrayne (XI, n = 3) can be considered as a cyclohexane molecule in which two opposite bonds have been greatly elongated by the insertion of an α-diyne group. Consequently (XI, n = 3) could exist either in the chair or boat form, and now that the normal 1:4 interaction in the cyclohexane boat form is impossible, it is of interest to establish the preferred conformation. X-ray evidence[43] has indicated that in the crystal, (XI, n = 3) has a centre of symmetry, and so must exist in the chair form. Considering



chair



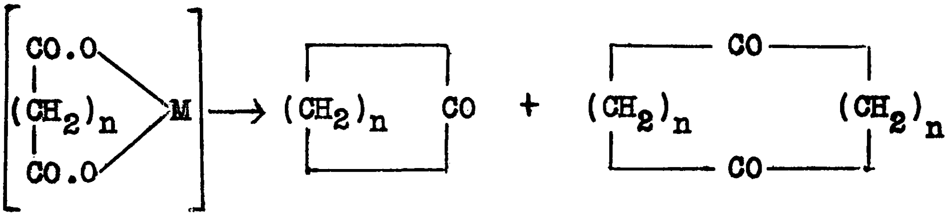
boat

the staggering of the hydrogen atoms in "Catalin" models of both forms, it can be seen that the chair form is likely to be the more stable conformation.

Production of Symmetrical Macrocycles

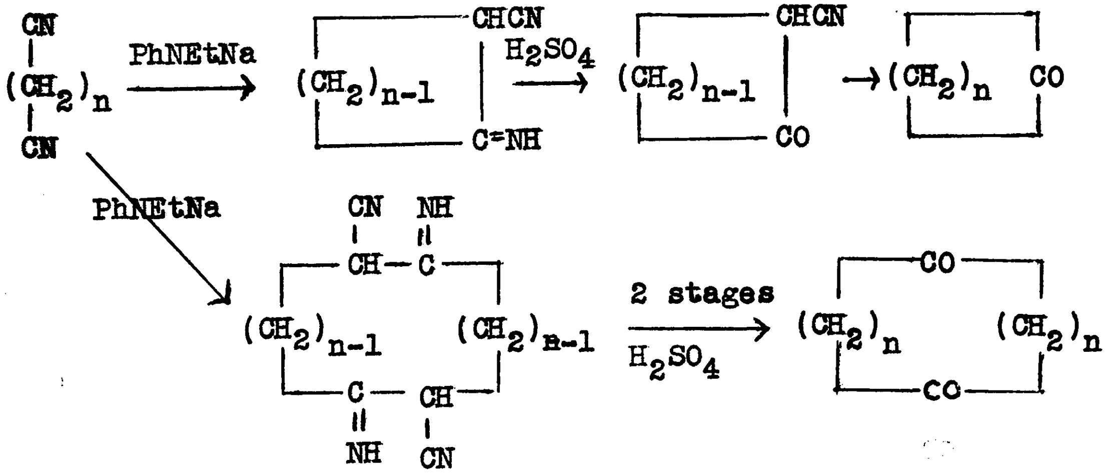
The formation of these poly-ynes appears to be one of the few reactions in which two or more molecules of a symmetrical difunctional compound condense at both ends to give a carbocyclic large ring. Other examples of this type of reaction are :-

a) Pyrolysis of heavy metal salts of aliphatic α:ω-dicarboxylic acids,[139-142] where M can be a heavy metal such as



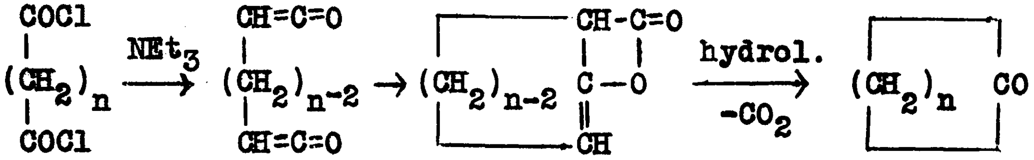
thorium or yttrium.

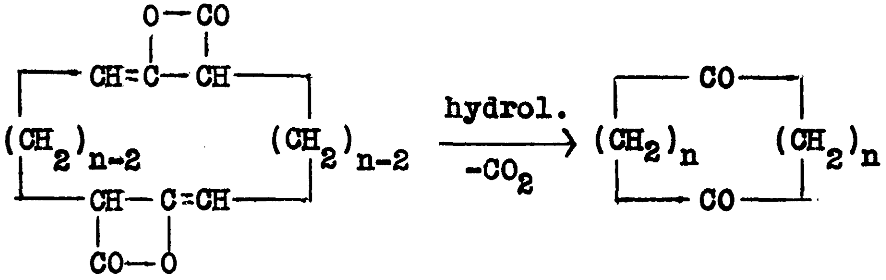
b) Treatment of the corresponding dinitrile with the sodium



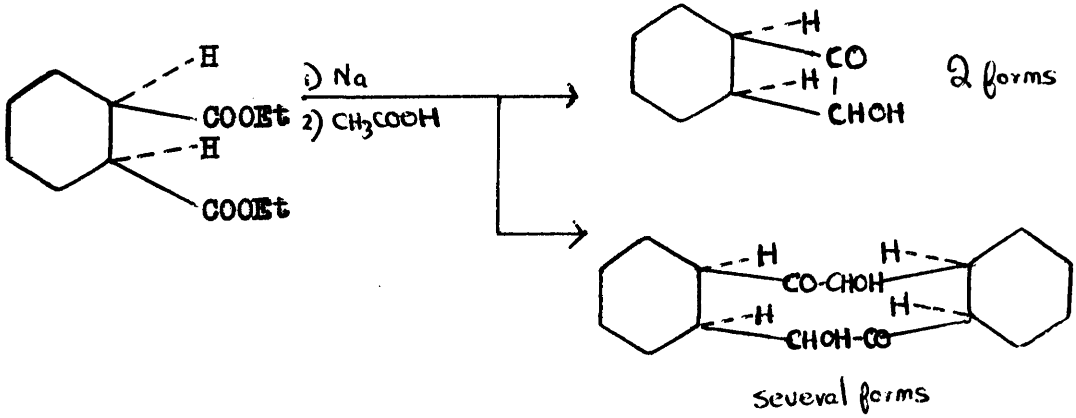
or lithium salt of an aliphatic/aromatic secondary amine,[143-144] under high-dilution conditions.

c) Dimerisation of the diketene, from the action of a tertiary amine on the diacid chloride.[145-146] All these reactions lead to macrocyclic diketones derived from two molecules of the starting material, in addition to cyclic monomeric ketones.



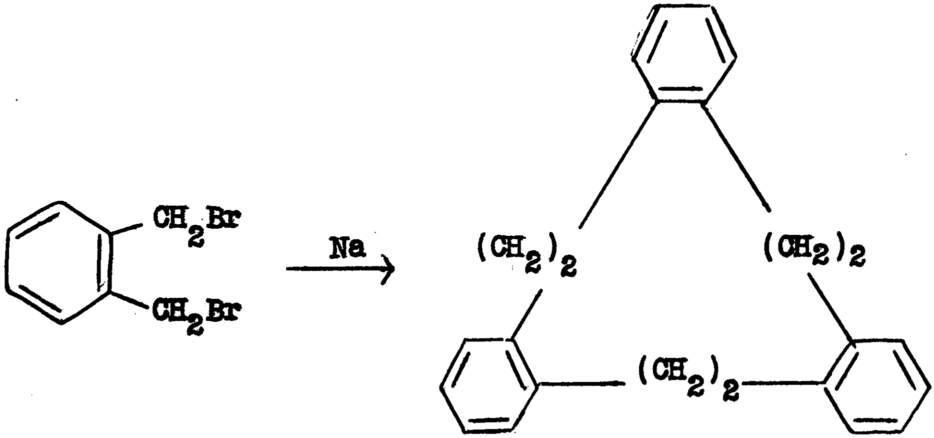


d) Also in this category is the acyloin condensation of

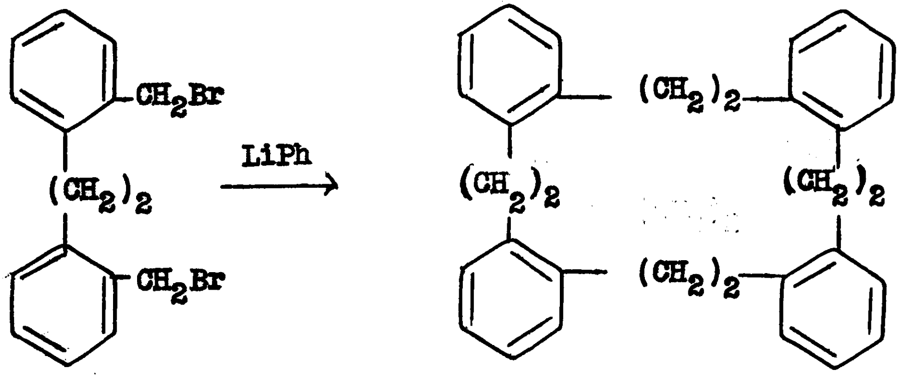


diethyl hexahydrophthalate to produce what is probably an eight-membered di-acyloin.[147]

e) The reaction of certain terminal dibromoalkylbenzenes with sodium or lithium phenyl has given large-ring



and other products



and polymeric products

hydrocarbons incorporating phenyl groups.[148-155]

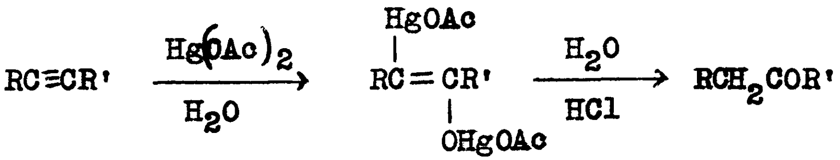
Hydration

Potentially one of the most interesting reactions of these large-ring poly-ynes is the hydration of the acetylenic and diacetylenic systems, possibly in a transannular fashion. As very little work had been reported[156-158] on the hydration of simple α-diynes, the hydration of (XX) and (XXI)[24] was undertaken. These compounds were prepared from the readily available but-3-yn-1-ol.[159-161] Both (XX) and (XXI) were found to be

$$HO(CH_2)_2C{\equiv}CC{\equiv}C(CH_2)OH \qquad CH_3COO(CH_2)_2C{\equiv}CC{\equiv}C(CH_2)_2OCOCH_3$$

(XX) (XXI)

resistant to hydration, the material being recovered unchanged after treatment with mercury resin in acetic acid.[162] An indirect method, addition of mercuric acetate, was tried, a method which has been used to accomplish the hydration of monoacetylenes.[163-165] The reaction is said to[165]

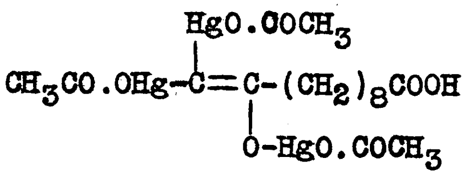


$$RC{\equiv}CR' \xrightarrow[H_2O]{Hg(OAc)_2} \underset{OHgOAc}{\overset{HgOAc}{RC{=}CR'}} \xrightarrow[HCl]{H_2O} RCH_2COR'$$

for example

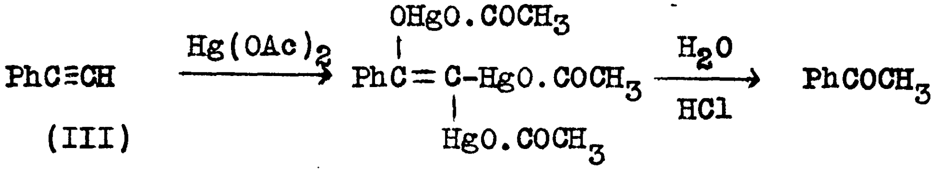
$$HC{\equiv}C(CH_2)_8COOH \xrightarrow[2)\ HCl]{1)\ Hg(OAc)_2} CH_3CO(CH_2)_8COOH$$

proceed through the unsaturated di- or (in the above example) triacetoxymercuri-derivative, to the ketone.



$$CH_3CO.OHg-\overset{\displaystyle HgO.COCH_3}{C}=\underset{\displaystyle O-HgO.COCH_3}{C}-(CH_2)_8COOH$$

This method was applied to the diol (XX), giving an oil which did not crystallise, even after acetylation, and which showed broad carbonyl absorption in the infrared spectrum. The diacetate (XXI), on submission to the same treatment gave an oil exhibiting hydroxyl and carbonyl absorption in the infrared. Since this reaction with mercuric acetate has been reported[163] to be irregular for some compounds, the method was then tried on the simple hydrocarbons phenylacetylene (III) and diphenyldiacetylene (IV). (III) gave acetophenone as expected. (IV), which



$$\underset{(III)}{PhC\equiv CH}\xrightarrow{Hg(OAc)_2}PhC=\overset{\displaystyle OHgO.COCH_3}{\underset{\displaystyle HgO.COCH_3}{C}}-HgO.COCH_3\xrightarrow[HCl]{H_2O}PhCOCH_3$$

resisted attack by treatment with mercury resin in acetic acid, gave a mixture of $PhCOCH_2COCH_2Ph$[166] (ca.50%), identified as the copper enolate,[166] and 2:5-diphenylfuran[167] (in small yield), together with some colourless amorphous material m.p. 130-145°, which was not further characterised. After this work had been carried out, Russian papers[168] appeared, containing a description of hydration experiments on (IV), using a mercuric sulphate catalyst. The products isolated were the same as in the above case.

The mercuric acetate method of hydration is worthy of application to other cases, as it seems to hydrate all the $C\equiv C$ content present, whereas mercury resin apparently has little effect on the resonance-stabilised α-diyne unit.

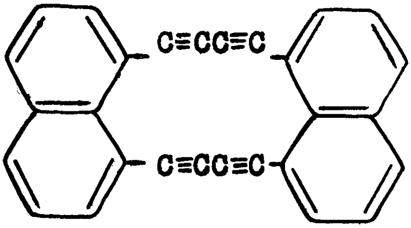
PART I

SECTION III

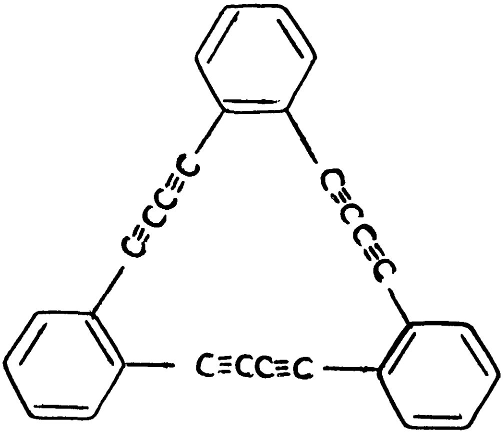
CONJUGATED MACROCYCLIC SYSTEMS

DISCUSSION

The extension of the oxidative coupling of ethynyl compounds to reaction in organic medium has made feasible the synthesis of novel conjugated cyclic systems.



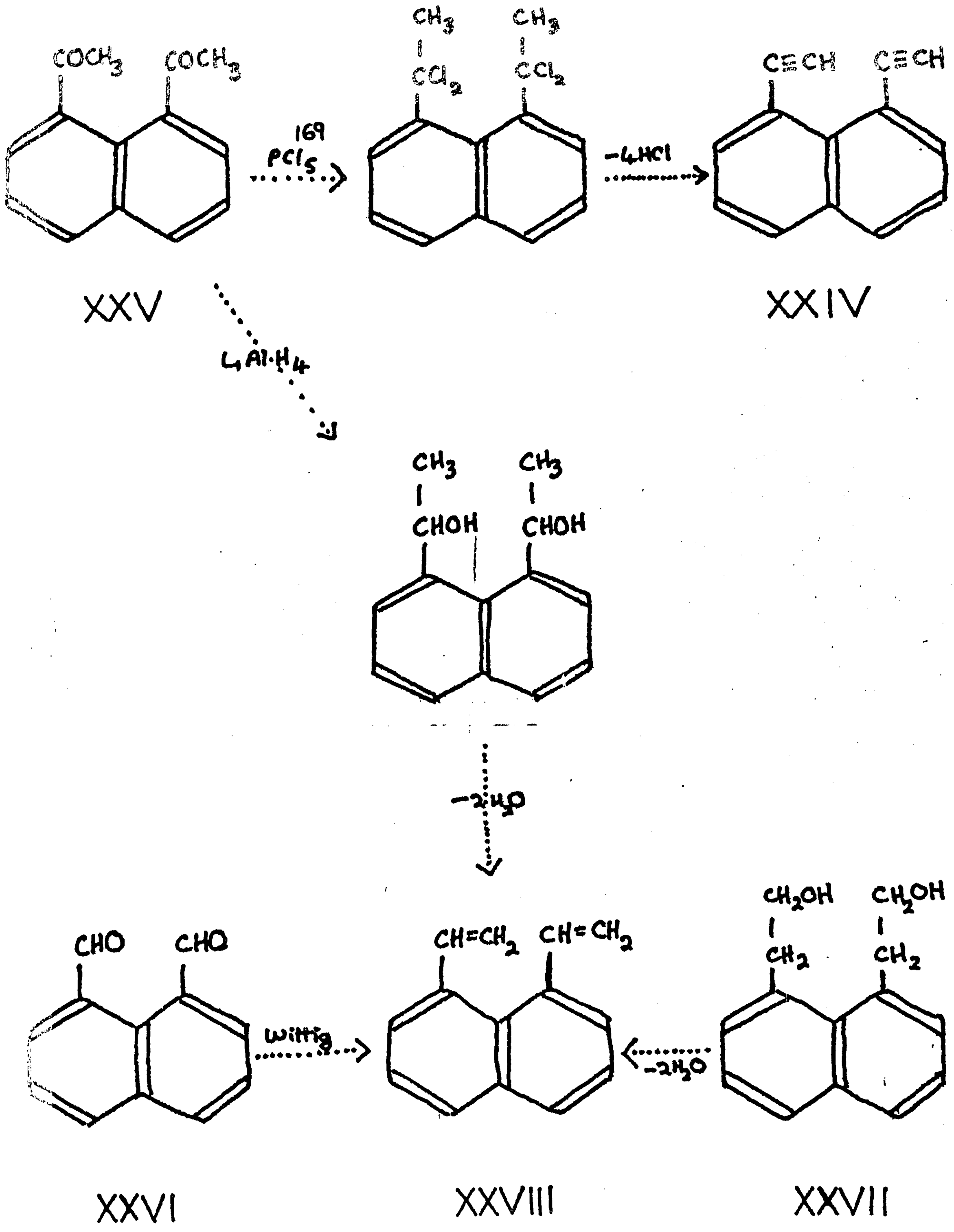
(XXII)



(XXIII)

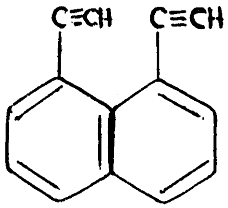
The structures (XXII) and (XXIII) were deemed likely to be reasonably stable, and to offer some hope of successful synthesis. They should be planar, rigid, strainless systems, and one might conceive of some measure of conjugation round the ring. Also the availability of electrons might allow of complexing a metal ion within the molecule. The properties, e.g., light absorption, were expected to be of interest, and reactions such as hydration and hydrogenation seem worthy of investigation, with the possibility of transannular reaction.

Fig.6

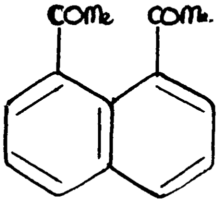

COCH3
COCH3
XXV
169
PCl5
CH3
CCl2
CH3
CCl2
-4HCl
C≡CH
C≡CH
XXIV
LiAlH4
CH3
CHOH
CH3
CHOH
-2H2O
CHO
CHO
XXVI
Wittig
CH=CH2
CH=CH2
XXVIII
-2H2O
CH2OH
CH2
CH2OH
CH2
XXVII

Attempted Synthesis of Macrocycle (XXII)

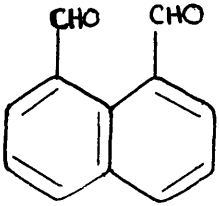
The starting material required for the proposed macrocycle is 1:8-diethynylnaphthalene, (XXIV). Several routes to this compound were suggested, and those considered most feasible are detailed in fig. 6. Compounds (XXV), (XXVI), and (XXVII) were considered to be possible intermediates.



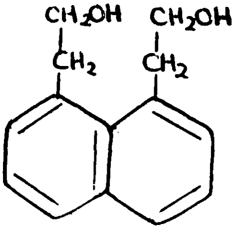
(XXIV)



(XXV)

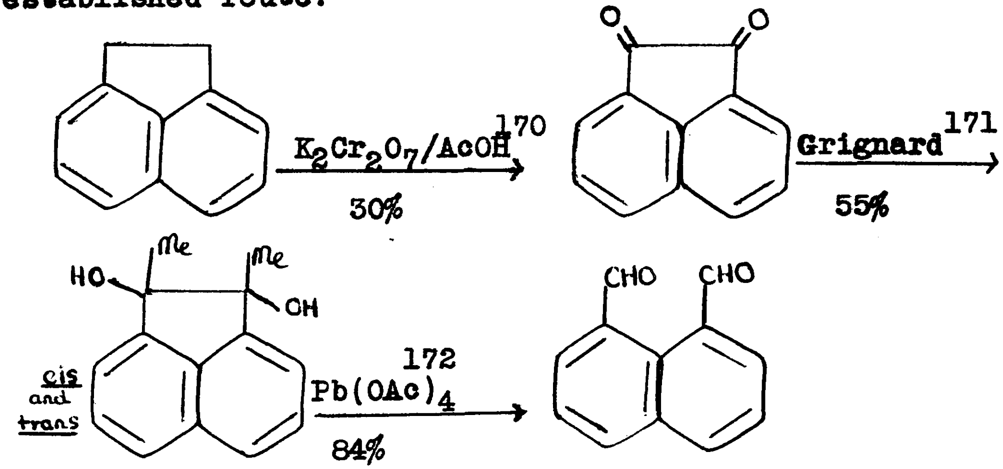


(XXVI)



(XXVII)

The diene (XXVIII) was the principal objective, as there seemed reasonable hope of its conversion to the diyne (XXIV). (XXV) was obtained by the following established route.



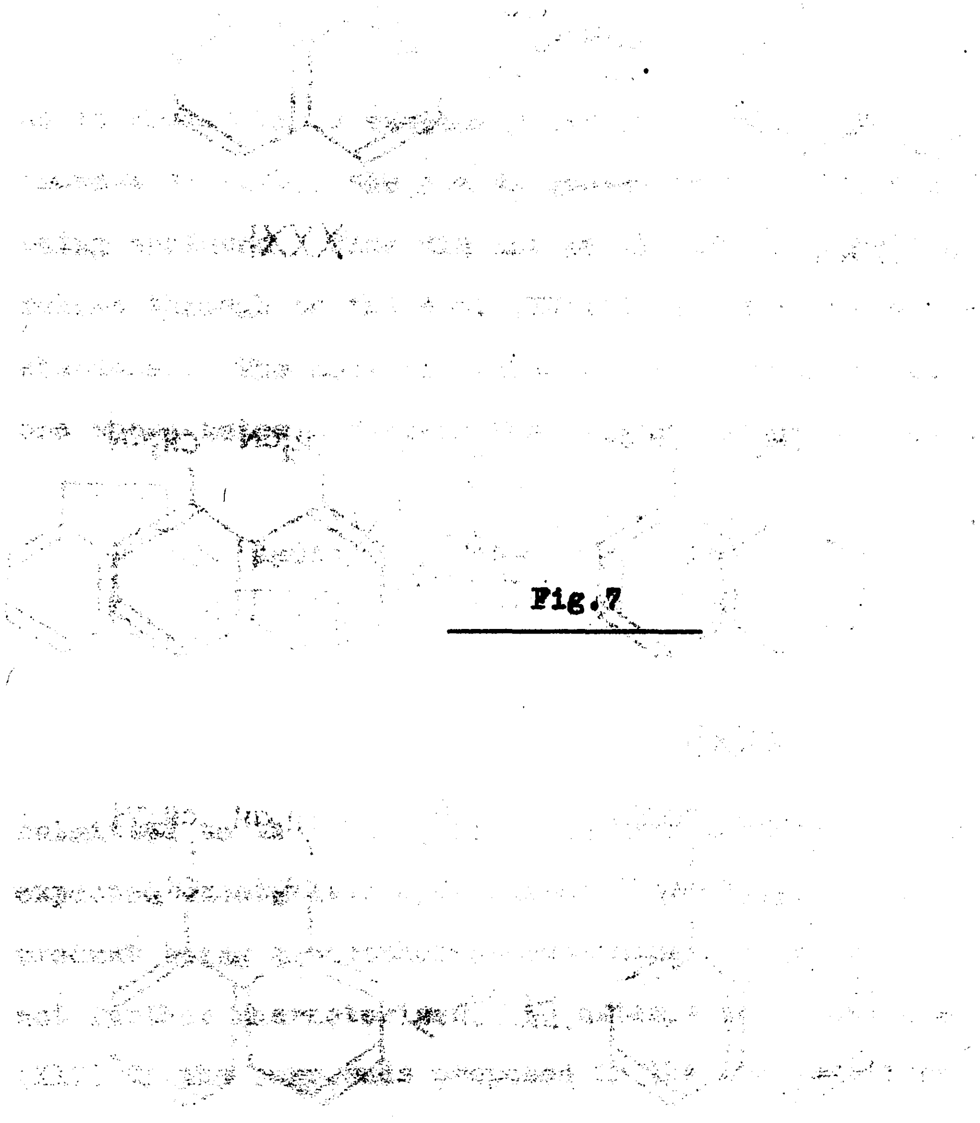
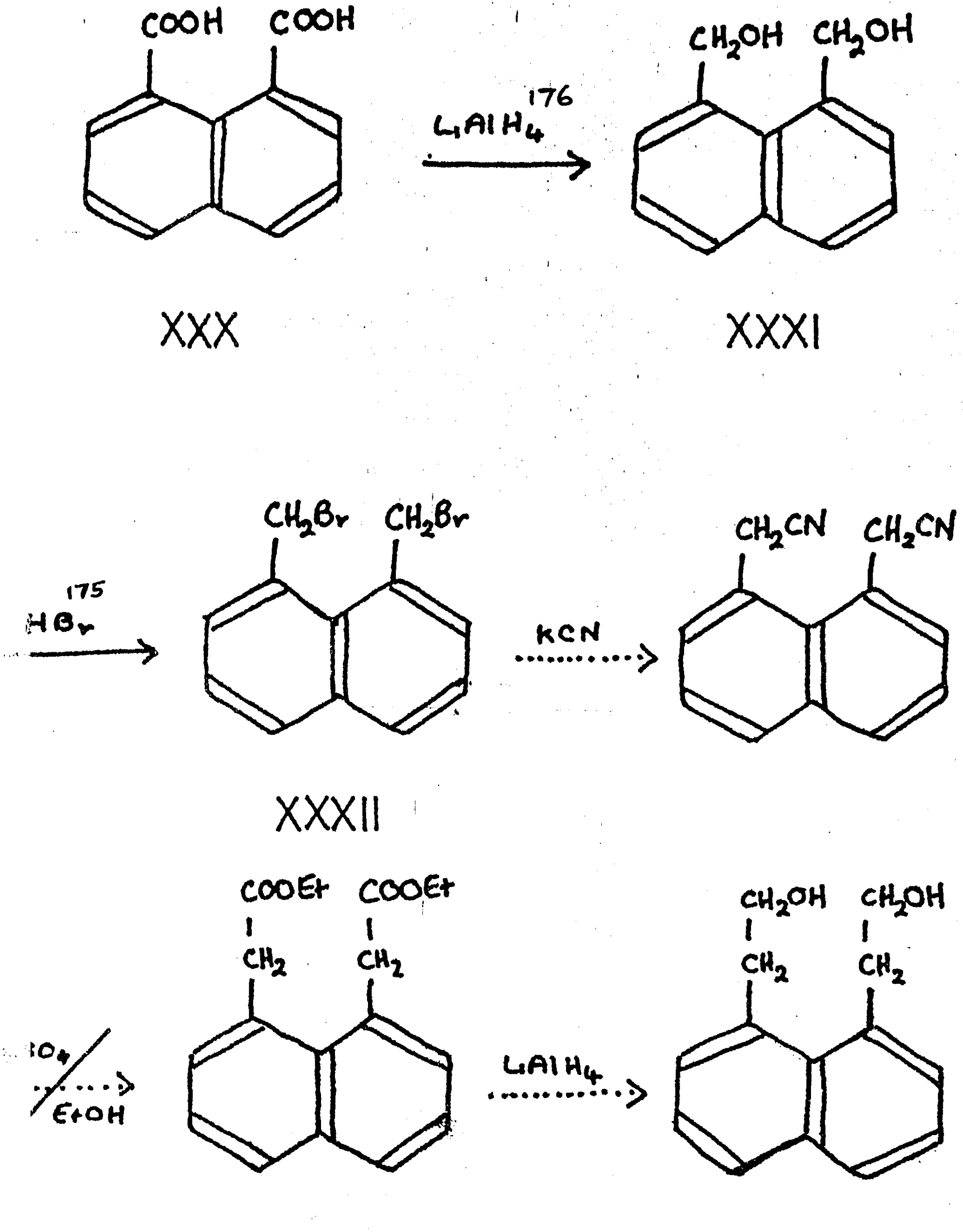


Fig.7



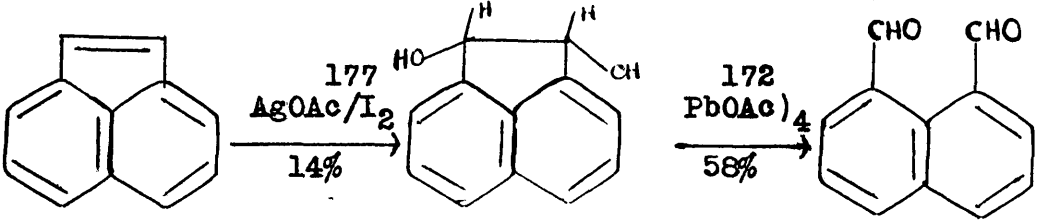
XXX

XXXI

XXXII

XXVII

Synthesis of (XXVII) suggested a parallel with the route of Halford and Weissman[173] to the diene (XXIX),[174] outlined later. The proposed route to (XXVII) is shown in fig.7. This route was only taken as far as the bromide[175] (XXXII), as it proved to be extremely tedious, requiring large amounts of (XXX), the yields quoted in the literature[176] not being achieved. Time did not permit of carrying the scheme through to the diol (XXVII), and the route was abandoned. The most promising route appeared to be the one shown below. However the dialdehyde (XXVI), when

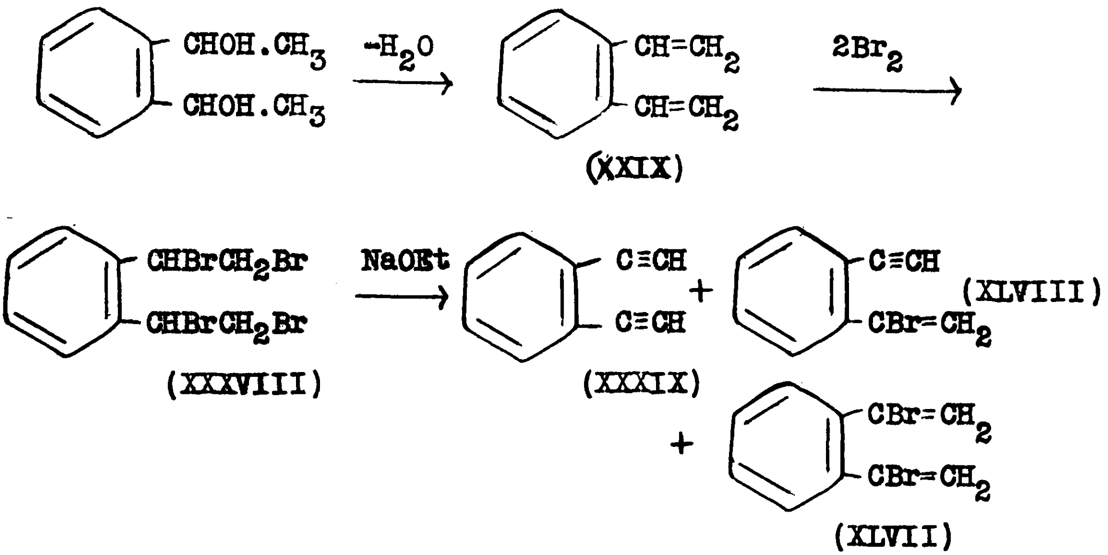


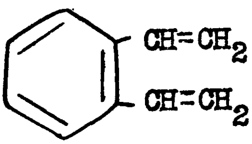
(XXXIII) (XXVI)

submitted to the Wittig[178] reaction,gave no trace of the expected unsaturated hydrocarbon (XXVIII), the sole product being a phosphorus-containing liquid which was not further characterised, No attempt was made to convert (XXV) to the compounds proposed in the aforementioned route, and work on these 1:8-naphthalenes was abandoned, in view of the facility with which intra-molecular side-reactions occurred. The general chemistry of these 1:8-naphthalenes has not yet been subjected to extensive investigation, and the evidence that is available indicates that the chemistry of such molecules is extremely complex, steric effects causing much hindrance to the normal reactions of the functional groups. Attention was therefore turned to systems which would be less susceptible to this type of behaviour, in particular the o-disubstituted benzene series, of which o-diethynylbenzene (XXXIX) is the obvious starting material for the proposed synthesis of (XXIII).

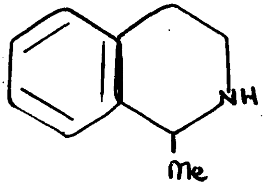
Synthesis of Macrocycle (XXXII)

For the synthesis of the second proposed macrocycle, several routes came under consideration. o-Diethynylbenzene (XXXIX) has been prepared by Deluchat,[174] according to the following method. Deluchat reported that attempts to dehydrobrominate (XXXVIII) with potassium hydroxide (solid) gave naphthalenic products. The final route selected in this work was from the diene (XXIX) by bromination and dehydrobromination rather than by exhaustive methylation and deamination of a substituted tetrahydro-isoquinoline,



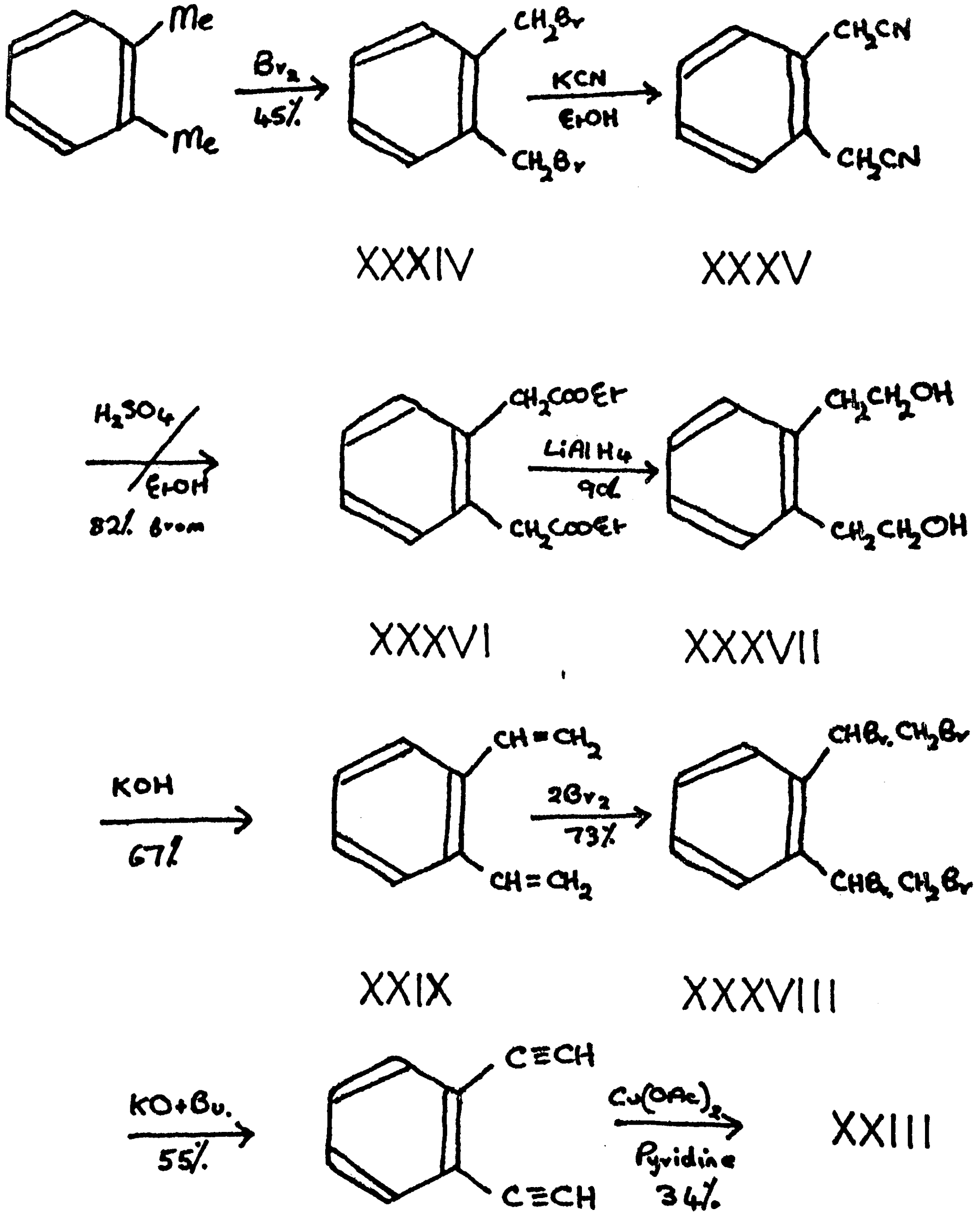


(XXIX)



or possible ethynylation using lithium acetylide on

Fig.8



XXXIV XXXV

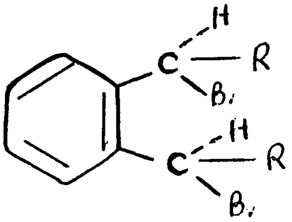
XXXVI XXXVII

XXIX XXXVIII

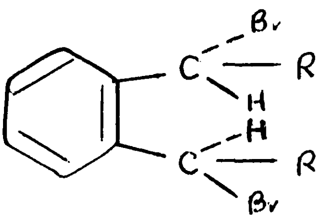
XXIII

XXXIX

o-dibromobenzene. The route to the diene (XXIX) was that of Halford and Weissman,[173] adjuged preferable to that of Deluchat,[174] and gave comparable results in our hands, (see fig.8). The diene (XXIX), reported as showing no tendency to polymerise at room temperature, set to a colourless glass after four weeks at room temperature, affording a 25% recovery of diene on distillation, and a residual brittle, yellow polymer. (XXIX) gave the tetrabromide (XXXVIII) on treatment with bromine in carbon tetrachloride (preferred to Br_2/ether - Deluchat[174]). Only one crystalline bromide was isolated (73%), although two



meso



d:l, racemate

$R = -CH_2Br$

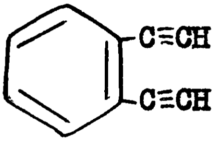
compounds are possible, the meso and the d,l-racemate. Possibly the trans- bromination of the first olefinic bond exerts some stereochemical control over the addition of the second mole of bromine to the remaining olefinic bond. Deluchat also reports[174] only one bromide. However, lachrymatory oils were also produced, from which could be isolated further small quantities of (XXXVIII).

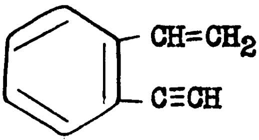
Dehydrobromination

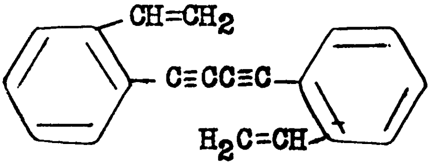
Attempted dehydrobromination of the tetrabromide (XXXVIII) with sodamide in liquid ammonia[179-180] gave a mixture of two hydrocarbons, subsequently shown to be (XXXIX) and (XL). The existence of absorption at 995cm.$^{-1}$ and 915cm.$^{-1}$,

(XL). The existence of absorption at 995cm.$^{-1}$ and 915cm.$^{-1}$, of

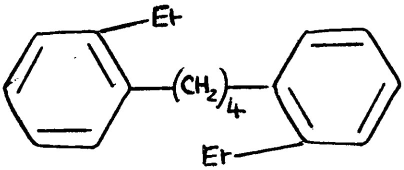
and of C≡C stretch at 1620cm.$^{-1}$, in the infrared spectrum of the distillate indicated the presence of appreciable amounts of the $CH=CH_2$ grouping. When the product was


(XXXIX)


(XL)

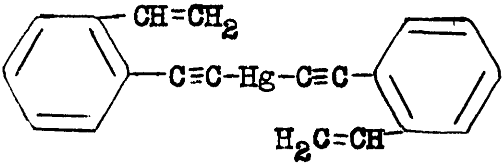

(XLI)

coupled in high-dilution by the action of cupric ion, the only identifiable crystalline product was (XLI), isolated in 20-30% yield after chromatographic treatment. Proof of this structure followed from the analytical, molecular weight, and light absorption data. Furthermore, catalytic hydrogenation of (XLI) gave the fully saturated hydrocarbon (XLII), infrared absorption at 1378cm.$^{-1}$ proving the presence of the expected C-methyl group. Attempts to separate the


(XLII)

mixture of (XXXIX) and (XL) into its two constituents by chromatography resulted in only partial separation, the earlier fractions enriched in the diyne (XXXIX), the later fractions in the ene-yne (XL). Addition of bromine was found to lack specificity. Treatment with potassium mercuri-iodide,[181-182] K_2HgI_4, gave the insoluble polymeric mercury salt of (XXXIX), and (XLIII), the crystalline, benzene-soluble mercury salt of (XL). The polymeric

(XLIII)



m.p. 115°

mercury salt, however, could not be satisfactorily regenerated to the parent ethynyl compound, as it proved unexpectedly unreactive to alkaline potassium cyanide.[181]

The ultraviolet spectrum of (XLI) shows a fairly close correlation with that of diphenyldiacetylene[71] (IV),

close correlation with that of diphenyldiacetylene[71] (IV),

both spectra showing the regular spacing of peaks the characteristic of the diphenylpoly-ynes.[25,71,132,133] In the case of (XLI), the series of maxima extends further into the longer wavelengths, an effect which is repeated in the spectrum of the mercury derivative (XLIII), when compared with the spectrum of the mercury derivative of phenyl-

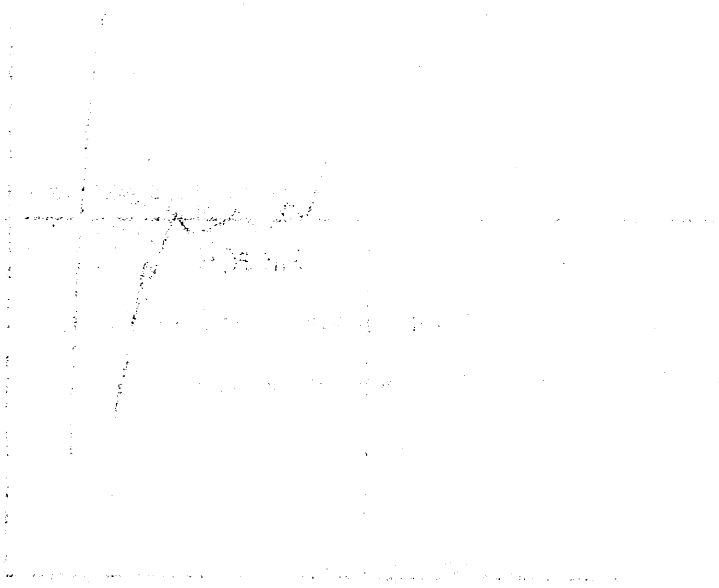
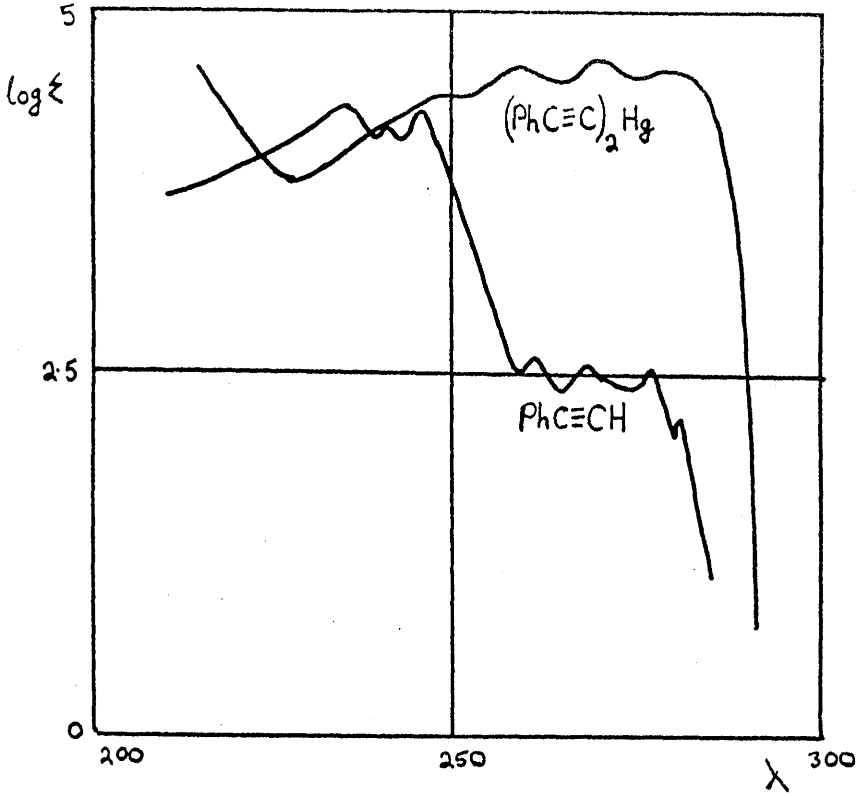
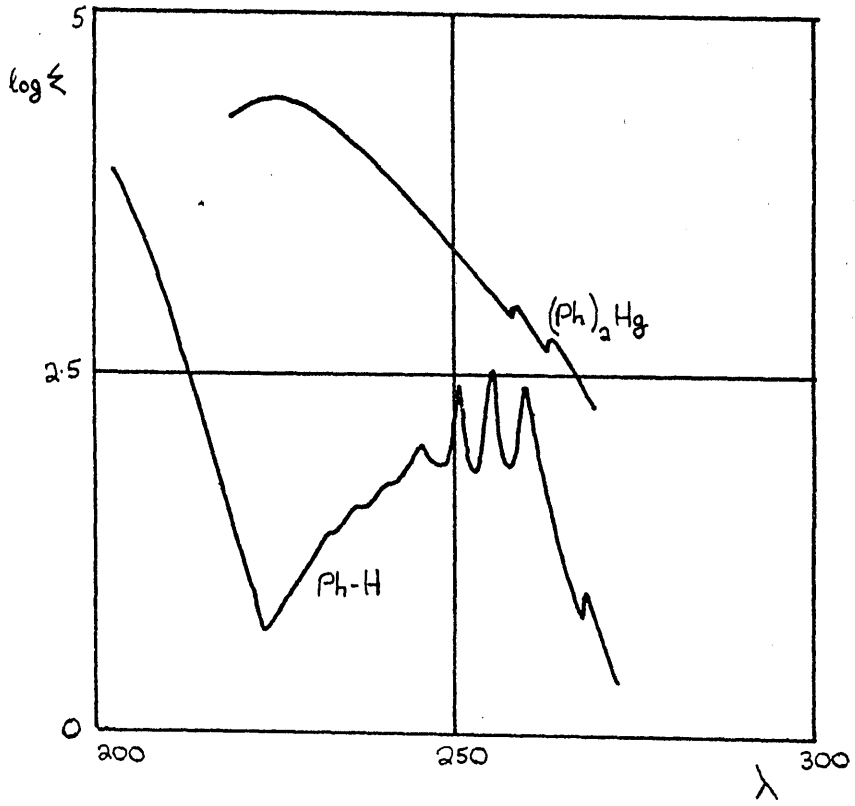


Fig.9

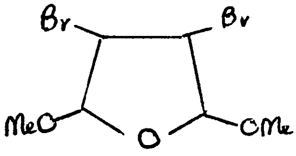

5
log ε
2·5
0
200
250
300
λ
$(PhC\equiv C)_2Hg$
$PhC\equiv CH$


5
log ε
2·5
0
200
250
300
λ
$(Ph)_2Hg$
Ph-H

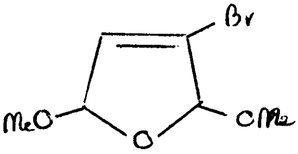
acetylene (LII).

Leandri and Tundo[183] concluded from an investigation of the ultraviolet spectra of mercury-substituted compounds, that the transitions in the diaryl mercury compounds, when compared with those of the parent aryls, exhibited an intensification and a shift to longer wavelengths. The curves of benzene and diphenylmercury are reproduced in fig.9, for comparison with the curve for phenylacetylene[184], and that of the mercury derivative. The similar intensification of the first transition, and the shift to longer wavelengths are clearly demonstrated for the acetylenic series, while the second transition appears to be swamped by the high-intensity absorption of the first.

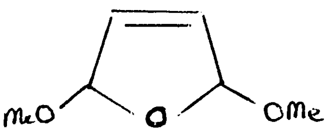
Cases of anomalous reaction of sodamide in liquid ammonia have been reported.[185-186] Attempted dehydrobromination of the furan derivative (XLIV) gave[186] the required monobromo compound (XLV), together with much



(XLIV)

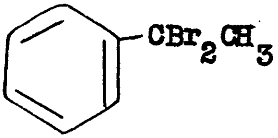


(XLV)

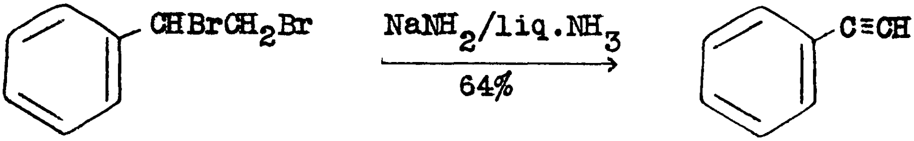


(XLVI)

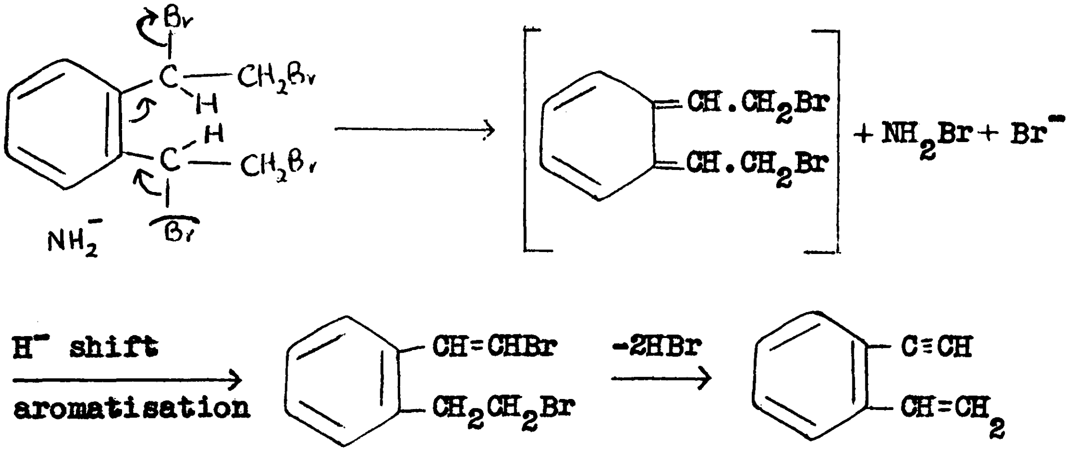
olefinic, bromine-free material, identified as (XLVI). Also Bourguel[187] showed that the action of sodamide, suspended in toluene/petrol, on α:α-dibromoethylbenzene gave styrene, as well as phenylacetylene and much solid



product, the latter probably resulting from condensation following previous elimination of bromine atoms from different molecules. Since styrene dibromide is



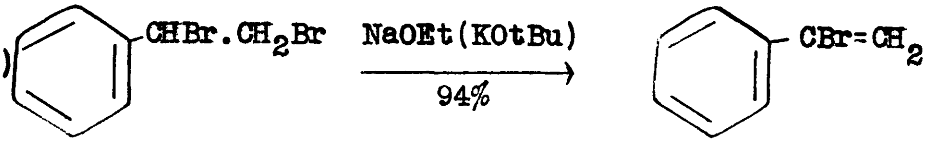
dehydrobrominated normally,[179] a 1:4-elimination is postulated in our case rather than a 1:2-elimination. The benzylic nature of the two α-situated bromine atoms is thought to cause the elimination postulated below, re-aromatisation



(XL)

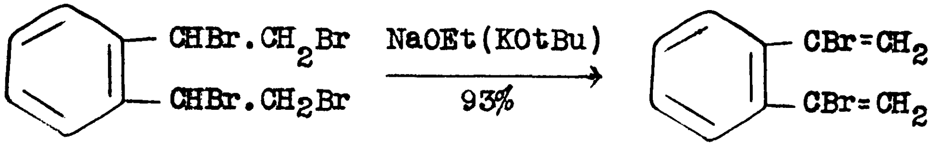
providing the driving force for the rearrangement (accompanied by a hydride shift) of the unstable intermediate. A more detailed study was undertaken, using a two-stage removal of hydrogen bromide. Under mild conditions, sodium ethoxide[188] was found to be satisfactory in effecting the removal of the first mole of hydrogen bromide. This was studied with both styrene dibromide and (XXXVIII).

a)



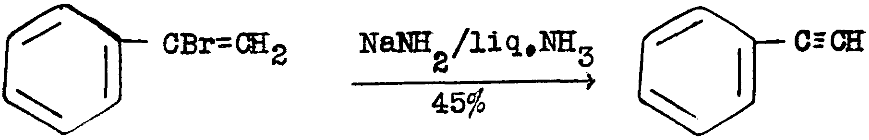
α-bromostyrene

b)



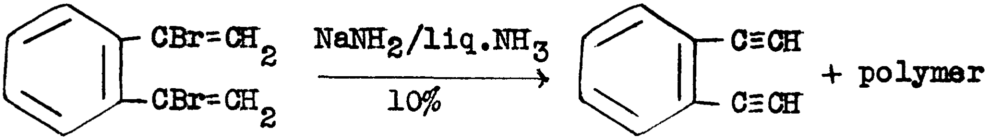
(XXXVIII) (XLVII)

Potassium t-butoxide was later used in these studies, as it offered less likelihood of replacement reactions. The yields are almost theoretical when the two solutions in hot t-butanol were mixed. It was thought that the second stage, removal of the remaining mole or moles of hydrogen bromide, would be effected by further treatment with potassium t-butoxide, or by sodamide in liquid ammonia,[179-180] since the anomalous reaction would not occur, the bromine atoms of (XLVII), attached to an unsaturated carbon atom, no longer having their benzylic character. With α-bromostyrene and sodamide in liquid ammonia, the expected reaction afforded phenylacetylene in reasonable yield,



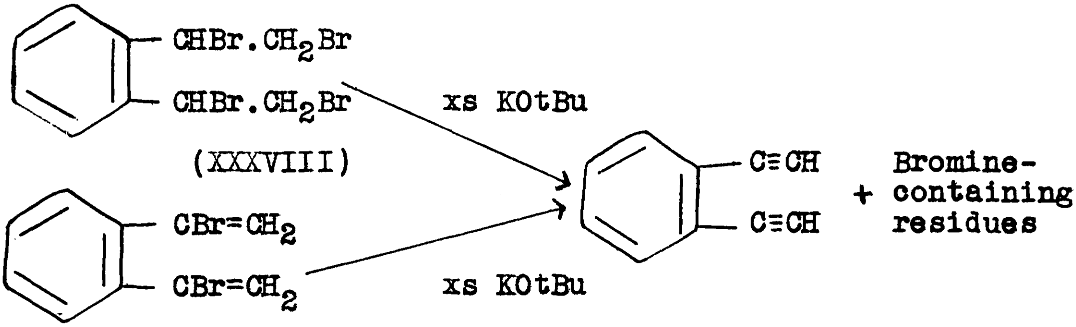
together with solid, presumably polymeric, residue.

However, in the case of (XLVII), the expected diyne was obtained in only 10% yield, being accompanied by a large polymeric brown residue, insoluble in either aqueous or



(XLVII) (XXXIX)

organic phase. Treatment of both α-bromostyrene and (XLVII) with potassium t-butoxide by mixing hot solutions of the reagents produced, in each case, mixtures of the required ethynyl compound and unchanged starting material, as determined by refractive index and infrared measurements. Continued refluxing with excess potassium t-butoxide,

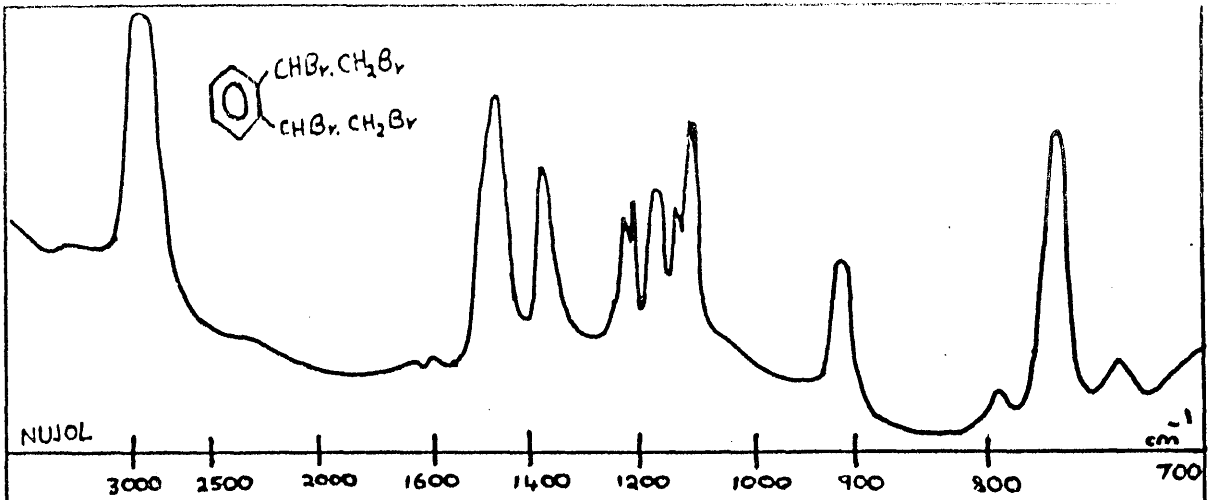


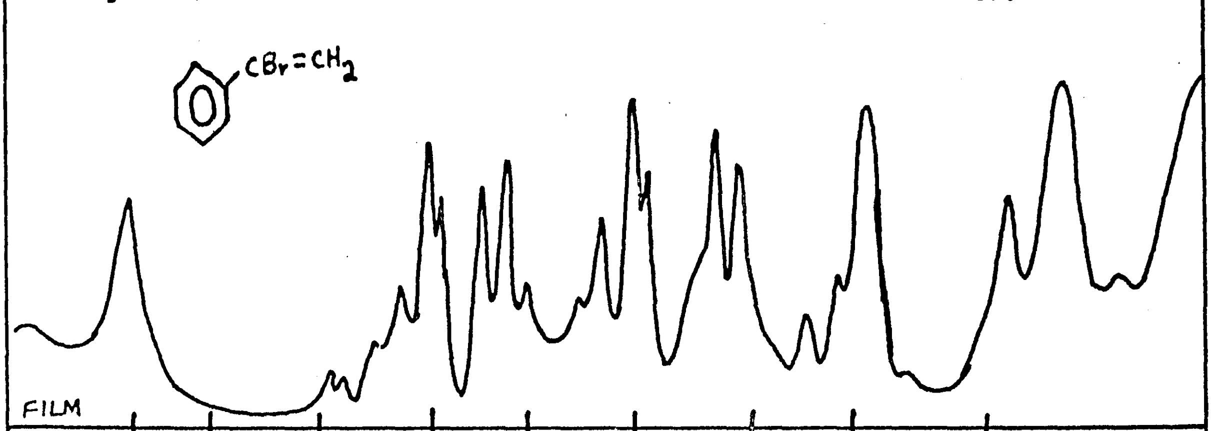
(XXXVIII)

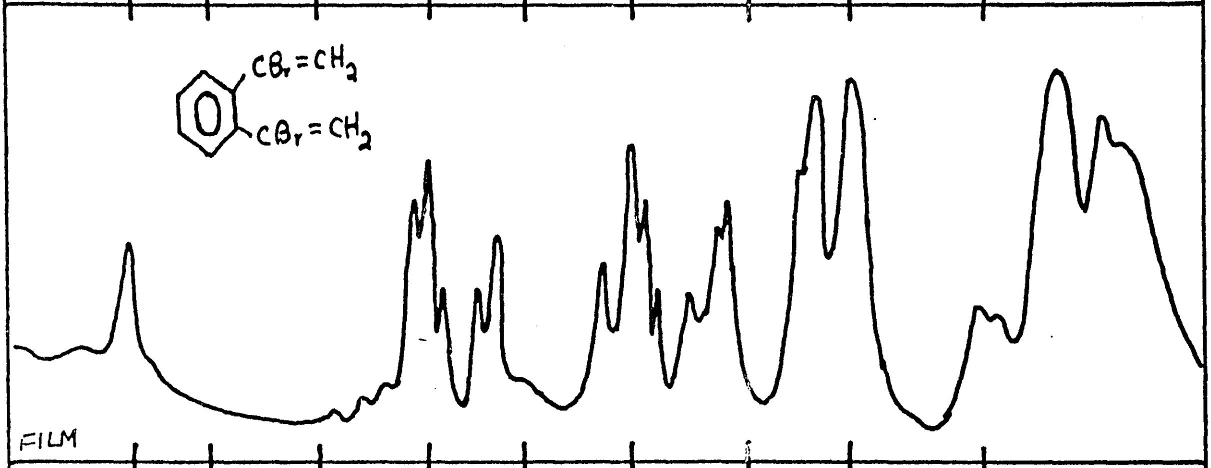
(XLVII)

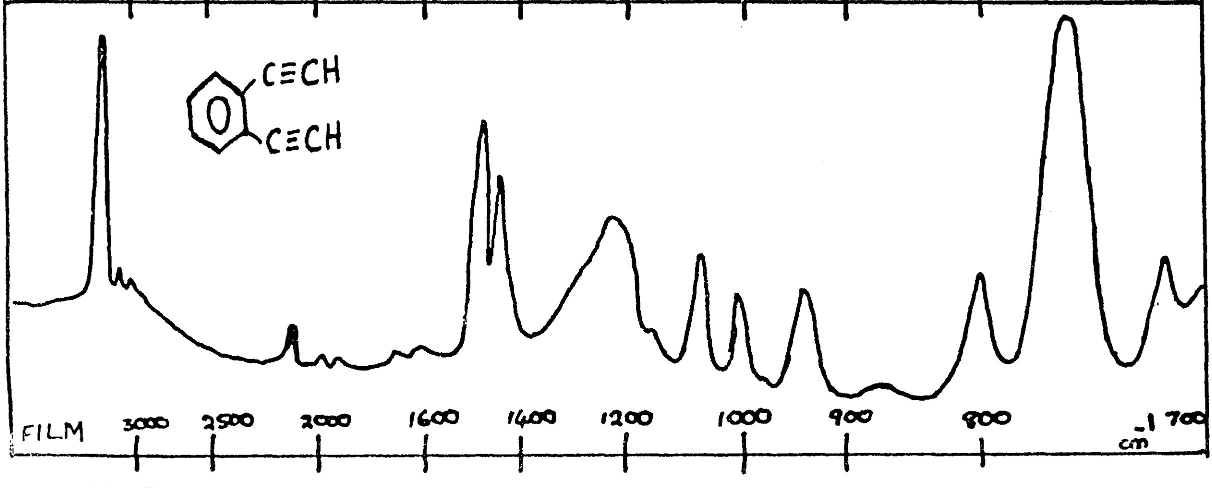
however, achieved fairly complete elimination. The di-enebromide (XLVII) has strong absorption in the infrared at 940cm.$^{-1}$ and 901cm.$^{-1}$, as well as C=C stretch at 1610cm.$^{-1}$. On prolonged treatment with potassium t-butoxide the reaction product showed little absorption at 901cm.$^{-1}$;

Fig.10

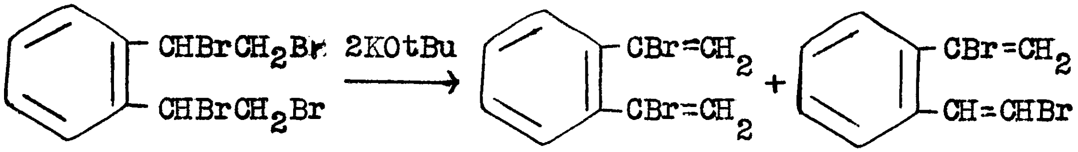

CHBr.CH2Br
CHBr.CH2Br
NUJOL
cm-1
3000
2500
2000
1600
1400
1200
1000
900
800
700


CBr=CH2
FILM


CBr=CH2
CBr=CH2
FILM

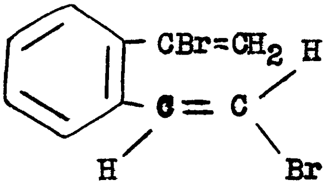

C≡CH
C≡CH
FILM
3000
2500
2000
1600
1400
1200
1000
900
800
700
cm-1

indicating removal of the $CBr{=}CH_2$ grouping, although C=C stretch absorption in the infrared and refractive index measurements indicated incomplete dehydrobromination. This is believed to be due to elimination of hydrogen bromide from (XXXVIII) to give the CH=CHBr grouping as impurity.

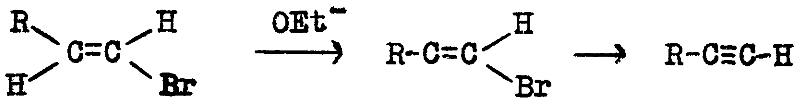


(XXXVIII) (XLVII) (XLIX)

This grouping has no absorption at 900cm.$^{-1}$(cf. infrared spectrum of β-bromostyrene) and the irregular elimination could be explained by the bulky t-butoxide ion "picking off" an outer β-hydrogen atom. Consideration of "Catalin" models of (XXXVIII) indicates that severe hindrance to access to the inner α-hydrogen atoms is present in certain conformations, and supports the latter possibility. The configuration of the β-enebromide group is thought to be trans. In the infrared spectrum, a band at 951cm.$^{-1}$ is present as a shoulder on the main absorption at 941cm.$^{-1}$ and might be ascribed to a trans double bond. The shift from the normal frequency (965cm.$^{-1}$) could be attributed to the influence of the main absorption band at 941cm.$^{-1}$, and to the effect of the bromine atom on the trans double bond.



This postulation is favoured by the fact that the grouping survives the $CBr=CH_2$ in dehydrobromination. This would be expected as in the above molecule, only *cis*-elimination of hydrogen bromide is possible from the *trans*-β-ene-bromide grouping. *Trans*-elimination is known to[189-190] proceed much more rapidly than *cis*, which requires a two-stage mechanism for its explanation.



The diyne (XXXIX) may be prepared from either (XLVII) or (XXXVIII) by the action of potassium t6butoxide in t-butanol, the highers yield obtained direct from a single operation being 55% of pure distilled material. Recent work[191] in these laboratories using potassium t-butoxide in benzene has raised the yield to 60%. Higher-boiling fractions appear to be a mixture of (XLVII) and the more unsaturated (XLVIII), reported by Deluchat.[174] The reaction has the advantage that, if incomplete, the recovered product may be recycled with further quantities of the reagent until physical measurements indicate complete dehydrobromination. O-Diethynylbenzene(XXXIX), identified by Deluchat by analysis of the silver salt, possesses a characteristic series of aromatic absorption bands in the in the infrared, and the ultraviolet spectrum resembles that of phenylacetylene, although of higher intensity. The diyne is less stable than phenylacetylene, and discolours on standing. It absorbs[191] four moles of hydrogen to give o-diethylbenzene, identified by infrared evidence and refractive index measurements.

Oxidative Coupling of O-Diethynylbenzene.

The pure diyne (XXXIX) was oxidatively coupled by the cupric acetate:pyridine:methanol reagent, employing high-dilution conditions, and the reaction product was an oily solid which could be chromatographed on alumina in benzene to give a lemon-yellow solid (31%) as needles. This compound is believed[192] to be the desired substance (XXIII), on the basis of its mode of preparation, its light absorption, analytical and molecular weight measurements, and its properties in general.

Although only one structure appears feasible from the product of the oxidative coupling of (XXXIX), i.e., trimerisation to give (XXIII), there exists the possibility of the formation of a cyclic dimer or cyclic polymer, or a linear polymer of unlimited chain length. A study of "Catalin"models of the possible cyclic products indicates the likelihood of the formation of the strainless, rigid trimer, [redacted] rather than any of the other severely strained cyclic possibilities, but the formation of the linear polymer cannot be discounted. Attempts to establish the structure of the substance are hampered by the instability of the compound, while the possible formation of ene-yne in the oxidative coupling might complicate the identification of the product.

General Properties The substance is very speedily oxidised in light or air to a black powdery solid, and decomposes in a matter of a few hours at room temperature in the absence of light and air (10^{-4} mm.). It can be stored at -10° for several weeks without appreciable decomposition, but explodes on heating to 80°. or on grinding. It crystallised from benzene or ether in concentrated solution as fine yellow needles, although slow evaporation of solvent gave rise to extremely long, hair-like crystals, on several occasions.

Molecular Weight by X-ray Measurements It is at present being investigated by x-ray crystallographic methods, which have given the unit cell measurements,[193] and assuming two moles in the unit cell, very satisfactory values were obtained for the molecular weight from crystals grown from ether and dioxane, the unit cell having been shown to be identical for crystals grown from benzene, ether, and dioxane. The molecular weight calculated for a crystal grown from benzene solution indicated the inclusion of one mole of benzene in the unit cell, and detection and quantitative estimation of this benzene were performed by co-distillation with dioxane, followed by determination of the benzene content of the distillate by intensity measurements in the ultraviolet (245-265 mμ).

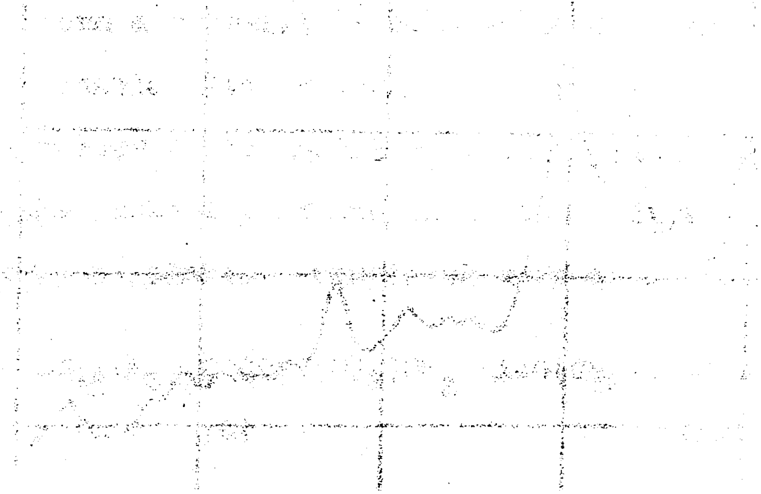
The method of immediate freezing of the dioxane solution, thus preventing the benzene from entering the unit cell of the solute, followed by evacuation and distillation of the solid solvent in a vacuum-line system, appears to be a practicable and accurate method of estimation of solvent of crystallisation. It may be worthy of application with respect to other systems, e.g., the well-known inclusion of the chloroform molecule in the unit cells of crystalline steroids.

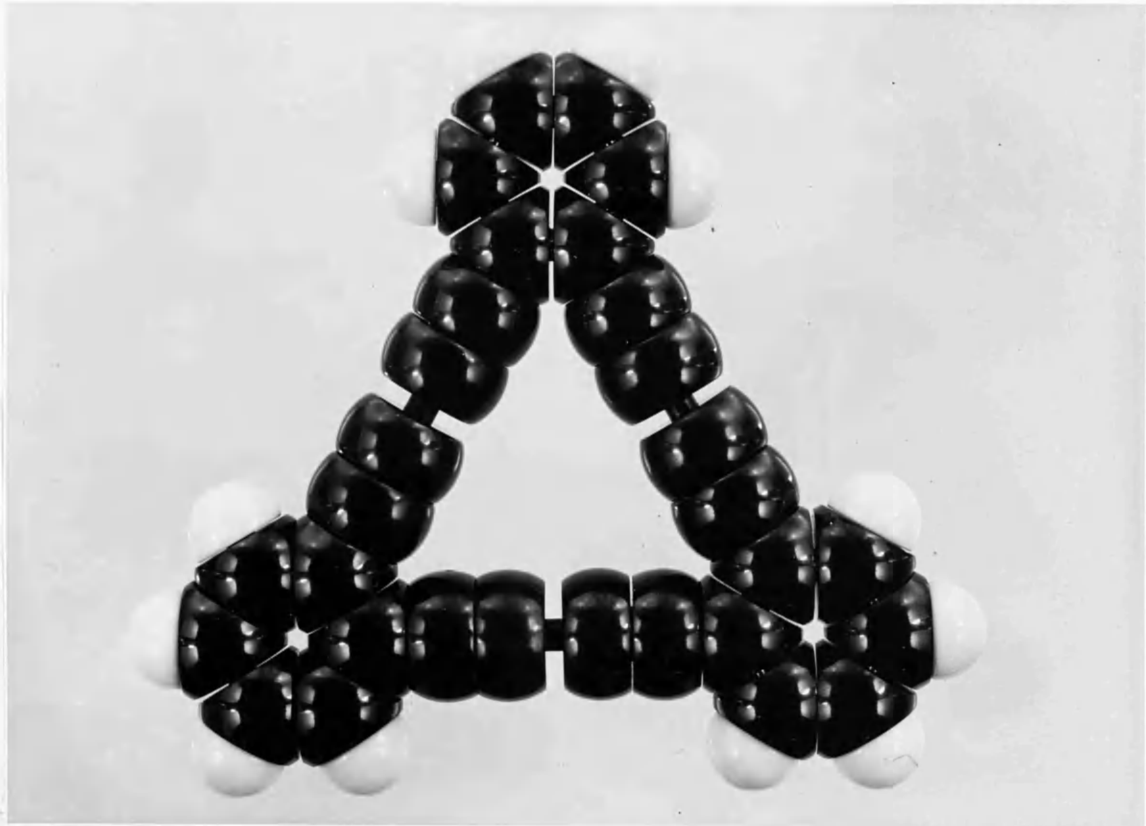
Analytical Data Analytical data satisfied the formulation $2C_{30}H_{12},C_6H_6$ for the unit cell of crystals incorporating benzene in their structure.

Light Absorption The infrared spectrum exhibited a series of bands due to the aromatic nucleus almost identical with that of o-diethynylbenzene. The C≡C stretching frequency was present as two prominent bands (2215, 2134cm.$^{-1}$) suggesting that the high conjugation encountered in this molecule does not appreciably alter the positions of the

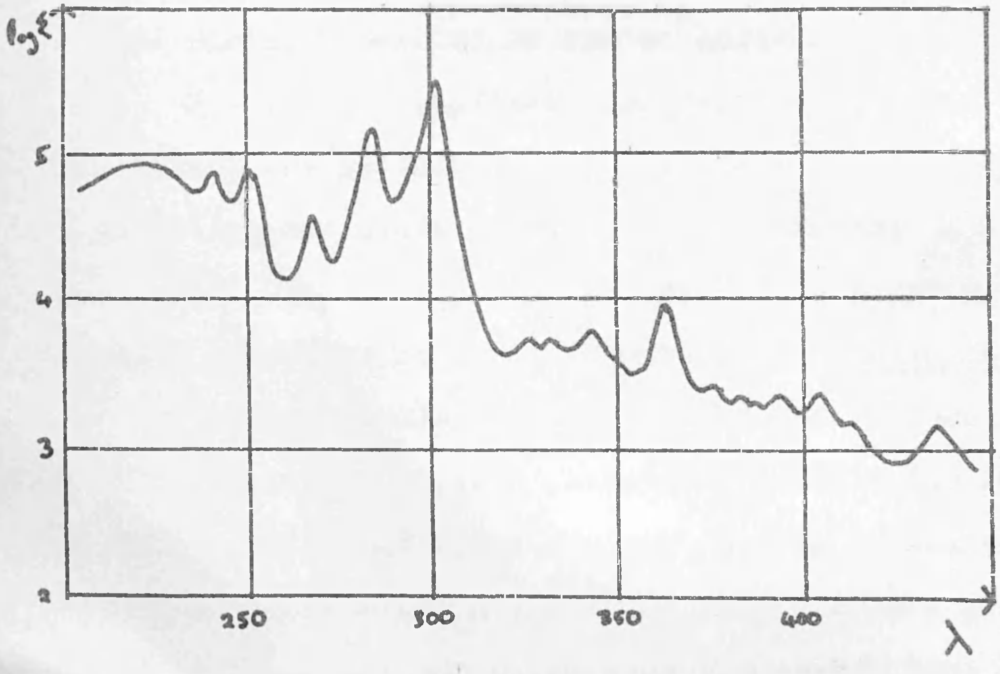
3849

Fig.11





XXIII - (Catalin model)



U.V. Spectrum of XXIII

of the bands. Absence of ethynyl absorption (<u>ca</u>. 3300cm.^{-1}) favoured the cyclic structure, as a very long-chain polymer would be required to render the absorption undetectable. The ultraviolet spectrum in hexane contains three transitions, with the principal series of bands exhibiting the regular spacing (<u>ca</u>. 2200cm.^{-1}) characteristic of the diphenylpoly-ynes,[25,71,132,133] the principal maximum having an intensity of 234,000.

<u>Nuclear Magnetic Resonance Spectrum</u> The spectrum was run on a very dilute solution, and the results[194] are of little significance. Decomposition of the sample was suspected. It is hoped to repeat the investigation with a pure sample, and possibly with hydrogenated derivatives of (XXIII).

<u>Complex Formation with Trinitrofluorenone</u> (XXIII) was found to form a crystalline complex with trinitrofluorenone[195-197] (T.N.F.), stable after storage for one year. Diacetylenic linkages appear to be unable to complex with T.N.F., in view of the inability of the following α-diynes to give stable complexes. Complexes were obtained, however,

$CH_3(CH_2)_3C{\equiv}CC{\equiv}C(CH_2)CH_3$ (L)

$AcO(CH_2)_7C{\equiv}CC{\equiv}C(CH_2)_7OAc$ (XXI)

from diphenyldiacetylene (IV), tolane (LI), and (XXIII), although not with the mercury derivative of phenylacetylene

(LII). The aromatic nucleus appears necessary for complex

$PhC\equiv CC\equiv CPh$ (IV) $PhC\equiv CPh$ (LI) $PhC\equiv C-Hg-C\equiv CPh$ (LII)

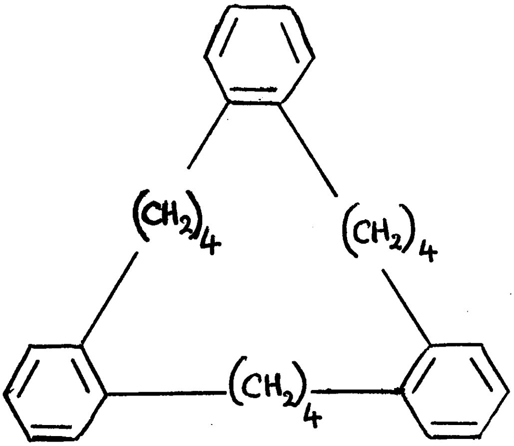
formation with T.N.F. (cf. the work of Orchin[196] and Newman[197]). In the case of (LII), the mercury atom will prevent complete conjugation between the two rings, with consequent inability of the compound to form a stable complex with T.N.F. Since none of the above acetylenic cpmpounds forms a complex with hexanitrosobenzene (H.N.B.), while aromatic compounds readily complex,[198] the diacetylenic system may be presumed to have a negative effect in this type of complexing. In the case of (XXIII), analytical data of what appears to be a pure, single crystalline compound suggest a ratio of 1.5 moles of T.N.F., the first such ratio reported, and from the rigid triangular shape of the structure postulated for (XXIII), a geometrical explanation of the unusual ratio is possible.

<u>X-Ray Determination of Structure</u> Further x-ray crystallographic studies have indicated that the cyclic trimer cannot be fitted into the unit cell, although no cyclic alternative can do so. A polymeric chain structure was considered more likely to fit the available data. It is hoped that further measurements on (XXIII) and its

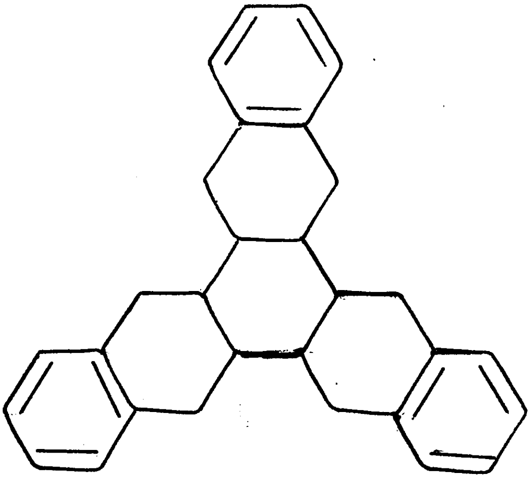
hydrogenated derivatives will clarify the present situation.

Hydrogenation of (XXIII)

Hydrogenation of the yellow poly-yne in ethyl acetate over Adams' platinum catalyst took place fairly slowly, with almost theoretical uptake of hydrogen. The resultant oil was with difficulty induced to crystallise, affording a very low yield (ca. 1%) of crystalline material m.p. 136-138°. The consitution of this hydrocarbom has been formulated as (LIII), on the basis of its light absorption, molecular weight, and analytical data. The infrared spectrum of (LIII) has no C-methyl band at 1376cm.$^{-1}$; and the ultraviolet spectrum has maxima identical with that of tetralin[184], which also contains four methylene groups per aromatic ring. The low yield of crystalline hydrocarbom



(LIII)



(LIV)

is thought to be due to partial condensation across the ring system, leading eventually to the polycyclic hydrocarbon (LIV). More recent work in these laboratories[191] has produced hydrocarbons from the poly-yne (XXIII) by primary reduction with excess sodium in liquid ammonia, followed by hydrogenation to complete uptake of hydrogen. In this way two hydrocarbons have been isolated, a high-melting compound m.p. 230-231° [3% from the diyne (XXXIX)], and a lower-melting hydrocarbon m.p. 120-122° [15% from the diyne (XXXIX)]. Analyses of these hydrocarbons show the presence of <u>ca</u>. 2 new rings, as neither light absorption data nor tetranitromethane tests reveal the presence of double bonds. Consequently the transannular hydrogenation postulate appears well founded. Light absorption data of both compounds show maxi~~x~~a identical with these of tetralin although the intensities are much above the original values for (LIII). Although mass spectrographic determination of molecular weight gave results of little significance with (LIII), application to both of these new hydrocarbons has given values for the molecular weights of 398±5, in close agreement with the theoretical 390-396, according to the number of rings introduced by the reduction. No trace of C-methyl absorption was found in the infrared spectrum of either compound.

The above evidence, when summarised, appears to favour the cyclic nature of the compound, and that its structure is that of the cyclic trimer. It is hoped that further physical determinations will clarify the situation, and that future hydrogenation and hydration studies will provide corroborative evidence.

PART I

EXPERIMENTAL

GENERAL

Melting points were determined on a Kofler block and are corrected.

The petrol referred to is the light petroleum fraction of b.p. 40-60°.

Sublimations were carried out at 10^{-4} mm. on the Towers' mercury vapour apparatus.

The alumina used for chromatography was "Brockman" grade V, unless otherwise stated.

The ultraviolet spectra were determined on a Unicam S.P.500 spectrophotometer, and , in one case, on a Cary automatic recording spectrophotometer.

Infrared absorption measurements were made on a Perkin Elmer model 13, double beam spectrophotometer, using a rock salt prism, as a nujol mull, unless a solvent is specified. For more accurate measurements, a Unicam S.P. 100 spectrophotometer, with a sodium chloride prism, was employed, with carbon tetrachloride as solvent.

SECTION I

Oxidative Coupling in Aqueous Phase - Dimethylethynylcarbinol (5g.) was added with stirring to a solution of cupric sulphate (12.5g.), sodium acetate (34g.), acetic acid (1.5g.) and cuprous chloride (0.5g.) in water (500ml.). When the blue solution was heated on the steam-bath, the colour changed to green after ten minutes, and later a yellow solid precipitated, deepening in colour on standing. After thirty minutes at 70°, the final colour of the precipitate was red, with a grey-green supernatant liquor. The solution was allowed to cool overnight, the pH having remained constant at 5.5 throughout the reaction. On filtration, the red cuprous derivative of the carbinol was obtained (3.3g., 36%), and upon ether extraction of the filtrate, the crystalline diol, 2:7-dimethylocta-3:5-diyne-2:7-diol[100] (2.9g., 58%) as needles on recrystallisation from ether:petrol, m.p. 130-131° (lit. 132°). Repetition of the experiment, including pyridine (25ml.) as a complexing agent for the cupric ion, did not affect the yield.

Cupric Acetate - Anhydrous cupric acetate was prepared in almost quantitative yield by the method of Spath.[199]

Oxidative Coupling Using Minimum Amount of Water. - Dimethylethynylcarbinol(0.25g.) was dissolved in a solution of cupric acetate (0.5g.), sodium acetate (1g,), and water (2-3ml.) in ethanol (30ml.). A trace of cuprous chloride was added to the bright blue solution, and the solution changed colour to green on heating on the steam-bath, finally turning reddish-brown after twenty minutes' heating. On working up by removal of the main bulk of the solvent, followed by addition of water, and ether extraction, the 2:7-dimethylocta-3:5-diyne-2:7-diol was obtained (0.15g., 60%).

Oxidative Coupling with Omission of the Buffering Agent. -Dimethylethynylcarbinol (0.5g.) was dissolved in a solution of cupric acetate (1.2g.) in water (30ml.), with a trace of cuprous chloride. The solution was heated on the steam-bath, turning green after a few minutes, and finally precipitating the red cuprous derivative. On extraction of the filtrate, 2:7-dimethylocta-3:5-diyne-2:7-diol (I) was obtained (0.24g.,48%). Repetition with cupric sulphate replacing the cupric acetate failed to achieve any reaction.

Oxidative Coupling in Organic Phase with Omission of the Cuprous Salt Catalyst. - Dimethylethynylcarbinol (II) (0.5g.) was dissolved in a solution of cupric acetate (1g.) in pyridine (50ml.) and the solution heated on the steam-bath. A green colour developed almost immediately, and after twenty minutes the solution was removed from the steam-bath and allowed to cool. On standing, the solution regained the original blue colour. Working up by acidification and ether extraction yielded the diol (I) (0.39g., 78%). Repetition of the above in aqueous phase gave similar results, but in lower yield, precipitation of the cuprous derivative taking place.

Oxidative Coupling of a Cuprous Derivative - The cuprous derivative (1g.) of phenylacetylene, prepared by heating the hydrocarbon with aqueous cupric acetate solution, was dissolved in pyridine (60ml.) and added to excess cupric acetate (2g.) in pyridine (60ml.). The colour changed to green, and the solution was heated for a total of twenty minutes on the steam-bath. After working up by acidification and ether extraction, diphenyldiacetylene (IV) (0.35g., 70%) was obtained as large prisms m.p. (aq. EtOH) 84-86° (lit.[16] 88°)

Conditions of Coupling - The various reagents and conditions are summarised below, in table IV.

Table IV

Reagent	Solvent	Results
cupric acetate	1) water 2) ethanol 3) dioxane 4) pyridine	All achieve satisfactory coupling. Pyridine:methanol is the best solvent as cupric acetate readily dissolves, and the cuprous derivative seldom precipitates.
cupric benzoate	pyridine: ether	Satisfactory coupling achieved. Removal of benzoic acid from the product is necessary.
cupric butyrate	benzene: ethanol	Satisfactory coupling achieved. Disadvantages are the smell and the need for removal of the butyric acid.
cupric stearate	pyridine: ether	Satisfactory coupling achieved. Necessity of removal of stearic acid constitutes a disadvantage.
cupric naphthenate	benzene	Satisfactory coupling achieved. Hydrocarbons contaminate the product and are difficult to remove.
cupric sulphate	water	Satisfactory coupling achieved. Disadvantages are the necessity for buffer solution and the partial precipitation of the cuprous derivative.

Reagent	Solvent	Results
cupric chloride	1) water 2) pyridine	Both couplings were successful. Disadvantages are the necessity for a buffer solution, precipitation of the cuprous derivative, and low solubility of the reagent in pyridine. (II) gave very poor yields of (I) with this reagent.
cupric salicylate	pyridine: methanol	Both attempted couplings were unsuccessful. Cupric ion too strongly complexed?
cupric salt of ethylene-diamine	ethylene-diamine	
ferric acetate	pyridine	Both were unsuccessful.
ferric nitrate	water	
cobaltic acetate	pyridine	No evidence of coupling observed in any of these cases.
cobaltic chloride	water	
cobalt naphthenate	benzene	

Optimum Conditions for Oxidative Coupling in Organic Phase - (II) (0.4g.) was added to a solution of cupric acetate (2g.) in pyridine:methanol:ether (200ml.). On refluxing the solution on the steam-bath, an immediate colour change to green was noticed, and after twenty minutes, the final colour was blue-green. After removal of the main bulk of solvent, followed by acidification and ether extraction, (I) was obtained (0.35g., 88%). Repetition in ethanol proved almost as successful.

Catalytic Oxidative Coupling. - (II) (0.8g.) was added to a solution of cupric acetate (0.01g.) in pyridine (10ml.), methanol (10ml.), and ether (30ml.). The solution was refluxed with passage of oxygen, turning green on removal of the oxygen supply, and regaining the blue colour on reconnecting the supply. The solution was refluxed in this way for seven hours, then left overnight, numerous colour changes, and reverse colour changes having been brought about. On acidification and ether extraction, (I) (0.65g., 81%) was obtained.

SECTION II

Sebacoyl Chloride[200] - Sebacic acid (60g.) and thionyl chloride (60ml.) were mixed in a 250ml. r. b. flask fitted with a reflux condenser protected by a silica drying tube. The mixture was refluxed for an hour on the steam-bath, then excess thionly chloride was removed by evaporation at reduced pressure, leaving a yellow liquid (68.7g., 98%). Acidic absorption was absent from the infrared spectrum, and on distillation in vacuo, sebacoyl chloride was obtained as a colourless oil b.p. 128-134°/0.3 mm.

Dibut-3-yn-1-ol sebacate - To a mechanically stirred solution of sebacoyl chloride (13.3g.) in dry ether (150ml.) was added but-3-yn-1-ol (8g.), then pyridine (10.5g.) was added dropwise. The resulting precipitate was filtered off, and the neutral filtrate evaporated down to yield a colourless crystalline solid (17g.). Acid absorption being detected in the infrared spectrum, the product was dissolved in ether and passed over an alumina column. The product was recovered from the eluate (11g., 61%), as large colourless plates m.p. 65-65.5°, $\nu_{C=O}$ 1745cm.$^{-1}$. (Found ; C, 70.5; H, 8.4; $C_{18}H_{26}O_4$ requires C, 70.6; H, 8.5%).

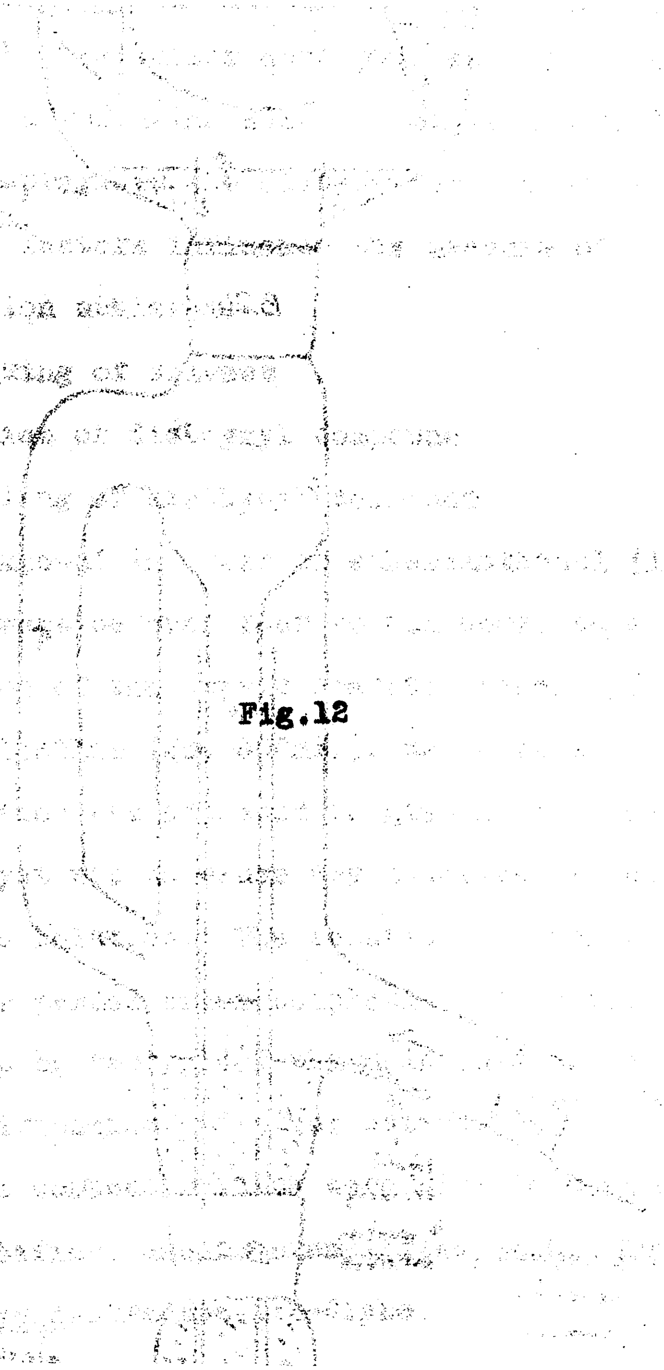
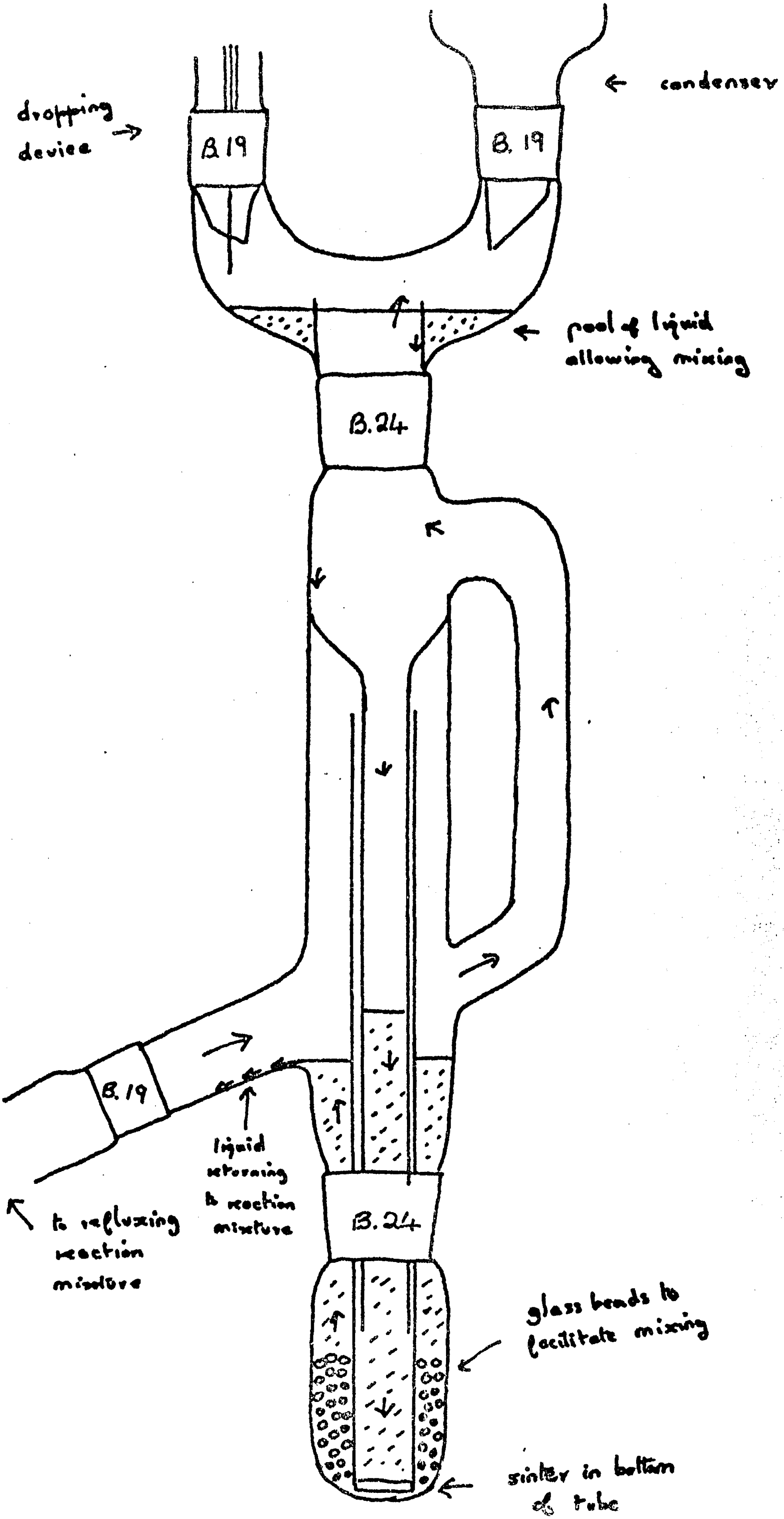


Fig.12


dropping device
condenser
B.19
B.19
pool of liquid allowing mixing
B.24
B.19
liquid returning to reaction mixture
to refluxing reaction mixture
B.24
glass beads to facilitate mixing
sinter in bottom of tube

General Method for Cyclisation Using the High-Dilution Technique - The high-dilution apparatus employs a source of cupric ion in a refluxing solvent (ether:methanol: pyridine), which provides the diluent for the starting material. Three factors influence the measure of successful dilution achieved:-

a) rate of refluxing of solvent

b) rate of addition of diethynyl compound

c) speed of coupling of diethynyl compound.

The diethynyl compound in ether or ether:methanol (100-200 ml.) was added dropwise over four to ten hours to a refluxing solution of the cupric acetate reagent in pyridine:methanol:ether (300-600ml.), as shown in fig.12. The ether proportion was adjusted to give a satisfactory rate of reflux, yet not to cause any undesired precipitation of salts from the solution. The solution was refluxed for a further shorter period after completion of addition before working up by removal of the main bulk of solvent, followed by acidification and ether extraction. In the case of diethynyl compounds which were slow to couple, the procedure was modified, and is exemplified in the later preparation of cyclotetradeca-1:3-diyne.

Cyclic Ester of Sebacic Acid and Octa-3:5-diyne-1:8-diol, (XIV) and the Cyclic Diester (XV).-

a) Dibut-3-yn-1-yl sebacate (1g.) was added in ether: pyridine (100ml.) over four hours to a refluxing solution of cupric acetate (3g.) in ether:pyridine (500ml.). The solution was refluxed for a further hour, then the green solution was evaporated to smaller volume, acidified at 0°, and ether extracted. On evaporation of the neutral ether extract a brown oil was obtained, crystallising on standing to a mass of needles. After chromatographic treatment in benzene over alumina (30g.), the pure cyclic monomer (XIV) was obtained from the benzene and benzene:ether eluates as colourless flat needles (0.47g., 47%) m.p. 55-56°, (Found : C, 71.2; H, 7.9; M (Rast), 334; $C_{18}H_{24}O_4$ requires C, 71.1; H, 7.9%; M, 304). Light absorption - ν 2256, 2150, 1742cm.$^{-1}$, λmax. 226, 238, and 254mμ (ε 680, 550, and 220 respectively). Ether elution afforded only microscopic amounts of the dimer (XV).

The pure cyclic monomer (XIV) (0.205g.) was hydrogenated over Adams' platinum catalyst (in ethyl acetate) and absorbed 57ml. (theory 60ml.) in ten minutes, whereupon absorption ceased.

b) Coupling in lower dilution afforded a colourless solid, extractable with hot petrol, from which it crystallised in prisms (9%). On chromatography in benzene over alumina, followed by repeated recrystallisation from petrol, the pure cyclic dimer (XV) was obtained (2%) m.p. 109-110°. Light absorption : λmax. 225, 240, and 254mμ (ε 830, 750, and 380 respectively), infrared spectrum similar to that of (XIV), (Found : C, 71.0; H, 8.0; M(Rast), 653; $C_{36}H_{48}O_8$ requires C, 71.1; H, 7.9%; M, 608).

c) Repeated use of this method of high-dilution coupling employing very slow addition has increased[201] the yield to 63% of pure monomer.

Aqueous Phase Coupling of Dibut-3-yn-1-yl Sebacate - (XIII) (0.5g.) in dioxane (150ml.) was added to a suspension of cuprous chloride (5g.), ammonium chloride (8g.) and ammonia (2.5ml.) in water (20ml.) and the mixture shaken in oxygen in a hydrogenation-type apparatus until no more oxygen was absorbed. After three hours, uptake of oxygen had virtually ceased, and the reaction was stopped, the dioxane removed, and the mixture extracted with ether. A brown solid (0.35g.) m.p. 57-60° was obtained, possessing a large absorption in the infrared at *ca*. 3300cm.$^{-1}$, indicating much unchanged starting material, with possibly some longer-chain material present. Ether-insoluble polymeric material accounted for the remainder of the starting material. Repetition of the above experiment, using a smaller quantity of dioxane (5ml.) and a higher reaction temperature (70°) gave an ether-soluble solid identified as unchanged starting material, and a crystalline solid (0.13g.) m.p. ca. 100°, with ethynyl absorption in the infrared, indicative of a short-chain polymer, from the intensity of the band. This solid was not further investigated.

Tetradeca-1:13-diyne - Liquid ammonia (500ml.) was run into a three-necked r.b. flask fitted with a stirrer and cooled in a cooling bath at -50°. Ferric nitrate (0.5g.) was added, then sodium (6g.) added portionwise with stirring, allowing the blue colour to disappear after each addition. Acetylene, purified by passage through two sulphuric acid traps combined with a cold trap, was passed for two hours until the precipitate of disodium acetylide had disappeared, and a grey solution resulted. An autoclave was cooled down with liquid air, then with liquid ammonia, and 1:10-dibromodecane added (25g.) in ether (40ml.). The solution of sodium acetylide was then added, the autoclave sealed, and the reaction allowed to proceed for twenty-four hours. The autoclave was then opened and ammonia allowed to escape. Ammonium chloride, a solution of ammonium chloride in water,and crushed ice were added, in that order, and the mixture repeatedly extracted with ether. Some polymeric material was deposited. The ether extract, after washing and drying, gave a reddish-brown oil which solidified on scratching with a glass rod, in the form of plates (9g.,57%) m.p. 29-30°. The solid gave a negative Beilstein test, and crystallised from petrol at low temperature. Sublimation afforded small colourless plates m.p. 33-34°, ν 3275, 2100cm.$^{-1}$, (Found : C, 88.7; H, 11.3; $C_{14}H_{22}$ requires C, 88.4; H, 11.6%). Basification of the acid washings of the ether extract yielded a small quantity of low-melting solid, with a negative Beilstein test, possibly the diamine formed by ammonolysis of the dibromide.

Cyclotetraceca-1:3-diyne and Cycloöctacosa-1:3:15:17-tetrayne -Tetradeca-1:13-diyne (1g.) was dissolved in a solution of cupric acetate (4g,) in pyridine (100ml.), methanol (600ml.) and ether (800ml.). The solution was refluxed for a total of seventy-two hours, and samples withdrawn at intervals showed little reduction in the intensity of the ethynyl absorption. The ether was therefore removed and replaced by pyridine (500ml.), and oxygen was bubbled continuously through the refluxing solution. After a further seventy-two hours, the solution was brown and the intensity of the ethynyl absorption in the infrared was very small. The solution was then evaporated to low volume, acidified, and ether extracted. The neutral extract deposited a red oil, mainly soluble in hot petrol.

The petrol-soluble oil was chromatographed over alumina in petrol to give, in the early fractions, *cyclo*tetradeca-1:3-diyne as a colourless oil (0.17g., 17%), which, after distillation in a molecular still, formed prisms m.p. 18°, (Found : C, 89.1; H, 10.4; $C_{14}H_{20}$ requires C, 89.4; H, 10.6%) Light absorption : absence of ethynyl band, and ν 2215cm.$^{-1}$, λmax. 230, 242, and 257mu (ε 690, 600, and 440 respectively). Later fractions gave *cyclo*öctacosa-1:3:15:17-tetrayne (0.30g., 30%) as needles m.p. 101-102° from methanol:ether, (Found : C, 89.1; H, 10.5; M(Rast), 395; $C_{28}H_{40}$ requires C, 89.4; H, 10.6%; M, 376). Light absorption : infrared spectrum similar to that of the monomer, λmax. 226, 239, and 254mu (ε 980, 930, and 630 respectively).

Hydrogenation of Cyclotetradeca-1:3-diyne - *Cyclo*tetradeca-1:3-diyne (128mg.) was shaken in ethyl acetate with hydrogen over Adams' platinum oxide catalyst, and absorbed 55ml. (theoretical 64ml.) after uptake had ceased. On removal of the solvent, a colourless solid was obtained, which was extracted with petrol and chromatographed over alumina in petrol, yielding plates (30mg., 23%) m.p. 54-55°, undepressed on admixture with a genuine sample of *cyclo*tetradecane.[129] The petrol-insoluble portion was a brown oil with acidic absorption in the infrared.

Hydrogenation of Cycloöctacosa-1:3:15:17-tetrayne - *Cyclo*öctacosa-1:3:15:17-tetrayne (75mg.) was shaken in ethyl acetate with hydrogen over Adams' platinic oxide catalyst until uptake of hydrogen ceased, absorbing 36ml., (theoretical 38ml.). On evaporation of the solvent , a solid remained, partly soluble in petrol, which on chromatography over alumina in petrol gave cyclooctacosane (20mg.)25%) as plates, m.p. 47-48° (lit. 48°[129]). A small amount of red oil remained, insoluble in petrol.

Terephthaloyl Chloride[202] - Terephthalic acid (50g.) was mixed with phosphorus pentachloride (135g.) in a 1 litre r.b. flask, fitted with an air condenser, protected by a silica drying tube. The mixture was heated until a uniform brown melt resulted, then refluxed for thirty minutes, following which phosphorus oxychloride was removed under reduced pressure on the steam-bath, and the residue extracted with ether. The extract yielded terephthaloyl chloride as pale yellow needles (51g., 90%) m.p. 79-80° (lit. 81°[202]). Terephthalic acid (4g.) was recovered unchanged from the residues.

Dibut-3-yn-1-yl Terephthalate - Terephthaloyl chloride (3g.) was added portionwise to a solution of but-3-yn-1-ol (2.4g.) in 10% sodium hydroxide solution (60ml.), kept at room temperature. The mixture was shaken for a few minutes, and allowed to stand for thirty minutes with occasional shaking, then filtered, affording a crystalline precipitate (2g,, 48%). The solid was purified from acid by passage over an alumina column in ether, followed by recrystallisation from methanol. The solid crystallised as colourless needles m.p. 114-115° (Found: C, 71.3; H, 5.2; $C_{16}H_{14}O_4$ requires C, 71.1; H, 5.2%). Light absorption : ν 3240, 2100, and 1710cm.$^{-1}$, λmax. 242, 285, and 295mμ (ε 21,000, 1800, and 1500 respectively).

Diprop-2-yn-1-yl Terephthalate - Terephthaloyl chloride (8g.) was added slowly with stirring to prop-2-yn-1-ol (5.5g.) in 10% sodium hydroxide solution (180ml.). The mixture was allowed to stand for thirty minutes with occasional shaking, then filtered to give a crystalline precipitate (6g., 63%). The pure diester was obtained by passage over an alumina column in ether, followed by recrystallisation from methanol, as colourless needles m.p. 108-109° (Found : C, 69.6; H, 4.1; $C_{14}H_{10}O_4$ requires C, 69.4; H, 4.1%). Light absorption : ν 3230, 2105, and 1710cm.$^{-1}$, λmax. 242, 285, 295mμ (ε 21,000, 1800, and 1500 respectively).

2-Chloromethyltetrahydropyran -This preparation was carried out according to Crombie *et al.*,[135] and gave impure material in 50% yield, hydroxyl absorption being present in the infrared. Removal of the hydroxyl-containing impurity by shaking with alumina afforded pure 2-chloromethyltetrahydropyran (43%), n_D^{20} 1.4619 (lit. 1.4620[135]), absence of hydroxyl absorption in the infrared spectrum.

Hex-5-yn-1-ol - This was prepared by the method of Eglinton,[29] and a reaction time of forty-five hours was allowed. On distillation, the pure material (72%) had n_D^{20} 1.4513 (lit. 1.4510).

Dihex-5-yn-1-yl Terephthalate - Terephthaloyl chloride (5g.) was added portionwise to a swirled mixture of hex-5-yn-1-ol (5g.) and 10% sodium hydroxide solution (100ml.). On continued shaking, the mixture warmed up, and the ester was precipitated at the completion of the reaction. The mixture was cooled under the tap with shaking, and the solid quickly filtered off and repeatedly washed with water, affording the crude material (6g., 80%). On purification by passage over alumina in ether, the pure diester was obtained as colourless needles m.p. 84-87°, raised to 87-88° by repeated recrystallisation from methanol, (Found : C, 73.7; H, 6.4; $C_{20}H_{22}O_4$ requires C, 73.6; H, 6.7%); light absorption : ν 3240, 2100, and 1726cm.$^{-1}$, λmax. 242, 285, and295 mμ (ε 21,000, 1800, and 1500 respectively).

Cyclic Diester of Terephthalic Acid and Dodeca-5:7-diyne-1:12-diol - Dihex-5-yn-1-yl terephthalate (1g.) was dissolved in a solution of cupric acetate (3g.) in pyridine:ether (6:1, 700ml.), and the solution was refluxed for a total of sixty-seven hours. The final colour of the solution was green. The solvent was then removed, the solution acidified and ether extracted, the extract yielding a brown solid (0.65g.), insoluble in petrol. The solid was almost completely soluble in benzene, and the benzene solution was passed through an alumina column, giving a microcrystalline solid (0.35g., 35%), followed, on elution with ether, by a brown, oily solid (0.01g.). The colourless solid had m.p. 190-200°, and further chromatography established the presence of only one compound, m.p. (repeated recrystallisation from benzene) 210-211°. (Found : C, 74.05; H, 6.5; M, 618; $C_{40}H_{40}O_8$ requires C, 74.25; H, 6.2%; M, 648), light absorption : ν 2100, 1727cm.$^{-1}$, absence of ethynyl absorption, λmax. 242, 285, and 294 mμ (ε 38,000, 3900, and 2900 respectively). The later-eluted brown solid had m.p. 165°, and had hydroxyl absorption in the infrared. The petrol washings yielded a very small amount of needle crystals on chromatographic treatment in benzene over alumina,, m.p. 145-148°, light absorption: ν 1720cm.$^{-1}$, absence of ethynyl absorption, λmax. 244, 250, 256, 286, and 294 mμ, on a solution of unknown concentration.

<u>Dodeca-5:7-diyne-1:12-diol</u> - Hex-5-yn-1-ol (2g.) was added to a solution of cupric acetate (3g.) in pyridine: methanol (150ml.) and the solution refluxed on the steam-

bath for seven hours, then allowed to stand overnight. On acidification, followed by ether extraction, an oil was obtained, solidifying on standing. On crystallisation from ether:petrol, thick needles were obtained, m.p. 49-50°, (Found : C, 74.4; H, 9.4; $C_{12}H_{18}O_2$ requires C, 74.2; H, 9.3%), light absorption: ν 3400, 2174, and 2130cm.$^{-1}$ absence of ethynyl and carbonyl absorption, λmax. 227,238, and 254 mμ (ε 400, 380, and 230).

<u>Attempted Cyclisation of Dihex-5-yn-1-yl Terephthalate</u> - Dihex-5-yn-1-yl terephthalate (1g.) was dissolved in ether:pyridine (1:1, 150ml.) and added over three hours to a refluxing solution of cupric acetate (5g.) in pyridine: methanol:ether (2:2:1, 500ml.) under high-dilution conditions, and the solution refluxed for a further four hours, and stood overnight. No colour change was noticed, and a sample showed little reduction in the intensity of the ethynyl absorption in the infrared. The solution was then refluxed for seventy hours, whereupon the intensity of the ethynyl absorption in the infrared was found to be very small. The reaction product was then isolated by removal of solvent, acidification, and ether extraction, as a brown solid (0.88g.), insoluble in petrol. On chromatography of the solid in benzene over alumina, dimethyl terephthalate (0.60g., 100%) was obtained as long needles m.p. 142°, undepressed on admixture with a genuine

sample.[202] Further elution with methanol afforded a brown, low-melting solid, which was recrystallised from ether: petrol to give colourless needles (0.2g., 33%) m.p. 47-49°, undepressed on admixture with a genuine sample of dodeca-5:7-diyne-1:12-diol.

Attempted Cyclisation of Dibut-3-yn-1-yl Terephthalate - Dibut-3-yn-1-yl terephthalate (2g.) in ether (150ml.) was added under high-dilution conditions over two hours to a refluxing solution of cupric acetate (4g.) in pyridine (600ml.) and the solution refluxed for a further two hours. The solution turned green soon after the commencement of the reaction, and some precipitation of yellow solid took place. On removal of the bulk of the solvent, followed by acidification and ether extraction, the neutral extract afforded a partly solid residue. Terephthalic acid was removed by redissolving the solid in ether, and the recovered extract was sublimed, giving colourless needles (20mg., 1%) m.p. 107-109°. (Found C, 71.6; H, 6.0; M (Rast), 244; $C_{16}H_{14}O_4$ requires C, 71.6; H, 4.5%; M, 270), light absorption : reduced ethynyl absorption in the infrared, ultraviolet spectrum similar to that of the open-chain diester (XVI, n = 2). Appreciable quantities of the cuprous derivative remained in the reaction vessel, and some polymer was obtained during the ether extraction.

Attempted Cyclisation of Diprop-2-yn-1-yl Terephthalate - Diprop-2-yn-1-yl terephthalate (2g.) in ether (150ml.) was added over three hours under high-dilution conditions to a refluxing solution of cupric acetate (4g.) in pyridine:ether (5:1, 600ml.). The solution was refluxed for two hours after completion of addition, finally going dark brown in colour. On working up by partial removal of solvent, followed by acidification and ether extraction, the neutral extract afforded a dark brown oil. On distillation in a molecular still, the oil gave a solid in the higher part of the tube, contaminated by a yellow oil. Repeated sublimation at lower temperatures afforded the solid as colourless needles (25mg., 1%) m.p. 135-136°. (Found : C, 63.9; H, 6.2; M(Rast), 289; $C_{14}H_{10}O_4$ requires C, 70.0; H, 3.3%; M, 242), light absorption : absence of ethynyl absorption in the infrared, ultraviolet spectrum similar to that of the starting open-chain diester (XVI, n = 1).

Attempted Cyclisation of Diethyl Hepta-1:6-diyne-4:4-dicarboxylate - Diethyl hepta-1:6-diyne-4:4-dicarboxylate (2g.) was dissolved with cupric acetate (5g.) in pyridine: ethanol (1:1, 700ml.) and allowed to stand for one month at room temperature. A sample was worked up for infrared analysis, and exhibited only small residual ethynyl absorption. The solution was acidified at 0° and ether extracted. The neutral extract on evaporation afforded a browny oil which was chromatographed on alumina (50g.) in benzene. A yellow oil containing appreciable ethynyl grouping from its absorption in the infrared, was obtained from the benzene eluate, while chloroform eluted a red oil which, having been observed to polymerise to a gum during earlier runs, was hydrogenated in ethyl acetate over Adams' platinic oxide catalyst for twenty-one hours. The uptake of hydrogen was 460ml. (theoretical for the tetrayne, 540ml.). The infrared spectrum of the recovered oil suggested a saturated cyclic ester, ν 1720cm.$^{-1}$, absence of acetylenic and C-methyl absorption, but the oil set to an intractable gum on standing, and no characterisation was achieved. The red oil had the following light absorption : ν 1720, 2100cm.$^{-1}$, λmax. 254 mμ (ε 730), and absorption rising steadily toward the shorter wavelengths, with ε 1700 at λ 226 mμ.

<u>Octa-3:5-diyne-1:8-diol</u> <u>and</u> <u>Octa-3:5-diyne-1:8-diacetate</u> - But-3-yn-1-ol (2g.) was dissolved in a solution of cupric acetate (1g.) in pyridine:methanol (1:1, 100ml.). The solution was heated at 70° for thirty minutes, causing the discharge of the blue colour, regenerated by bubbling oxygen through the solution. On working up by evaporation,

acidification and ether extraction, the neutral extract afforded an oil which showed no tendency to crystallise, although a silver nitrate test proved negative. The impure (XX) was dissolved in dry pyridine (25ml.) with acetic anhydride (3g.), the solution maintained at 60° for twenty minutes, then allowed to stand overnight (cf. Bowden *et al.*[24]). Addition of the solution to chipped ice (100g.) afforded a colourless solid which was filtered off and recrystallised from petrol (60-80°) as colourless flaky plates (1.2g., 38%) m.p. 62-63° (lit. 63°[24]).

Hydration of Octa-3:5-diyne-1:8-diacetate

a) Mercury resin[162] - Octa-3:5-diyne-1:8-diacetate (0.3g.) was dissolved in 90% acetic acid (2.2ml.) and mercury resin (0.5g.) added. The solution was refluxed for two hours, and on rendering alkaline, followed by ether extraction, an oil was obtained which crystallised as tufts of flaky needles from petrol m.p. 58-59°, undepressed on admixture with the starting material. Oily residues showed hydroxyl absorption in the infrared, with small acetate and very small $C\equiv C$ stretch absorption. Little hydration appears to have been achieved, and hydrolysis seems to be a competing side reaction.

b) Mercuric acetate - Octa-3:5-diyne-1:8-diacetate (0.3g.) in glacial acetic acid (1.5ml.) was added to mercuric oxide (0.75g.) in glacial acetic acid (4ml.) and the solution was refluxed for five hours on the water-bath, depositing a large precipitate of mercurous acetate. The solution was then filtered, the filtrate saturated with hydrogen sulphide, and the sulphide precipitate filtered off. The filtrate was taken to dryness and ether extracted, and the neutral extract gave an oil which on petrol extraction afforded crystals m.p. 59-61°, undepressed on admixture with the starting material. The residual oil had hydroxyl and carbonyl absorption in the infrared, as well as acetate absorption. 2:4-Dinitrophenylhydrazine reagent gave a faint red precipitate which was not further identified.

Hydration of Phenylacetylene - Phenylacetylene (0.3g.) and mercuric oxide (2.0g.) were dissolved in glacial acetic acid (11.5ml.) and refluxed for five hours. The solution was decomposed with acid, ether extracted, and the ether carefully removed to give acetophenone (0.25g., 67%), identified as its 2:4-dinitrophenylhydrazone[203], m.p. 242-244°, (lit. 249°)

Diphenyldiacetylene - Phenylacetylene (2g.) was added to a solution of cupric acetate (4g.) in pyridine:methanol (1:1, 150ml.) and refluxed for two hours, the solution turning green after thirty minutes. On working up by evaporation to low volume, followed by acidification and ether extraction, a solid was obtained (1.7g., 85%), crystallising from aqueous ethanol as large prisms m.p. 85-86° (lit. 88° [16]).

Hydration of Diphenyldiacetylene -

a) Mercury resin - Diphenyldiacetylene (0.2g.), mercury resin (0.5g.) in acetic acid (2.9ml.) and water (0.4ml.) were refluxed for six hours. The solution on cooling deposited the unchanged starting material (0.17g,), identified by m.p. and mixed m.p. with diphenyldiacetylene, undepressed.

b) Mercuric acetate - Diphenyldiacetylene (0.4g.) and mercuric oxide (2.6g.) were refluxed in glacial acetic acid for five hours. Concentrated hydrochloric acid was then added, and the mixture poured into water. On ether extraction an oil was obtained which, on treatment with the 2:4-dinitrophenylhydrazine reagent, gave a small yield of a red precipitate m.p. 167-175°. The light absorption of the oil had ν 1593cm.$^{-1}$, and the oil gave a positive ferric chloride test. The oil deposited solid insoluble in methanol, m.p. 127-145°, which was not further characterised, and the methanol soluble portion, on treatment with a hot aqueous solution of cupric acetate, afforded a copper enolate which crystallised on scratching with a glass rod, as fine green needles m.p. 195-197° after one recrystallisation from benzene. The copper enolate of 1:4-diphenylbuta-1:3-dione has m.p. 199-201° [166]

The β-diketone was obtained in 50% yield (calculated on the copper enolate). On dilution of the mother liquors with petrol, a small precipitate of solid (50mg., 12%) was obtained m.p. 77-81°. On recrystallisation from aqueous ethanol, it was obtained as fine colourless needles m.p. 85-87°, identified as 2:5-diphenylfuran (lit. 91°[167]) by characteristic infrared absorption as well as by melting point.

SECTION III

Acenaphthenequinone- was prepared by the method of Graebe and Gfeller[170] in 30% yield, m.p.(after one recrystallisation from acetic acid) 261-262° (lit. 267°).

Cis- and Trans-1:2-Dihydroxymethylacenaphthene - were prepared by the method of Maxim[171] in overall 55% yield, 45% as the trans- form m.p. 178-179° (lit. 182-183°), 10% as the cis- form m.p. 185° (lit, 187-189°). The extraction method, however, was modified, so as to make use of the solubility of the trans- form in ether to separate it from the ether-insoluble cis- form, which can be extracted and recrystallised from ethyl acetate.

1:8-Diacetylnaphthalene (XXV) m.p. 169-170° (lit. 171-172°) was prepared by the method of Criegee[172] from both the cis- and the trans-diols in 84% and 65% yield respectively.

1:8-Dicarbomethoxynaphthalene was prepared by the method of Geissman and Morris[204] in 70% yield of pure material m.p. 102-103° (lit. 102-103°) from a poor quality grade of 1:8-naphthalic acid.

1:8-Bis-(hydroxymethyl)-naphthalene

A) To a slurry of lithium aluminium hydride (2g.) in dry ether (150ml.) in a three-necked r.b. flask fitted with a stopper, stirrer and reflux condenser, protected by a drying tube, was added 1:8-naphthalic acid (5g.), partially dissolved in dioxane (150ml.) in small portions, with a further quantity of dry ether (150ml.) to facilitate solution. The solution was refluxed for forty hours, whereupon very little residual carbonyl absorption remained in the infrared spectrum. On working up with sodium potassium tartrate solution, a solid (2.7g., 62%) was obtained m.p. 150-152°, crystallising from chloroform as needles m.p. 154-155°. Boekelheide reports[176] high yields and m.p. 158°, but we have been unable to achieve similar results on a large scale.

b) To a slurry of lithium aluminium hydride (0.6g.) in ether (100ml.) in a three-necked r.b. flask fitted with a dropping funnel, reflux condenser, and stirrer, protected by drying tubes, was added the dimethyl ester of (XXX) (3.2g.), dropwise (in ether) over thirty minutes. The solution was refluxed for ten hours, and , on detecting residual carbonyl absorption in the infrared of a sample, for a further four hours with a further quantity of lithium aluminium hydride (0.4g.). On working up by decomposition of the complex with sodium potassium tartrate solution, an ether extract was obtained yielding (XXXI) as colourless needles (1.5g., 70%) m.p. 151-152°. In repetition on a large scale, however, the yield decreased to 35%, with probable large losses through use of excessive amounts of water to break up the emulsions formed in the working up.

<u>1:8-Bis-(bromomethyl)-naphthalene</u> - The diol (XXXI) (2.0g.) was added portionwise to concentrated hydrobromic acid (35ml.) at 0° and maintained at that temperature for two hours, then at room temperature for forty-eight hours (cf. Boekelheide's preparation of the dichloride[176]). The solid became soft on reacting, and hardened to a cake on standing. On recrystallisation from petrol (60-80°), the dibromide (XXXII) was obtained (1.77g., 60%) as needles m.p. 129-130° (Found : C, 46.1; H, 3.3; Br, 50.6; $C_{12}H_{10}Br_2$ requires C, 45.9; H, 3.2; Br, 50.9%). Bergmann reported[175] m.p. 130-131.5° and gave only a bromine analysis.

Cis-<u>Acenaphthene-1:2-diol</u> was prepared by the method of Gunstone and Morris[177] in 42% yield of crude solid and 14% pure, from petrol:ethyl acetate. Attempts to hydroxylate acenaphthylene with hydrogen peroxide:t-butanol, using osmium tetroxide and vanadium pentoxide as catalysts, returned unchanged acenaphthylene.

<u>Naphthalene-1:8-dialdehyde</u> (XXVI) was prepared by the method of Criegee[172] in 58% yield m.p. 123-125° (lit. 130°).

<u>Wittig Reaction with Naphthalene-1:8-dialdehyde</u> (XXVI) - Triphenylphosphonium methyl bromide was prepared according to Wittig and Schollkopf.[178] Triphenylphosphonium methyl bromide (3.57g.) was added to a solution of phenyl-

lithium,[205] prepared from lithium metal (0.25g.) and bromobenzene (2.2g.) under an atmosphere of nitrogen. The dark red solution was added through a plug of cotton wool to a solution of the dialdehyde (XXVI) (0.92g.) in ether (100ml.), and washed through with ether. A white precipitate was formed, which reddened on standing. The mixture was allowed to stand for thirty minutes, refluxed for three hours, and kept overnight. On filtration, a red solution was obtained, and a blackish precipitate. The red solution was washed with sodium metabisulphate solution, acid and water, giving an oil partly soluble in petrol, the remainder being ether-soluble, with hydroxyl absorption in the infrared spectrum. Chromatography of the petrol-soluble portion on alumina afforded a colourless oil, and on stripping the column, small amounts of a yellow oil. The colourless oil on distillation afforded a clear liquid, b.p. 138°/1 mm., (Found : C, 79.4; H, 6.5%; with a residue of phosphorus), light absorption : ν 1585, 878cm.$^{-1}$, λmax. 251 mμ (ε 9000). The product was not further characterised, as the reaction is obviously complex.

O-<u>Divinylbenzene</u> (XXIX) was prepared from o-xylene by the route of Halford and Weissman,[173] with the following modifications. In the preparation of the diester (XXXVI) via the dicyanide (XXXV), omission of isolation of the pure

(XXXV) raised the overall yield (from the dibromide) from 60 to 82%. In the extraction of the water-soluble diol (XXXVII), extreme care was necessary for high yields. (XXIX) showed ν 1625, 991, and 915cm.$^{-1}$, and (XXIX) (14g.), on standing in a stoppered vessel for four weeks, set to a viscous glass, distillation of which at 120-200°/20 mm. afforded only 2.5g. (25% recovery) of the olefin. The residue was a brittle yellow cake.

Tetrabromide of O-Divinylbenzene (XXXVIII) - (XXIX) (45g.), in a small volume of carbon tetrachloride, was brominated with the theoretical quantity of bromine (110g.) in carbon tetrachloride (100ml.), by dropwise addition with stirring to the cooled solution. On overnight standing, a colourless solid (10g.) was deposited. The solution was evaporated to smaller volume, and on cooling, a further crop (90g.) was obtained. Precipitation with petrol afforded a further 13g. of product. Bromine was added to the mother liquors until the red colour persisted, and a further small amount of solid was deposited on cooling and evaporation of the pasty oil. The final product (113g., 73%) crystallised as colourless plates from petrol (60-80°), m.p. 72-74°. Deluchat reported[174] m.p. 71-74° on bromination in ether, no yield stated.

Treatment of (XXXVIII) with $NaNH_2$ in liquid NH_3 - The sodamide preparation followed the method of Vaughn *et al.*[179] Sodium (6g.) was converted to sodamide in liquid ammonia (200ml.) using ferric nitrate as catalyst. (XXXVIII) (17g.) in ether (150ml.) was added over five minutes and the reaction mixture allowed to stand for thirty minutes. Excess sodamide was decomposed with ammonium chloride (25g.) and the mixture transferred to a beaker covered with cellophane to prevent volatilisation losses, and allowed to evaporate. After the ammonia had evaporated, ether extraction afforded a black oil from which, on distillation, was obtained a colourless liquid (4g.) b.p. 60-64°/1 mm., n_D^{20} 1.5880, light absorption : ν 3275, 2100, 1620, 995, and 915cm.$^{-1}$ The Lassaigne test for bromine was negative.

Attempted Cyclisation of the Reaction Product - To a refluxing solution of cupric acetate (6g.) in pyridine: methanol:ether (3:3:1, 350ml.), a solution of the product (1g.) from the above reaction in ether (150ml.) was added dropwise over three hours, employing the high-dilution conditions. After completion of the addition, the reaction mixture was refluxed for a further three hours. The solution was then evaporated to low volume, acidified, and ether extracted. The neutral extract afforded an oil which slowly solidified. The solid was extracted with petrol and ether:petrol, then chromatographed on alumina in petrol, a colourless solid (0.2g., 20%) being obtained, crystallising from methanol as needles, m.p. 104-105°, (Found : C, 94.2; H, 5.5; M(Rast), 252; $C_{20}H_{14}$ requires C, 94.5; H, 5.5%; M, 254), light absorption ; ν 2100, 995, and 915cm.$^{-1}$, λmax. 242, 283, 300, 321, and 344 mμ (ε 76,000, 28,000, 35,500, 36,500, and 30,000). Absorption of bromine was much quicker than with diphenyldiacetylene, but was still not selective. Later fractions from the column afforded some blackish material which had no melting point below 300°, and was not further characterised.

Hydrogenation of 0-0'-Divinyldiphenyldiacetylene (XLI)

(XLI)(313mg.) was hydrogenated in ethyl acetate over Adams' platinic oxide catalyst for five hours, and absorbed 272ml. (theoretical 317ml.) of hydrogen. The solution was passed through an alumina column and evaporated to give an oil from which, on distillation, was obtained (XLII) as a colourless oil (150mg., 46%) b.p. 180-190° (bath temp.)/1 mm., n_D^{24} 1.5382 (Found : C, 90.0; H, 10.1; $C_{20}H_{26}$ requires C, 90.2; H, 9.8%), light absorption : 1378cm.$^{-1}$ and typical aliphatic and aromatic absorption.

Attempted Purification of (XXXIX) from (XL) -

a) Addition of bromine lacked sufficient specificity.

b) Chromatography on alumina in petrol achieved only partial enrichment; early fractions enriched in (XXXIX), later fractions enriched in (XL).

c) Addition of excess potassium mercuri-iodide solution afforded the mercury derivatives of the two components, (XXXIX) and (XL). The mercury derivative of o-vinylethynylbenzene , (XLIII) was extracted with benzene, as needles m.p. 115°, light absorption : λmax. 242, 264, 278, and 292 mμ (ε 52,000, 32,000, 42,000, and 43,000). The insoluble polymeric derivative of o-diethynylbenzene remained, but treatment with alkaline potassium cyanide proved unexpectedly ineffective in liberating the parent acetylene.

The mercury derivative of phenylacetylene, (LII), was prepared by the same method and had light absorption : λmax. 250, 258, 270, and 278 mμ (ε 25,000, 43,000, 49,000, and 36,000).

Styrene Dibromide was obtained almost quantitatively by addition of the calculated quantity of bromine in carbon tetrachloride to a solution of freshly distilled styrene in the same solvent. It was obtained from petrol (60-80°) as needles m.p. 69-71° (lit. 71°[206]).

α-Bromostyrene - Styrene dibromide (26.5g.) in ethanol was treated with a solution of sodium ethoxide [from sodium (2.3g.) in ethanol (150ml.)] and brought to reflux temperature . After one minute's refluxing, the alcohol was removed, water added, and on ether extraction an oil (17g.) was obtained. The oil was distilled to give a colourless liquid (14g., 80%) b.p. 70-80°/1.5 mm., n_D^{20} 1.5886 (lit. 1.5881[207]), light absorption : 883cm.$^{-1}$ and absence of ethynyl absorption.

O-Di-(α-bromovinyl)-benzene (XLVII) - (XXXVIII) (45g.) in hot ethanol (250ml.) was added slowly to a solution of sodium ethoxide, from sodium (4.6g.) in ethanol (100ml.). The solution was brought to reflux temperature and refluxed for one minute. On working up by evaporation, addition of water, and ether extraction, an oil was obtained (27g., 93%) n_D^{20} 1.6384 (lit. for (XLVII) 1.6360[174]), light absorption ; ν 901cm.$^{-1}$, absence of ethynyl absorption. On distillation, four fractions were obtained :

Fraction	Weight	n_D^{20}	b.p./5 mm.
1)	5g.	1.6295	120-138°
2)	15g.	1.6380	138-142°
3)	4g.	1.6430	142-146°
4)	1g.	1.6520	146-155°

1) contained some ethynyl absorption at 3275cm.$^{-1}$, 2) and 3) were of satisfactory purity (Found 3) : Br, 55.2; $C_{10}H_8Br_2$ requires Br, 55.5%). The last fraction was thought to contain unreacted (XXXVIII), and a tarry residue remained in the distilling flask.

Phenylacetylene

a) α-Bromostyrene (12g.) was added in ether (100ml.) to a suspension of sodamide from sodium (3.5g.), using ferric nitrate as catalyst, in liquid ammonia (200ml.) over five minutes, and allowed to stand overnight, in a Dewar flask, protected by cellophane. Excess ammonium chloride (20g.) was then added, and the mixture added to water (500ml.). Ether was added and the layers separated. The ether extract afforded a liquid which on distillation gave phenylacetylene (3g., 45%) b.p. 138-140°, n_D^{20} 1.5485 (lit. 1.5517[208]), light absorption : ν 3275 and 2100cm.$^{-1}$

b) α-Bromostyrene (2g.) in t-butanol was treated with a solution of potassium t-butoxide from potassium (0.8g.) in t-butanol (45ml.). A white precipitate was obtained, and the mixture was allowed to stand for one hour. The mixture was worked up by distilling off the t-butanol, addition of water, and ether extraction. The oil (1g.) obtained from the extract proved to be a mixture of phenylacetylene and unchanged α-bromostyrene, light absorption : ν 3275, 2100 and 883cm.$^{-1}$, n_D^{20} 1.5835 (lit. for phenylacetylene 1.5517[208]).

O-Diethynylbenzene

a) (XLVII) (20g.) in ether (50ml.) was added over five minutes to a suspension of sodamide from sodium (7.5g.), using ferric nitrate as catalyst, in liquid ammonia (250ml.).

The solution was stood overnight in a Dewar flask protected by cellophane, then ammonium chloride (20g.) added to decompose excess sodamide, and the residue added to water. An oil was obtained from the ether extract which, on distillation, gave o-diethynylbenzene (1g., 10%) b.p. 72-75°/5 mm., n_D^{20} 1.5890 (lit. 1.5915[174]), light absorption: ν 3275, and 2100cm.$^{-1}$. A bromine-containing polymeric brown solid formed during the reaction accounted for the remainder of the starting material. This solid was found to be insoluble in both aqueous and organic media.

b) (XXXVIII) (10g.) in hot t-butanol (50ml.) was added to a solution of potassium t-butoxide from potassium (3.5g.) in t-butanol (200ml.), affording the instantaneous formation of a copious white precipitate. On working up by distilling off most of the t-butanol, addition of water and ether extraction, an oil was obtained (5g.) n_D^{20} 1.6142 (lit. for (XXXIX) 1.5915[174]), light absorption : ν 3275, 2100, 1620, and 901cm.$^{-1}$. Further treatment of this incompletely dehydrobrominated product with an additional quantity of the butoxide reagent from potassium (2g.), employing a reflux period of two hours, and a similar working up of the product, afforded an oil n_D^{20} 1.5945 which gave on distillation a first fraction consisting of pure o-diethynylbenzene (1.6g.,54%) b.p. 65-70°/1.5 mm., n_D^{20} 1.5900, light absorption : absence of olefinic absorption. Later fractions afforded a yellow oil (0.5g.) b.p. 70-113°/1.5 mm., n_D^{20} 1.6129, light absorption : ν 1620 and 901cm.$^{-1}$, as well as ethynyl absorption. Repetition of this process employing benzene as a solvent for the potassium t-butoxide reagent has produced[191] yields of pure (XXXIX) in excess of 60%.

Preparation of (XXIII) - (XXXIX) (1.5g.) in ether: methanol (1:1, 150ml.) was added dropwise over five hours under high-dilution conditions to a refluxing solution of cupric acetate (7.5g.) in pyridine:methanol:ether (2:2:1, 500ml.). The solution was then refluxed for a further four hours, and filtered to remove a red cuprous derivative (0.58g.) The infrared spectrum of a sample showed no residual ethynyl absorption, and the solution was evaporated to low volume, acidified, and ether extracted. The neutral extract gave an oily solid. This solid was extracted with benzene, leaving a brown polymer, insoluble in all solvents. The dark-coloured benzene extract afforded a yellow solid on evaporation (0.72g., 48%), which was redissolved in benzene and passed through an alumina column. A bright yellow band was eluted rapidly, and a dark brown band remained at the top of the column, only eluted with methanol. On evaporation of the yellow solution, a lemon-yellow solid was obtained (0.47g., 31%) as fine needles, decomposition point 80°, (Found : C, 96.4; H, 3.85, M(x-ray data), 370, 373; $C_{30}H_{12}.\frac{1}{2}C_6H_6$ requires C, 96.35; H, 3.65%; M, 372.4), light absorption : ν 2215, and 2134cm.$^{-1}$, λmax. 220.5, 242.5, 251, 267, 283.5, 301.5 mμ (log.ε 4.98, 4.87, 4.86, 4.65, 5.14, 5.37 respectively). The compound exploded on heating or grinding, and turned black rapidly, obvious decomposition having taken place after four hours in absence of both air and light.

<u>X-Ray Determination of Molecular Weight</u> - X-ray analysis of a single crystal grown from benzene indicated[193] a unit cell having a = 28.3 Å, b = 3.88 Å, c = 11.53 Å, and β = 90°, giving a molecular volume of 1244 Å^3. X-ray powder photographs of crystals grown from benzene, ether and dioxane indicated that the unit cell was essentially the same in each case, measurement of the diameters of the prominent rings on each photograph affording the following data.

Nature of ring	Diameter of ring (in mm.)		
	Crystal ex Benzene	Ether	Dioxane
weak	40.95	-	-
weak	32.25	32.95	32.50
weak	29.00	29.00	28.80
strong	26.60	26.30	26.25
weak	21.00	21.20	21.00
strong	16.00	15.85	15.85
weak	13.40	13.85	13.50

Density determinations on each type of crystal were carried out by flotation of a crystal in an aqueous medium, and gave the following results, enabling calculation of the molecular weight on the assumption of two moles per unit cell.

	Density	Molecular Weight
Crystal from benzene	1.076 g./c.c.	403
ether	0.988	370
dioxane	0.995	373

$C_{30}H_{12}$ requires M, 372.4, and assuming one mole of benzene to be present in the unit cell, $C_{30}H_{12}.\frac{1}{2}C_6H_6$ requires M, 411.

<u>Detection of Benzene in the Crystal Structure</u> - (XXIII) (10.5mg.), crystallised from benzene, and thoroughly dried by pumping in vacuo for two hours at room temperature, was dissolved in dioxane (2ml.), and the solution transferred to a trap in a vacuum line. The solution was chilled in a liquid air bath, the bath removed, and the frozen dioxane solution was distilled over in vacuo to a second similarly cooled trap. Normal redistillation of the distillate afforded a colourless solution. This distillate (1.6ml.), estimated for benzene content by ultraviolet absorption in the range λ 245-265 mμ, contained not less than 0.9mg. of benzene; $C_{30}H_{12}.\frac{1}{2}C_6H_6$ requires 1.1mg. of benzene per 10.5mg. of crystalline material. The estimation gave the

following data :

λmax.	$\varepsilon^{1\%}_{1cm.}$
249 mμ	1.36
255	1.73
261	1.24

Hydrogenation of (XXIII) - O-Diethynylbenzene (1.7g.) was oxidatively coupled as previously described to give (XXIII), dissolved in benzene, and this solution was carefully evaporated to dryness and the solid redissolved in ethyl acetate and hydrogenated over Adams' platinic oxide catalyst (200mg.) for nine hours, taking up 470ml. of hydrogen (theoretical 510ml.). After chromatography on alumina an oil was obtained, which partially crystallised on scratching with a glass rod, and was recrystallised from ethanol:ether, giving colourless needles (20mg., 1%) m.p. 124-132°. On sublimation at 90° on to a cold finger, small feathery needles were obtained, m.p. 136-138°, (Found : C, 90.6; H, 8.4; M (Rast), 350; $C_{30}H_{36}$ requires C, 90.85; H, 9.15%; M, 396). Light absorption : absence of C-methyl absorption in the infrared, but a spectrum resembling that of tetralin; λmax. 266 and 273 mμ (ε 1260 and 1200), showing a strong correlation with the maxima of tetralin, which has λmax. 266.5 and 273.5 mμ (ε 600 and 600). Mass spectrographic determination of molecular weight gave no significant result, peaks at 306 and 420 atomic units being obtained. Lack of material prevented further analyses or investigations.

Complex Formation with Trinitrofluorenene - The method of forming the complex was that of Newman,[197] - admixture of hot, saturated solutions in acetic acid, and recrystallisation of the resulting complex from the same solvent.

Component	T.N.F. Ratio
Dodeca-5:7-diyne	no complex
Octa-3:5-diyne-1:8-diacetate (XXI)	no complex
Mercury derivative of Phenylacetylene (LII)	no complex
Acenaphthylene (Deep red needles m.p. 176-177°)	1:1
Diphenyldiacetylene (IV) (Orange-red needles m.p. 160-161° (Found : C, 60.5; H, 2.6; N, 10.3; $2C_{13}H_5N_3O_7.C_{16}H_{10}$ requires C, 60.6; H, 2.4; N, 10.1%)	2:1
Tolane (LI) (Red needles, m.p. 132-133° (Found : C, 64.5; H, 3.2; N, 8.7; $C_{13}H_5N_3O_7.C_{14}H_{10}$ requires C, 65.6; H, 3.1; N, 8.5%)	1:1

Component	T.N.F. Ratio
Tolane (LI)	2:1

(Red needles m.p. 122-125°. Attempted purification only shifted equilibrium to favour the more stable complex of T.N.F. ratio 1:1)

(XXIII)	1.5:1

(Red needles, decomposing at 160°, (Found : C, 70.5; H, 2.8; N, 7.7; $2C_{30}H_{12}.3C_{13}H_5N_3O_7$ requires C, 70.4; H, 2.4; N, 7.5%)

Hexanitrosobenzene, though reputedly a stronger complexing agent than T.N.F.; when used in accordance with the experimental details of Bailey[198] gave no complex with any of the acetylenic compounds detailed above, although it gave a definite complex with acenaphthylene.

PART II

ADDITION OF DINITROGEN TETROXIDE TO LONG-CHAIN UNSATURATED ACIDS

Fig.13

HISTORICAL SURVEY OF THE ADDITION OF DINITROGEN TETROXIDE TO C—C MULTIPLE BONDS

		Ref.	
pre-1945	Riebsomer	209	Comprehensive review
1946-49	Levy *et al.*	45-49	Addition under controlled conditions, ionic mechanism
1948	Vasil'ev and Vil'yams	56	Addition to petroselinic acid
1950	Vasil'ev and Vovchenko	57	Addition to ethyl cinnamate
1951-52	Porter and Wood	51-52	Addition to long-chain olefins
1953	Vasil'ev and Mikerin	53	Addition to diethyl maleate
1953	Weghofer	217	Addition scheme
1953	Campbell *et al.*	218	Suggested a partly free-radical explanation
1953	Schechter and Conrad	50	Free-radical scheme of addition
1955	Schlubach and Rott	223	Addition to acetylenes and diacetylenes
1955	Vasil'ev	54	Addition to erucic acid
1956	Brand and I.Stevens	222	Proof of the free-radical nature of the reaction
1957	Freeman and Emmons	224	Addition to acetylenes
1957	T.Stevens	225	Addition to camphene
1958	T.Stevens and Emmons	226	Further confirmation of the free-radical nature of the reaction

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HISTORICAL

The best known and most important reaction of dinitrogen tetroxide is that of addition to carbon-carbon multiple bonds, although much work has been reported[209] on the use of dinitrogen tetroxide for nitration and oxidation and other miscellaneous reactions. Dinitrogen tetroxide has been used for nitration of both aromatic and aliphatic compounds, resulting in the production of the corresponding nitro-derivatives. In reactions involving the use of dinitrogen tetroxide, oxidation is often a complicating factor, and the reagent has been used as an oxidising agent for paraffin hydrocarbons, oximes, and many other compounds. Oximes are oxidised by dinitrogen tetroxide to the corresponding dinitro-compounds in good yield.[210-211] Among the miscellaneous reactions are the conversion of the

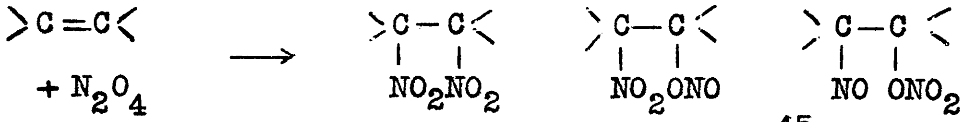
$$2RCOONa + 2N_2O_4 \longrightarrow (RCO_2)O + 2NaNO_3 + N_2O_3$$

alkali metal salts of organic acids in good yield to the corresponding anhydrides,[212] and the reaction with organometallic compounds to give in many instances,[213] good yields

$$ArMgBr + N_2O_4 \longrightarrow Ar\overset{+}{N}\equiv N.\overset{-}{NO}_3$$

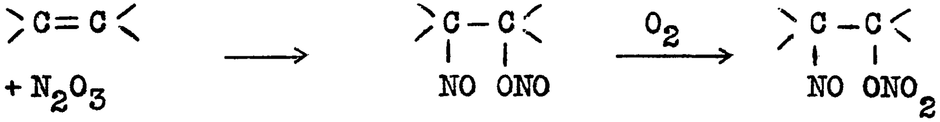
of the aromatic diazonium nitrates. Dinitrogen tetroxide has also been observed[214] to effect the isomerisation of a *cis*-olefin to a *trans*-.

The reaction of dinitrogen tetroxide with carbon-carbon double bonds was placed on a firm experimental basis by Levy *et al*.[45-49] Three modes of addition were reported prior to this work, though Riebsomer, in his review,[209] pointed out that much of the early work had been done with nitrous fumes (a mixture of dinitrogen trioxide and tetroxide in uncertain amounts).



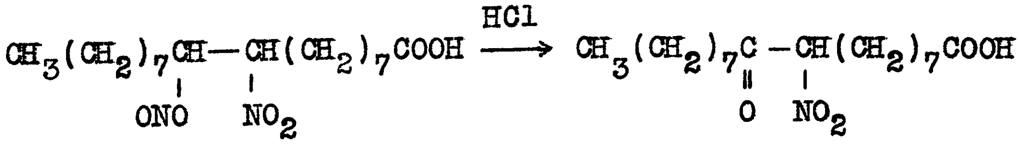
$$>C{=}C< \; + N_2O_4 \longrightarrow \underset{NO_2\;\;NO_2}{>C-C<} \qquad \underset{NO_2\;\;ONO}{>C-C<} \qquad \underset{NO\;\;ONO_2}{>C-C<}$$

Levy *et al*.[45] have shown that the product arising from the postulated third mode of addition is in fact formed by the addition of dinitrogen trioxide, followed by oxidisation of the nitrite grouping to the nitrate.

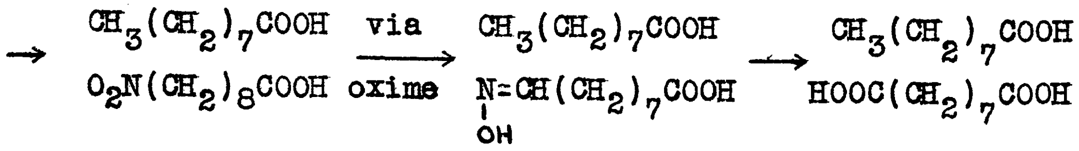


$$>C{=}C< \; + N_2O_3 \longrightarrow \underset{NO\;\;ONO}{>C-C<} \xrightarrow{O_2} \underset{NO\;\;ONO_2}{>C-C<}$$

An interesting application of the reaction has been the positioning of the double bond in oleic acid by treating the unstable adduct in a sealed tube with concentrated hydrochloric acid to give azelaic and pelargonic acids, after splitting at the position of the double bond.[215] The yields of the acids were not stated.



$$CH_3(CH_2)_7\underset{ONO}{CH}-\underset{NO_2}{CH}(CH_2)_7COOH \xrightarrow{HCl} CH_3(CH_2)_7\underset{O}{\overset{}{C}}-\underset{NO_2}{CH}(CH_2)_7COOH$$



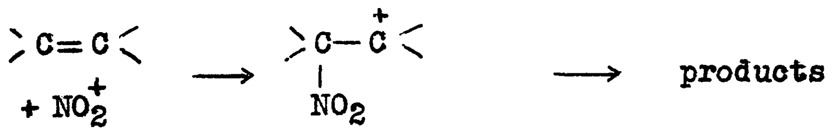
$$\rightarrow \begin{array}{l} CH_3(CH_2)_7COOH \\ O_2N(CH_2)_8COOH \end{array} \xrightarrow[\text{oxime}]{\text{via}} \begin{array}{l} CH_3(CH_2)_7COOH \\ \underset{\substack{| \\ OH}}{N}{=}CH(CH_2)_7COOH \end{array} \longrightarrow \begin{array}{l} CH_3(CH_2)_7COOH \\ HOOC(CH_2)_7COOH \end{array}$$

A similar scheme is given for the other isomeric nitro-nitrate.

With the work of Levy came the concept of controlled experimental conditions[45] to avoid competing oxidative side reactions, resulting in the production of unstable, tarry, polymeric products. Levy stressed[45] the necessity for pure dinitrogen tetroxide and pure peroxide-free olefins to obtain consistent results and stable products. It is probable that an interest in the chemistry of the nitronium ion stimulated Levy[45] (in conjunction with Ingold) to postulate an ionic mechanism for the reaction. They believed the first step to be heterolysis of the tetroxide,

1) $N_2O_4 \longrightarrow \overset{+}{NO_2} + NO_2^-$

2)

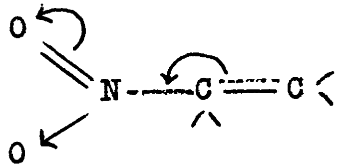


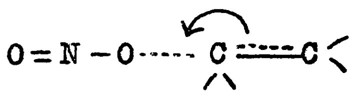
$$\begin{array}{c} >C{=}C< \\ +\ \overset{+}{NO_2} \end{array} \longrightarrow \begin{array}{c} >C{-}\overset{+}{C}< \\ | \\ NO_2 \end{array} \longrightarrow \text{products}$$

and subsequent attack by the nitronium ion. This hypothesis satisfactorily explained the observed initial attack on the carbon atom richer in hydrogen, and carbon-nitrogen rather than carbon-oxygen attachment. However, dinitrogen tetroxide has been shown[216] to ionise under heterolytic conditions to give a nitrosonium ion and a

$$N_2O_4 \longrightarrow NO^+ + NO_3^-$$

nitrate anion, and no products from these reactants have been isolated. Also dinitrogen tetroxide is known[216] from paramagnetic and spectral studies to homolyse readily to nitrogen dioxide radicals, and at 27°, about 20% of the tetroxide exists as the simpler form, while in ether solution at 5°, it is dissociated to the extent of ca. 1%. The colour changes on varying the temperature are related to the equilibrium between the two forms. Consequently a free-radical mechanism would seem a more logical explanation. The orientation observed can be explained by a free-radical mechanism, but carbon-nitrogen attachment must involve an explanation based on greater hyperconjugative resonance in the transition state





accompanying carbon-nitrogen bond formation, according to Schechter.[50]

The results of Porter and Wood[51-52] in the addition of dinitrogen tetroxide to olefins of higher molecular weight in general supported the results obtained by Levy. These authors reported roughly equal amounts of NO_2-NO_2 and NO_2-ONO addition, and noticed the increased difficulty in separation of the constituents with lack of water-solubility of the nitro-alcohol, due to chain length. They reported a lack of crystallinity in the higher molecular weight adducts, and made some investigation of their reactions, without achieving quantitative yields in any operation. They concluded[52] that the oxides of nitrogen were not suitable for the general characterisation and analysis of olefins. No mention was made of the mechanism of the reaction.

In 1953, Weghofer[217] claimed a 42% yield of crystalline nitrosate $MeCH(NO)-C(ONO_2)Me_2$ on addition of dinitrogen tetroxide at -60° in the absence of solvent, to 2-methylpent-2-ene. The remainder he identified as the nitro-alcohol. He gave a general scheme of addition :

$\nearrow$ NO_2-NO_2 (if a symmetrical olefin)

olefin + N_2O_4 $\longrightarrow$ NO_2-NO_2 and $NO-ONO_2$ (unsymmetrical olefin, addition in presence of solvent)

$\searrow$ NO_2-ONO and $NO-ONO_2$ (unsymmetrical olefin, addition without solvent)

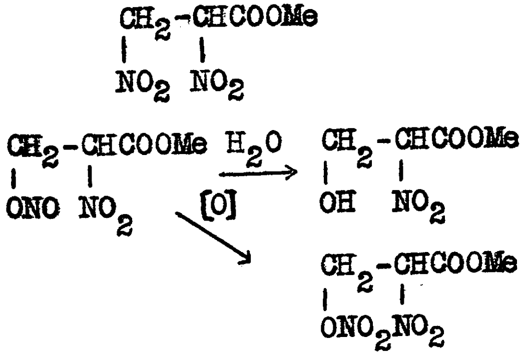
Addition to heptene was claimed[217] to produce a nitro-alcohol and a nitroso-alcohol $RCH(OH)-CH(NO)R$ in the form of the oxime. In the light of the earlier work, and of later additions of dinitrogen tetroxide under controlled conditions, these results seem scarcely credible, and the purity of the dinitrogen tetroxide used must be questioned. Weghofer also made an investigation of the reactions of the nitro-alcohols.

Mechanistic Investigations

The first doubts as to the ionic nature of the reaction were expressed by Campbell *et al.*[218] On re-investigation of the work of Schmidt[219] and Wieland,[220] on the addition of dinitrogen tetroxide to tolane, they were unable to explain the formation of substantial amounts of *cis*-1:2-dinitrostilbene by an ionic mechanism, and concluded that addition to the unsaturated centre might proceed, at least in part, by a free-radical mechanism. The work of Schechter and Conrad[50] provided concrete evidence for such a mechanism, in that only a homolytic process could explain the addition products of dinitrogen tetroxide to methyl acrylate.

Expected Products

(by ionic addition)



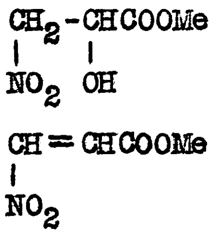
$$\begin{array}{ll} CH_2 & -CHCOOMe \\ | & \ \ | \\ NO_2 & \ NO_2 \end{array}$$

$$\begin{array}{ll} CH_2 & -CHCOOMe \\ | & \ \ | \\ ONO & NO_2 \end{array} \xrightarrow{H_2O} \begin{array}{ll} CH_2 & -CHCOOMe \\ | & \ \ | \\ OH & NO_2 \end{array}$$

$$\xrightarrow{[O]} \begin{array}{ll} CH_2 & -CHCOOMe \\ | & \ \ | \\ ONO_2 & NO_2 \end{array}$$

Actual Products

(Schechter 1953)



$$\begin{array}{ll} CH_2 & -CHCOOMe \\ | & \ \ | \\ NO_2 & OH \end{array}$$

$$\begin{array}{l} CH{=}CHCOOMe \\ | \\ NO_2 \end{array}$$

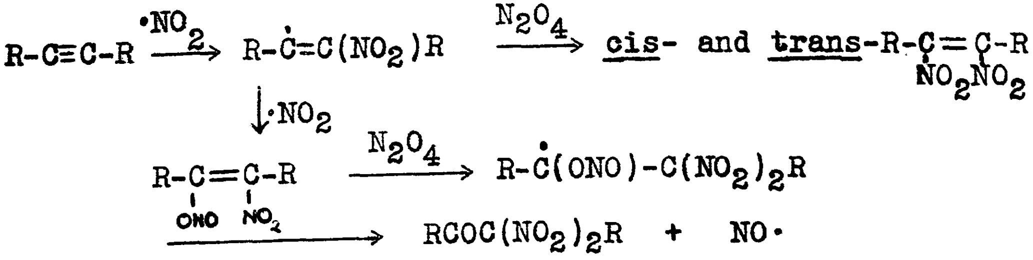
$(COOH)_2 2H_2O$

polymeric products

The above reversal of the expected orientation in addition rendered the ionic mechanism unlikely, and a free-radical addition process was postulated on the basis of the nature of the reaction medium, the similarity of the reaction to the addition of nitryl chloride to acrylic systems,[221] and the extensive polymerisation during the reaction. The homolytic process was assumed to involve initial attack by nitrogen dioxide at the terminal position, with exclusive carbon-nitrogen attachment, employing the previously stated explanation based on greater hyperconjugative resonance in such attachment.

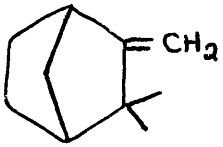
Confirmation of the radical nature of the reaction was provided by the work of Brand and I.Stevens,[222] using bromotrichloromethane as a transfer agent to divert the course of the reaction of dinitrogen tetroxide with *cyclo*-hexene. The observed complete suppression of the "normal" adducts indicated that the heterolytic process, if operating at all, was of minor importance, the main products being 1-bromo-2-nitro*cyclo*hexane, 1-bromo-2-chloro*cyclo*hexane, and 2-chloro*cyclo*hexanol. The existing evidence relating to the stereochemistry of free-radical additions to double bonds has also been summarised by these authors. Disubstituted double bonds appear to undergo a thermodynamically controlled non-stereospecific reaction, where the intermediate radical has the opportunity to reach conformational equilibrium. As a consequence, addition to <u>cis</u> and <u>trans</u> isomers produces a product whose composition is the same from the <u>cis</u> as from the <u>trans</u> isomer. Trisubstituted double bonds undergo a stereospecific addition arising from kinetic control, in that steric factors may raise the energy of one of the conformations of the inverting radical so that its lifetime is short in comparison with that of the other.

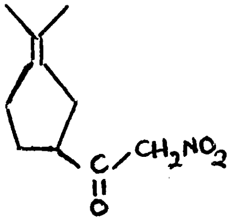
The addition of dinitrogen tetroxide to acetylenic compounds appears to have gained interest recently with the work of Schlubach and Rott,[223] and of Freeman and Emmons.[224] The former have added dinitrogen tetroxide to propyne, but-2-yne, buta-1:3-diyne, and diphenyldiacetylene, the latter affording a 34% yield of the crystalline 1:4-dinitro-1:4-diphenylbuta-1:2:3-triene, assigned the <u>cis</u> configuration. Freeman and Emmons have carried out additions to but-2-yne, hex-2-yne and hex-3-yne, and have established the configurations of the products from infrared evidence. They propose a free-radical mechanism as the most reasonable explanation for the formation of the products isolated. The continued reaction is believed to explain the



$$\begin{tikzcd}[column sep=small] R\text{-}C\equiv C\text{-}R \arrow[r, "\cdot NO_2"] & R\text{-}\dot{C}{=}C(NO_2)R \arrow[r, "N_2O_4"] \arrow[d, "\cdot NO_2"] & \underline{cis}\text{- and }\underline{trans}\text{-}R\text{-}\underset{NO_2}{C}{=}\underset{NO_2}{C}\text{-}R \\ & R\text{-}\underset{ONO}{C}{=}\underset{NO_2}{C}\text{-}R \arrow[r, "N_2O_4"] \arrow[dr] & R\text{-}\dot{C}(ONO)\text{-}C(NO_2)_2R \\ & & RCOC(NO_2)_2R \;+\; NO\cdot \end{tikzcd}$$

appearance of the α:α-dinitroketomes. T.Stevens has studied[225] the effect of oxygen on the reaction of dinitrogen tetroxide with camphene. Dinitrogen tetroxide adds to camphene under nitrogen in the usual manner, forming the expected products, the nitro-alcohol, nitro-nitrate, nitro-olefin and the dinitro-compound. In oxygen, however, the reaction took a different course, the products formed being the nitro-nitrate (5%), nitro-alcohol and dinitro-compound (10%), and an α-nitroketone (22%). About 30% of the adduct consisted of nitro-acids of undetermined constitution. The intermediate formation of an α-nitroperoxy radical or an α-nitroperoxynitrate is postulated to explain the effect of oxygen on the course of the reaction.





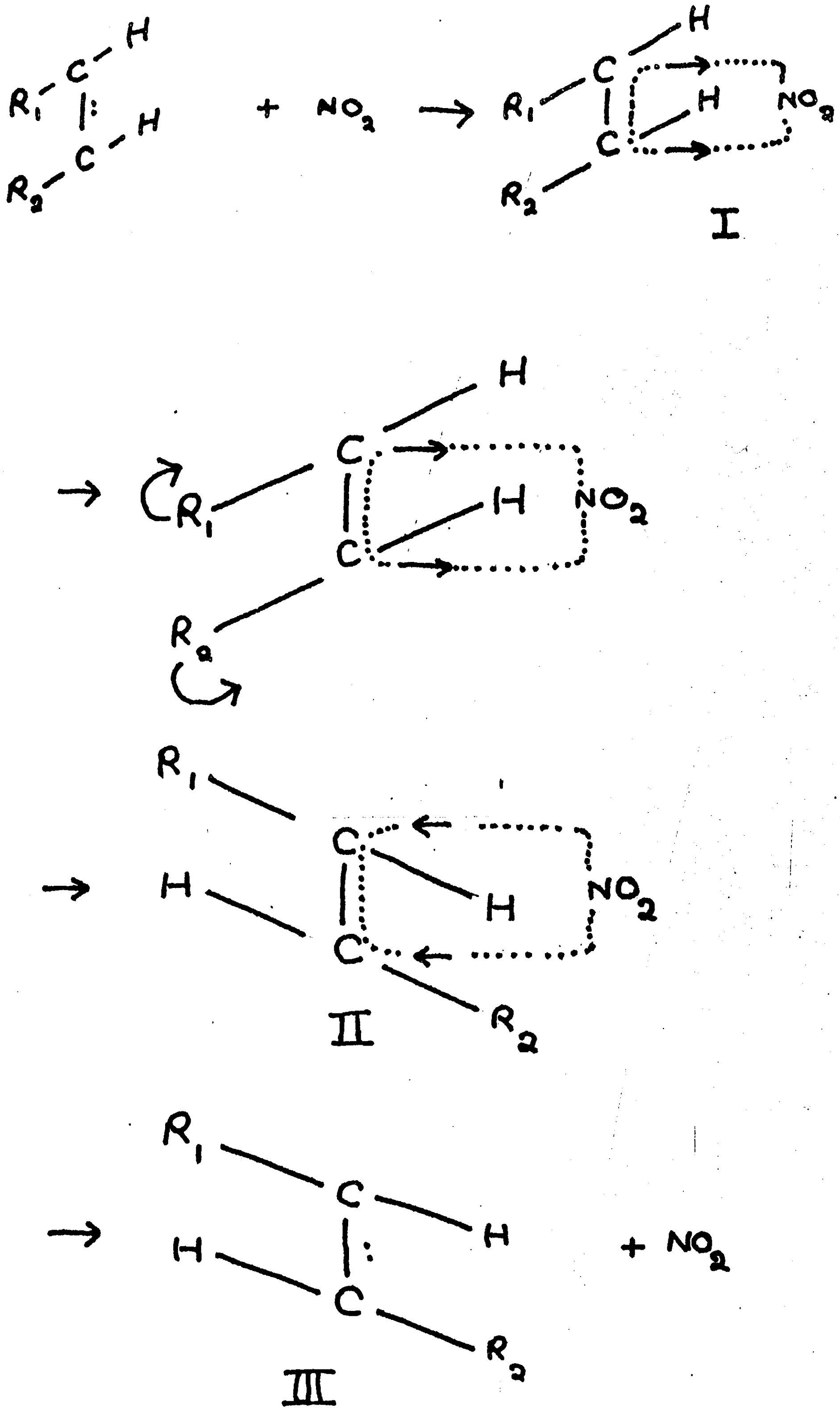
Finally the same author has elegantly demonstrated[226] the radical nature of the dinitrogen tetroxide-olefin reaction in ether solution by obtaining β-nitroalkyl iodides in high yield in the presence of iodine. Also β-iodonitroethylenes were produced from acetylenes, i.e., the intermediate nitroalkyl radical was trapped by iodine before further reaction could take place.

Vasil'ev et al. have carried out additions of dinitrogen tetroxide to ethyl cinnamate,[57] diethyl maleate,[53] erucic,[54] undecylenic,[55] and petroselinic[56] acids. The structures advanced for the addition products appeared unsatisfactory, and addition of dinitrogen tetroxide to the last three olefins has been re-investigated in the course of this present work.

Cis-Trans Isomerisation

It is not surprising that the isomerisation of unsaturated fatty acids by oxides of nitrogen[227] led to the formation of considerable quantities of nitrogen-containing products. Griffiths and Hilditch used[227] oxides of nitrogen as isomerising agents for oleic, erucic, and petroselinic acids, and compared the results with the isomerising effect of heat treatment with sulphur. They concluded that the equilibrium in the isomerisation lay at about 66% conversion to the trans isomer, (and somewhat less for petroselinic and erucic acids). The conditions favoured were the use of minimal amounts of oxides of nitrogen approximating in composition to N_2O_3, at temperatures of 10-20°. Higher temperatures, or excesses of reagent, led to larger amounts of addition products. In comparison, sulphur (1%) at 200° effected a 55-60% conversion, with about 2-3% of addition products formed. Khan[228] has

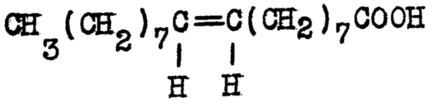
Fig.14


R₁
R₂
H
H
C
C
+ NO₂
NO₂
I
II
III
+ NO₂

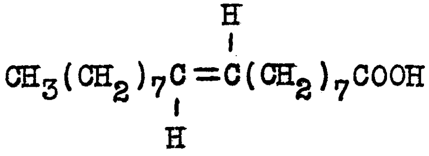
subsequently shown, by studying the effects of the pure oxides of nitrogen, that NO_2 is the active agent in the isomerisation, and has postulated a mechanism for the interconversion. The NO_2 molecule is thought to polarise the double bond, drawing the πelectrons towards itself to form a molecular complex (I) as illustrated (see fig,14). The molecule may now rotate freely about the activated carbon-carbon bond until a position of stablity (II) is reached. The stable molecule will then tend to withdraw its πelectrons and revert to the more stable trans-form (III), liberating NO_2. The measure of the successful achievement of this last step determines the extent of isomerisation. The failure to regain the πelectrons gives rise to the nitrogen-containing addition products.

DISCUSSION

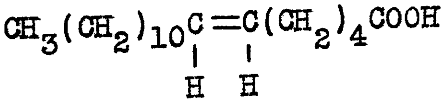
The addition of dinitrogen tetroxide to olefinic systems is worthy of study on several counts. There is interest in the mechanism of the reaction, with possible accompanying stereochemical control. The products are also of interest, as the α-dinitro-paraffins and α-nitro-alcohols are not otherwise easily accessible. In additions to unsaturated fatty acids the reagents could be made readily available, and the reaction might also be of commercial interest, offering a possibly convenient synthesis of amino acids and related compounds, or a method of breaking down the chain to yield short-chain difunctional compounds. On these counts, and because the work of Vasil'ev _et al._ on the addition to various unsaturated acids[54-56] and esters[53, 57] was not considered particularly satisfactory, an investigation of the addition of dinitrogen tetroxide to oleic and elaidic, petroselinic and petroselidinic, erucic and brassidic, and undecylenic acids was made.


$\mathrm{CH_3(CH_2)_7\underset{H}{C}{=}\underset{H}{C}(CH_2)_7COOH}$

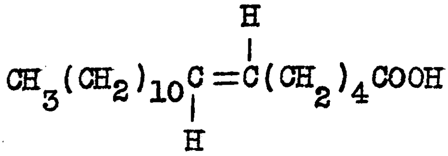
oleic acid


$\mathrm{CH_3(CH_2)_7\underset{H}{C}{=}\overset{H}{C}(CH_2)_7COOH}$

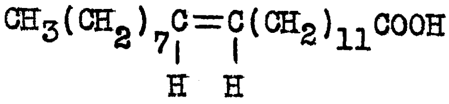
elaidic acid


$\mathrm{CH_3(CH_2)_{10}\underset{H}{C}{=}\underset{H}{C}(CH_2)_4COOH}$

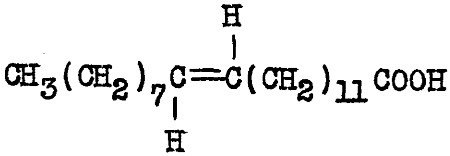
petroselinic acid


$\mathrm{CH_3(CH_2)_{10}\underset{H}{C}{=}\overset{H}{C}(CH_2)_4COOH}$

petroselidinic acid


$CH_3(CH_2)_7\underset{H}{C}=\underset{H}{C}(CH_2)_{11}COOH$

erucic acid


$CH_3(CH_2)_7\underset{H}{C}=\overset{H}{C}(CH_2)_{11}COOH$

brassidic acid

$H_2C=CH(CH_2)_8COOH$

undecylenic acid

The radical nature of the reaction appears fairly well established[50,222,226], but several reported findings cannot be explained on this basis, in particular, the findings of Weghofer[217] (described earlier) and of Vasil'ev *et al.*[53-57] The addition scheme of Weghofer is difficult to comprehend, and his claimed formation of a nitrosate is not met in any of Levy's exhaustive researches. The purity of the dinitrogen tetroxide of Weghofer must remain suspect. The work which concerned us most was the work of Vasil'ev *et al.* on the addition of dinitrogen tetroxide to the unsaturated fatty acids, petroselinic, erucic and undecylenic. The products resulting from these additions are summarised in table IV.

Table IV

1) Addition of N_2O_4 to petroselinic acid

Product	Yield	Properties	Structure
solid	17%	m.p. 121-122°	On reduction afforded diaminostearic acid
solid	17%	m.p. 92-94°	A nitrosate, on reduction affording a mixture of mono- and diaminostearic acids
oil	remainder	n_D^{20} 1.69	Treatment with alkali afforded the nitrous ester of hydroxy-

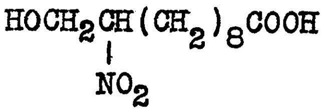
-nitrostearic acid
($C_{18}H_{34}N_2O_6$)

2) Addition of N_2O_4 to Erucic Acid.

Product	Properties	Structure
solid	m.p. 123°	$RCH(NO_2)CH(OH)R'$
solid	m.p. 136°	$RCH(OH)CH(NO_2)R'$

(Yields of pure compounds, and nature of remainder, not given.)

3) Addition of N_2O_4 to Undecylenic Acid

Product	Properties	Structure
solid	m.p. 121°	Nitroalcohol  $HOCH_2\underset{NO_2}{\underset{\vert}{CH}}(CH_2)_8COOH$

The only product identified (yield not stated). Oily adduct on heating affords sebacic acid.

In the work which follows, dinitrogen tetroxide has been prepared and added under standardised conditions to pure methyl oleate, to oleic, petroselinic and erucic acid and their trans isomers, and to undecylenic acid. In all experiments, pure dinitrogen tetroxide, redistilled in a current of oxygen over phosphorus pentoxide, was used.

Addition to Oleic Acid and its Methyl Ester.

Several additions were made to the above olefins under varying conditions, including reversal of the order of addition, and these are listed in table V. In the additions to oleic acid, the reaction mixture afforded no solid precipitate, and the resulting oil, after hydrolysis with dioxane:water, did not solidify.

Table V

Summary of Additions

Olefin	Carrier Gas	Temp.	Time (hours)	Solvent	Quantity of N_2O_4
1) oleic acid	oxygen	-10°	2½	ether	excess
2) oleic acid	nitrogen	0°	1½	ether	theory
3) oleic acid	nitrogen	10°	2½	cyclohexane	theory
4) methyl oleate	oxygen	-10°	2	ether	excess
5) methyl oleate	nitrogen	0°	2	ether	theory
6) methyl oleate	nitrogen	10°	1	carbon disulphide	excess
7) methyl oleate	air	0°	1½	carbon disulphide	excess olefin

The infrared spectra of these adducts were complicated by the presence of hydroxyl and acidic absorption, the adducts were therefore esterified with diazomethane in order to facilitate the interpretation of the spectra. Since no solid adducts were obtained on addition of dinitrogen tetroxide to oleic acid, subsequent runs were made using methyl oleate, avoiding the necessity for treatment with diazomethane. In these instances, the addition was found to be virtually complete, and some conclusions as to the course of the reaction may be drawn from the table of optical density data obtained from the spectra of the adducts (see table VI).

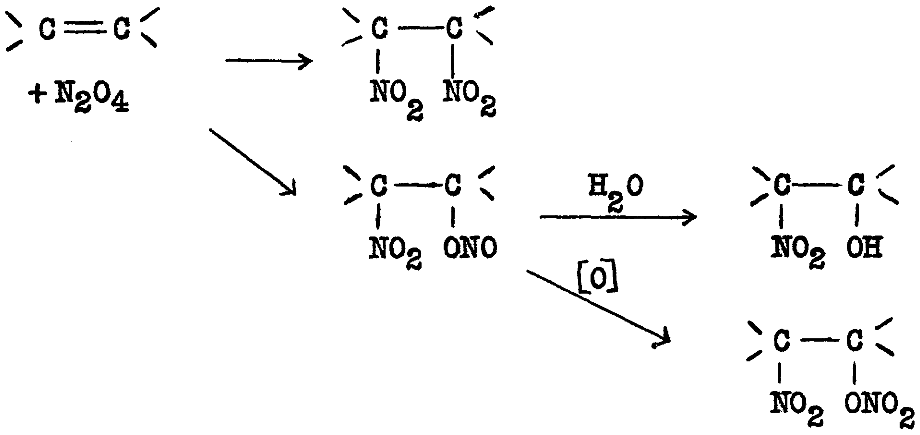
Table VI

Optical Density Results

(measured with liquid film, with C=O set at *ca.* 90% transmission; results expressed as O.D. : O.D. C=O)

	-OH 3400cm.$^{-1}$	-NO_2 1557cm.$^{-1}$	-ONO_2 1640cm.$^{-1}$	=C-NO_2 1520cm.$^{-1}$	-C=O 1740cm.$^{-1}$
1) oleic acid oxygen ether	0.23	1.00	0.66	-	1.00
2) oleic acid nitrogen ether	0.14	1.10	0.30	0.20	1.00
3) oleic acid cyclohexane nitrogen	0.14	1.10	0.40	0.16	1.00
4) methyl oleate oxygen ether	0.17	1.00	0.67	0.30	1.00
5) methyl oleate nitrogen ether	0.15	1.10	0.13	0.22	1.00
6) methyl oleate nitrogen CS_2	0.22	1.10	0.13	0.26	1.00
7) methyl oleate air CS_2 (reversal of addition)	0.24	0.78	0.23	0.48	1.00

No evidence of absorption attributable to a nitroso group was found. In run 6, using carbon disulphide as solvent, samples were withdrawn at intervals during the addition for infrared inspection. The gradual appearance of a band at 1670cm.$^{-1}$, as well as at 1557cm.$^{-1}$, was observed, indicating addition as -ONO and as $-NO_2$. No $-ONO_2$ absorption at 1640cm.$^{-1}$ was observed in the spectrum until late in the reaction. This supports the accepted[45] scheme of reaction, illustrated below. In the additions to oleic acid, it can be seen that the use of nitrogen as a carrier gas moderates the amount of nitrate formed, as might be expected, although it is questionable if the decrease in hydroxyl content is significant. The nitro-olefin is thought to result from elimination of the elements of nitrous acid from either of the two primary adducts. Levy[49] has accomplished the conversion of a *cyclo*hexene: dinitrogen tetroxide adduct to 1-nitro*cyclo*hexene in almost



quantitative yield by the action of dry ammonia, and we have found that on chromatography of the hydrolysed adduct on alumina, appreciable quantities of nitro-olefin are produced, apparently from the dinitro-adduct, as the intensity of the hydroxyl and nitrate absorptions in the infrared appears unchanged.

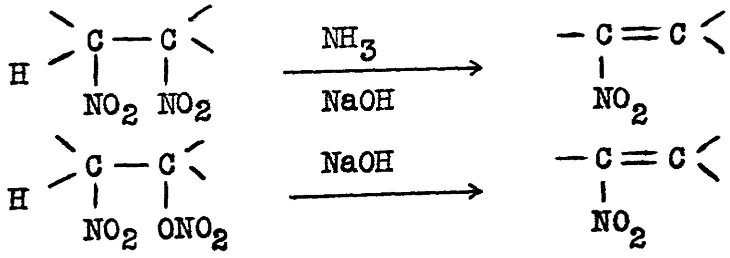
The methyl oleate adducts display a gradual diminution in nitrate content as the carrier gas is changed from oxygen to air and finally to nitrogen. It might be noted that in this case the diminution is more marked than the corresponding decrease in nitrate content shown by the acid adducts. Few conclusions could be drawn with regard to the effect of reversal of addition, as the excessive nitro-olefin content found in the product invalidates the rest of the data.

Attempted Separation of the Adducts into their Respective Components

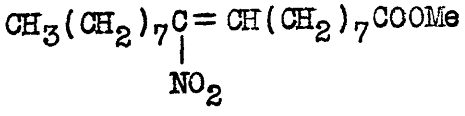
The use of alumina as the solid phase in chromatographic treatment of the esterified adducts did not yield reproducible results, but the use of silica[222] proved to be satisfactory. On elution with petrol:benzene:chloroform the mixtures were easily separated into two fractions of approximately equal size. The first appeared to be composed of any unreacted olefin, along with the dinitro-, nitro-nitrate and nitro-olefin adducts. The second was the pure nitro-alcohol, or mixture of nitro-alcohols, unless any acidic material was eluted at this point. Further attempted separation of the first fraction failed to isolate any one of the three adducts, although unreacted olefin could be removed. The nitro-alcohol fraction might be expected to contain four isomers, and was obtained as a yellow oil, in which no crystallisation could be induced, and distillation of which appeared impracticable.

Reactions of the Components

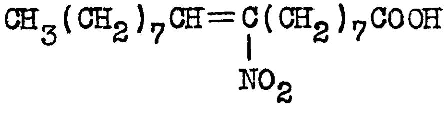
The contents of the first chromatographic fraction might be expected to be readily converted to the nitro-olefin by the action of base. Levy[49] has described the action of dry ammonia and of sodium hydroxide in eliminating the elements of nitrous acid, or nitric acid in the case of a nitro-nitrate adduct, to give nitro-olefins.



All attempts to accomplish this reaction with the nitro-adducts of the fatty acid and its methyl ester proved unsatisfactory. Infrared evidence indicated that the reaction is accompanied by side reactions such as the oxidative splitting of the nitro-olefin upon formation. The reaction also appeared sluggish, the $-NO_2$ absorption at 1557cm.$^{-1}$ was never completely removed from the spectrum. Several attempts to prepare the nitro-olefin (presumably as a mixture of two isomers) by treating the unhydrolysed adduct with dry ammonia were also made, as described by Levy[49] for cyclohexene. In all cases, the nitro-olefin was formed in appreciable amounts, but was accompanied by large quantities of nitro-alcohol, indicating that hydrolysis was taking place before the ammonia could effect the removal of the elements of nitrous acid. No satisfactory explanation of the presence of water is to hand. The reaction did afford a source of nitro-olefin in a reasonable state of purity, as on chromatographic treatment on silica, the nitro-olefin, along with small amounts of dinitro-adduct, was obtained as an oil. The two isomers might be expected to be formed in about equal amounts, as a result of a non-stereospecific addition. Reduction of the mixture



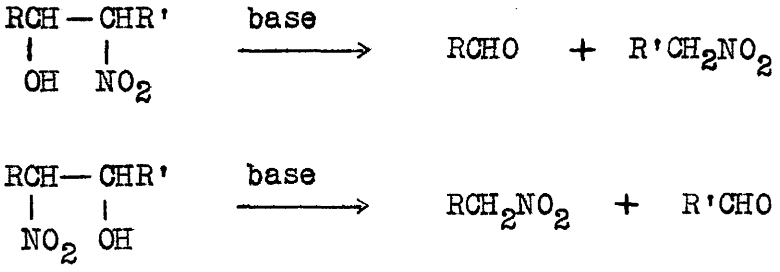
$CH_3(CH_2)_7\underset{\displaystyle NO_2}{\underset{|}{C}}=CH(CH_2)_7COOMe$



$CH_3(CH_2)_7CH=\underset{\displaystyle NO_2}{\underset{|}{C}}(CH_2)_7COOH$

with lithium aluminium hydride afforded an oil which appeared to be free of nitrogen, light absorption showing only a hydroxyl grouping. On benzoylation, light absorption of the resulting oil showed only ester absorption (-OCOPh). Lithium aluminium hydride has been known[229,230] to effect hydrogenolysis. The nitro-olefin proved unaffected by attempted reduction with Raney nickel.

The nitro-alcohol mixture of isomers was treated with aqueous alkali and the product separated into a neutral and an acidic fraction. The two positional isomers thought to be present might be expected to give a nitroparaffin, $CH_3(CH_2)_8NO_2$, and a nitro-acid, along with an aldehyde and an acid aldehyde, both of which would be likely to have been converted to the corresponding acid under the conditions.



$$\underset{OH}{RCH}-\underset{NO_2}{CHR'} \xrightarrow{base} RCHO + R'CH_2NO_2$$

$$\underset{NO_2}{RCH}-\underset{OH}{CHR'} \xrightarrow{base} RCH_2NO_2 + R'CHO$$

$$R = CH_3(CH_2)_7- , \quad R' = HOOC(CH_2)_7-$$

Only oily products were obtained, and from infrared evidence the major nitro- content was in the neutral fraction. This might indicate predominating nitrogen attachment to C_{10}, but the presence of unreacted material invalidates this conclusion.

Attempts to prepare the nitro-olefin from the mixture of nitro-alcohols by acetylation, followed by treatment with potassium carbonate, were unsuccessful, the oils obtained containing little nitro-olefin.

General Procedure for Analysis of Adducts

a) Separation Methods

b) Estimation Procedures not relying on Separation.

Separation Methods

Vapour Phase Chromatography - This technique is of little application except in the case of very low molecular weight, because of the high temperatures at which the column would have to operate. The adducts would also be unstable at those temperatures.

Chromatography - Reproducible results are obtainable on silica, eluting with petrol:benzene:chloroform:methanol in that order. The nitro-olefin, nitro-nitrate and dinitro-adducts are eluted with petrol as one fraction, the nitro-alcohol may be eluted with benzene:chloroform.

Crystallisation - In certain cases, by choosing reaction conditions so that part of the adduct separates as a precipitate during the addition, the dinitro-acid (one or both isomers) may be obtained in a pure condition.

For separation of the mixture of nitro-olefin, nitro-nitrate and dinitro-compound, it appears that counter-current chromatography or comparable high-resolution techniques would be necessary.

Estimation Procedures not relying on Separation

Titration -The determination of equivalent weight is of little application if there is more than one product, as the more products formed, the more difficult it is to interpret the value obtained.

Infrared Absorption - The liquid film spectra of the hydrolysed adducts shows the presence of nitro-alcohol, nitro-nitrate, nitro-olefin and, depending on the proportions of the components present, the dinitro-compound, by the following detailed absorptions.

Grouping	ν (cm.$^{-1}$)	ε
$-OH$	ca. 3400	medium
$-C\ O$	1740	very strong
$-NO_2$	1555	very strong
$-ONO_2$	1640	very strong
$=C-NO_2$	1520	very strong

Only a rough qualitative estimation of the nitro-nitrate content can as yet be made, as the data available are not sufficient for its quantitative estimation.

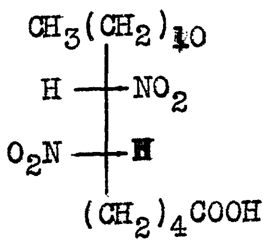
Ultraviolet Absorption - If the presence of nitro-olefin is indicated from the infrared spectrum, the intensity at λmax. ca. 245 mμ can provide a measure of the nitro-olefin content, (λmax. $C=C-NO_2$ ca. 240 mμ (ε ca. 5000).[133]

Nitrogen Analysis - An estimate of the total nitrogen content may be used in conjunction with infrared evidence to provide an estimate of the nitro-alcohol content, providing that the nitro-nitrate and nitro-olefin are not present to an appreciable degree.

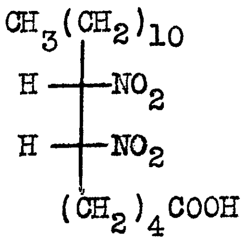
Iodine Number - The unreacted olefin in the adduct may be determined from this value. In conjunction with the estimate of *trans* olefin from the absorption at 965cm.$^{-1}$, it can be used to obtain an estimate of the relative proportions of *cis* and *trans* olefin remaining in the adduct.

Addition to Petroselinic Acid

The addition of dinitrogen tetroxide to petroselinic acid afforded two solid products, each in 12% yield, with melting points similar to those previously reported[56] (see table IV). The higher-melting solid was assigned the structure of a dinitro-acid on the basis of analytical and light absorption measurements. The lower-melting solid exhibited identical analytical and light absorption data, and thus the two solids are postulated as the *threo* and *erythro* forms of the dinitro-acid, and the higher-melting compound is tentatively assigned the *threo* configuration on the basis[231] of its higher melting point and lower solubility



threo form m.p. 127°

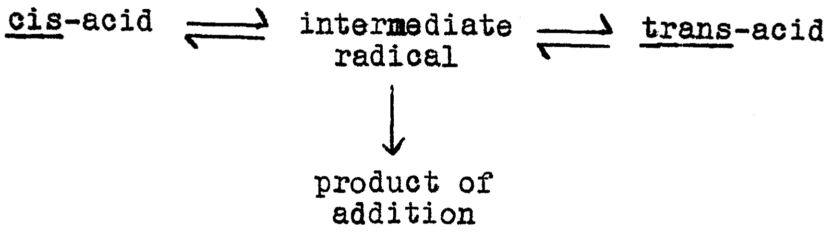


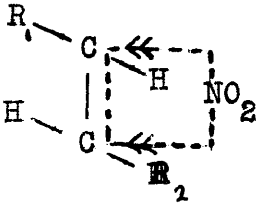
erythro form m.p. 92°

in ethanol. There is nothing in the properties of the lower-melting compound to suggest the nitrosate structure assigned by Vasil'ev et al.[56], and a nitrosate would be unable to yield a diaminostearic acid on reduction, as reported. The residual oil had n_D^{20} 1.465 (reported 1.69[56]) and from infrared absorption evidence consisted of a mixture of nitro-alcohol and nitro-nitrate. The postulation[56] of a nitrous ester of hydroxynitrostearic acid [presumably $RCH(ONO)-CH(NO_2)R'$] after treatment with alkali is difficult to comprehend. Addition of dinitrogen tetroxide to petroselinic acid under the standard conditions, as compared with that using the conditions of Vasil'ev, showed some differences, notably the reduction in the formation of nitro-nitrate, and the crystallisation of the residual oil to yield petroselidinic acid, the trans isomer.

Addition to Erucic Acid

Addition of dinitrogen tetroxide to erucic acid under the standard conditions afforded some dinitro- adduct, and much brassidic acid, the trans isomer, precipitated from the reaction solution in petrol. The oily remainder also deposited brassidic acid. There appear to be appreciable differences in the rate of addition of dinitrogen tetroxide to the three acids. Oleic acid adds dinitrogen tetroxide almost quantitatively under the given conditions, petroselinic acid affords both addition and isomerisation, while isomerisation appears to predominate in attempted addition to erucic acid. Thus the reverse reactions illustrated below appear to be more important in the case of addition to erucic acid than to oleic acid. Using the explanation of Khan[228], the stable conformation of the erucic acid:nitrogen dioxide intermediate is more effective in regaining its π electrons than is the similar complex with oleic acid.





Addition to the Trans Acids

As a consequence of the above results, the addition of dinitrogen tetroxide to the trans isomers of the three fatty acids was undertaken, in order to avoid confusion due to the competing isomerisation reaction. Addition of dinitrogen tetroxide to the three pure trans acids was performed under the standard conditions, allowing long reaction times, especially in the case of brassidic acid,

Table VII - Summary of Additions
(crude yields, based on starting olefin)

Compound	Petroselinic	Elaidic	Brassidic
Dinitro-adduct	12% solid m.p. 127°	14% solid m.p. 90°	13% solid m.p. 91°
(2 isomers possible)	12% solid m.p. 92°	*ca.* 14% oil	*ca.* 13% oil
Nitro-nitrate	15-20% oil	15-20% oil	10-15% oil
(4 isomers possible)			
Nitro-alcohol	45-50% oil ,	45-50% oil	50-55% oil
(4 isomers possible)			
Total	*ca.* 90%	*ca.* 90%	*ca.* 90%

Elaidic acid afforded a crystalline solid, identified by light absorption and analytical data as a dinitrostearic acid. It appeared to be a single isomer. Chromatography on silica of the esterified remainder afforded two major fractions. The light absorption of the first fraction showed the presence of the other dinitro-acid isomer, as well as nitro-nitrate and nitro-olefin, from the relative intensities of the peaks. The solid dinitro-adduct was assigned the *threo* structure, as the isomer present in the oil is presumably lower-melting. The second fraction was a mixture of nitro-alcohol isomers which could not be induced to crystallise.

Petroselidinic acid afforded the same products as did the *cis* isomer, and full addition was achieved. The dinitro-acids from all additions, whether to *cis* or to the *trans* form, were isolated in approximately equal proportions, this non-stereospecificity supporting the alleged free-radical nature of the addition.

Brassidic acid afforded a crystalline precipitate, identified by light absorption and analytical data as a dinitroerucic acid. It is likewise assigned the *threo* configuration as the second isomer could not be crystallised from the reaction mixture. The presence of the other isomer was established as for elaidic acid.

The yields quoted in table VII for the solid dinitro-acids and the nitro-alcohols are based on weights. The additions to elaidic and brassidic acids are also assumed to proceed in a non—stereospecific manner, and the yields of the second dinitro- isomers are assumed to equal those found for the solid isomers. This enables an estimate of the nitro-nitrate yield to be obtained from a difference in weight, an estimate which can be compared with that estimated from the infrared absorption of the band. Nitro-olefin is usually found to appear after chromatographic treatment, and is assumed to be formed from the dinitro- adduct. The reaction appears to produce 25-30% addition as $-NO_2,-NO_2$, and 60-70% as $-NO_2,-ONO$. Levy reported[49] 30% of dinitro- and 54% nitro-alcohol in the addition of dinitrogen tetroxide to cyclohexene.

The dinitro adduct of erucic acid formed a solid methyl ester m.p. 43-44°, while the methyl ester of the higher-melting dinitro- adduct of petroselinic acid had m.p. 47-48°. The lower-melting dinitro- adduct of petroselinic acid formed a liquid methyl ester which on attempted distillation under high vacuum decomposed to give an oil identified by analytical and light absorption data as a pure nitro-olefin. The distillate was slightly yellow, and decomposition accompanied the distillation. Attempts to convert the solid dinitro- adducts, and the nitro-nitrate of the methyl ester of petroselinic acid, to the nitro-olefin by the action of base, resulted in incomplete reaction, the formation of nitro-olefin being accompanied by splitting, and by much of the starting material remaining unaffected.

Addition of Dinitrogen Tetroxide to Undecylenic Acid

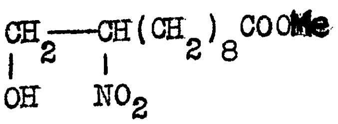
The addition to pure undecylenic acid produced oily material, which could not be induced to crystallise by itself or in a solvent at low temperatures. On chromatography of the esterified adduct, early fractions containing the expected mixture of dinitro-, nitro-nitrate, and some nitro-olefin were obtained, and later fractions crystallised to give the nitro-alcohol m.p. 55-56°. After recovery of acidic material from the column, the yields of the various adducts could be summarised as follows :

Compound	%		Mode of Addition
Dinitro-	20-25%		$-NO_2$, $-NO_2$
Nitro-nitrate	10-15%	65-70%	$-NO_2$, $-ONO$
Nitro-alcohol	55%		

The yield of nitro-nitrate was estimated from the infrared absorption spectrum, and the nitro-olefin present was assumed to have been formed from the dinitro- adduct on chromatographic treatment.

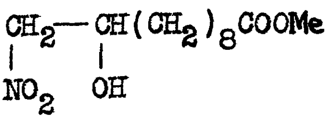
Reactions of the Nitro-alcohol

The nitro-alcohol ester was identified by infrared absorption and analytical measurements. The reactions of this compound were studied in view of the somewhat surprising postulate of nitrogen attachment to the penultimate carbon atom reported[55] for the corresponding acid, (a), rather than the expected terminal attachment (b).



$\underset{\text{OH}}{\text{CH}_2}-\underset{\text{NO}_2}{\text{CH}}(\text{CH}_2)_8\text{COOMe}$

(a)



$\underset{\text{NO}_2}{\text{CH}_2}-\underset{\text{OH}}{\text{CH}}(\text{CH}_2)_8\text{COOMe}$

(b)

Reaction with alkali afforded no 2:4-dinitrophenylhydrazone with the effluent, although a dark-red colouration was observed on testing the recovered oil with the reagent. This treatment completely eliminated the nitrogen content, (disappearance of nitro absorption at ν 1555cm.$^{-1}$), and mild oxidation of the recovered oil afforded sebacic acid in appreciable quantity. This evidence favours the expected structure (b), which might be expected to yield nitromethane and an aldehyde-acid, which would be partially converted to sebacic acid under the conditions. (a) might be expected to yield formaldehyde and a nitro-acid.

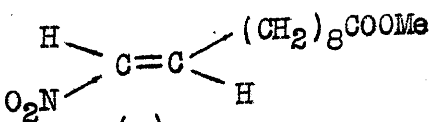
$$O_2NCH_2CH(OH)(CH_2)_8COOMe \xrightarrow{\text{base}} CH_3NO_2 + OHC(CH_2)_8COOH$$

$$\text{(b)} \qquad \xrightarrow{[O]} CH_3NO_2 + HOOC(CH_2)_8COOH$$

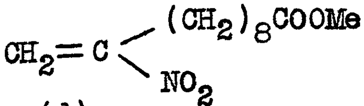
$$HOCH_2CH(NO_2)(CH_2)_8COOMe \xrightarrow{\text{base}} CH_2O \quad O_2N(CH_2)_9COOH$$

(a)

Confirmation by detection of nitromethane on treatment with alkali, or by reaction with formaldehyde to give a trihydroxynitromethane was achieved in neither case. Attempted dehydration to the nitro-olefin proved unsuccessful, although the nitro-olefin obtained on the chromatography of the original adduct had absorption in the infrared at 965cm.$^{-1}$, and no absorption at 890cm.$^{-1}$, indicating that the double bond is <u>trans</u>-substituted (c),



(c)



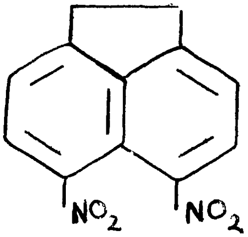
(d)

and not part of the exomethylene linkage (d). Since Levy has shown[45] that the same nitro-olefin is produced from the dinitro- and the nitro-nitrite (--> nitro-alcohol) adducts, the nitro-alcohol in this case might be expected to yield the nitro-olefin (c). From the above evidence, and from the lack of definite evidence published[54] in support of attachment to the penultimate carbon atom, the nitro-alcohol ester is believed to have structure (b), and the reported nitro-alcohol acid m.p. 121° is considered likely to have a similar orientation of addition. The incompleteness of hydrolysis observed on alkali treatment of the ester often complicated the reaction products and hindered possible crystallisation.

Addition of dinitrogen tetroxide to undecylenic acid in the presence of excess iodine gave rise to two products, the iodonitro- adduct of the type described by T.Stevens[226], and the iodonitrate from the ionic reaction described by Bachmann and Logan[232] for the synthesis of such compounds. T.Stevens[226] has reported this complication in the reaction with *cyclo*hexene. The use of higher temperatures in an attempt to increase the amount of free-radical addition and thus suppress the ionic addition reaction was of no avail, little difference in the composition of the reaction product being observed. Chromatographic treatment failed to achieve any separation of the components.

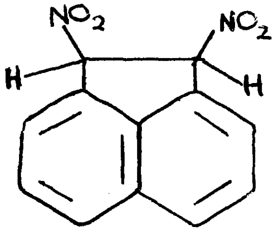
Addition of Dinitrogen Tetroxide to Acenaphthylene

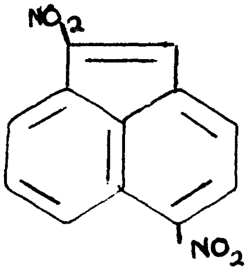
It was thought of interest to attempt addition of dinitrogen tetroxide to the reactive double bond of acenaphthylene. The addition products might be expected to be crystalline, and the yields obtained would determine the stereochemistry of the addition (only two isomers possible from each type of adduct). Also the addition to an aromatic compound has not been reported, However, acenaphthene itself has been nitrated with dinitrogen tetroxide to yield



5:6-dinitroacenaphthene,[233] and this reaction might be expected to interfere.

Addition to acenaphthylene under the standard conditions afforded solid products (25%) and the remainder as an intractable oil. For this reason the reaction was not further investigated, although a dinitro-derivative m.p. 160-161° was isolated in 15% yield. The analytical data favour a dinitro-adduct, but the low frequency of the nitro absorption in the infrared (1520cm.$^{-1}$), and the radically different ultraviolet spectrum (with greatly increased intensity) when compared with the spectra of acenaphthene and acenaphthylene, would be better explained by the inclusion of a nitro group





in the ring. The constitution of the adduct could be determined by degradation to the naphthalene nucleus, and detection of any substituted nitro group.

SUMMARY

The results obtained in the additions described follow the general pattern outlined by Levy[45] for the olefins of lower molecular weight. The products isolated correspond to those obtained by Levy[45], Schechter[50], and Porter and Wood,[51-52] namely the dinitro- and nitro-nitrite adducts, from which are obtained the nitro-nitrate, nitro-alcohol and nitro-olefins, by oxidation, hydrolysis, and elimination of the elements of nitrous acid, respectively. No evidence for the formation of any other compound was found, and the work of Weghofer[217] now seems even more anomalous. The findings of Vasil'ev *et al*.[53-57] also appear suspect in the light of the above results.

The work provides further support for the postulate[222] of non-stereospecific radical addition to disubstituted olefins, in the formation of the dinitro-acids in equal amounts from the addition to petroselinic acid, and the ionic mechanism of Levy[45] may no be safely discarded.

The reaction conditions employed allow a smooth reaction to proceed virtually quantitatively, but little variation has been achieved in directing the addition, except that the nitro-nitrate content can be substantially increased (5→30%) by the use of dinitrogen tetroxide in excess, or by the use of oxygen as a carrier gas.

Dinitrogen tetroxide has been added to oleic, erucic, and petroselinic acids, and to their trans isomers. The products from addition to both isomers had identical composition, evidence which supports the view[222] that the speed at which the intermediate radical reaches equilibrium is rapid compared with the speed of the second step of the addition. Also, there appears to be a difference in reactivity among the cis-acids in the ease of addition of the second mole of nitrogen dioxide to the intermediate, and the tendency for the radical to go tb the trans-acid by withdrawal of the π electrons of the latter appears to be highest in the case of erucic, and lowest in the case of oleic acid. The trans-acids formed appear slow to add dinitrogen tetroxide under the reaction conditions,

The preferred method of isolation for these adducts of high molecular weight is esterification, followed by chromatography. The dinitro-acids were the only compounds to precipitate during the reaction, and it may be possible to choose concentrations and temperatures to favour this precipitation. The remaining components are difficult to separate, special techniques such as counter-current chromatography may be required to achieve complete separation.

The properties and reactions of the crystalline dinitro-acids, obtained in 10-20% yield, appear worthy of study, with a view to preparing the corresponding diamino-acids, possibly by stereospecific reduction with palladised charcoal. The nitro-alcohols are available as a mixture of the possible isomers in ca. 50% yield, but preliminary investigation indicates that this oily mixture is not readily converted into crystalline derivatives, or useful degradation products, although reduction might afford tractable amino-alcohols. The reactions so far investigated, (hydrogenation, alkaline fission, removal of the elements of nitrous acid) appear difficult to achieve in a quantitative manner. The average yield (based on the olefin) of the products formed on addition to the four olefinic acids investigated may be summarised as in table VIII.

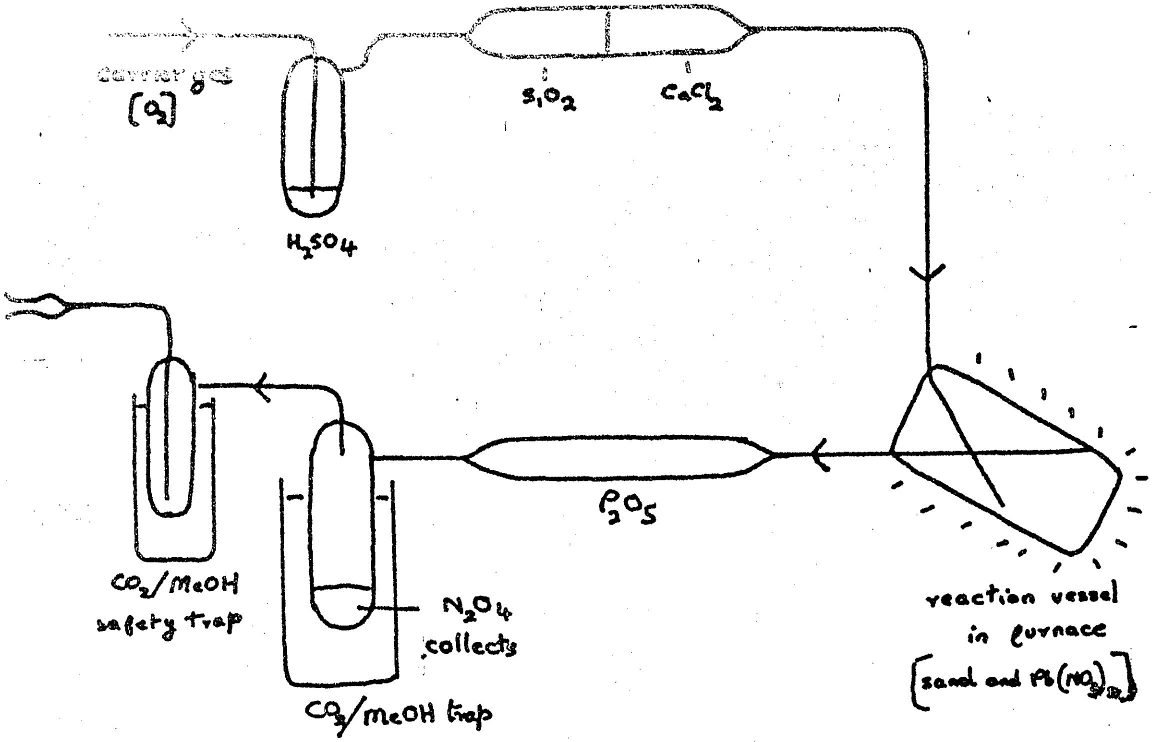
Table VIII

Adduct	Yield
Dinitro- (2 isomers possible)	25% (one or both isomers may be solid)

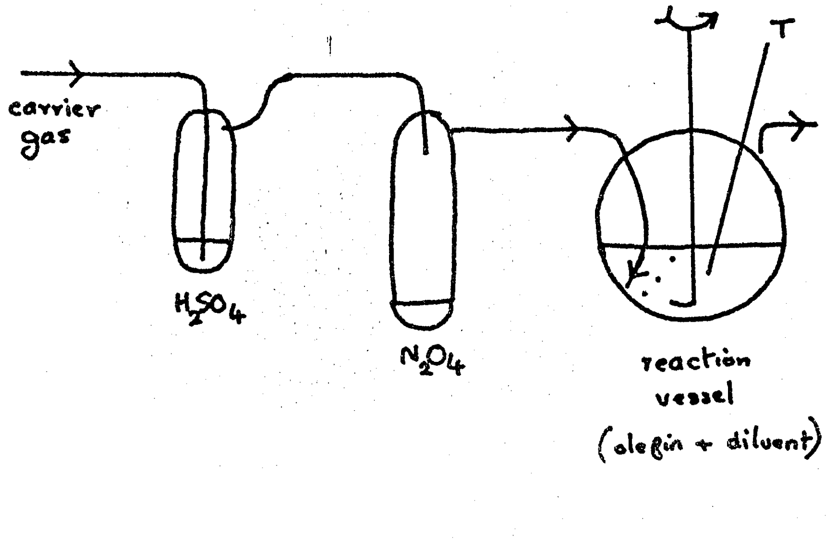
Adduct		Yield	
Nitro-alcohol	(4 isomers possible)	50%	(liquid mixture)
Nitro-nitrate	(4 isomers possible)	15%	(liquid mixture)

Fig.15

Preparation of N_2O_4



Addition of N_2O_4 to Olefins



EXPERIMENTAL

Preparation of Dinitrogen Tetroxide - Anhydrous lead nitrate (75g.) and silver sand (220g.) were dried at 220° overnight, thoroughly mixed, and transferred to the reaction vessel (see fig. 15). The furnace was brought to 500-600°, and the dinitrogen tetroxide evolved was swept out by the oxygen stream into the first trap, and condensed there by a dry ice/methanol bath. The dinitrogen tetroxide was redistilled by removing the furnace and the reaction vessel from the system, and replacing them with the trap containing the dinitrogen tetroxide, using a second such trap to collect the redistilled product. The characteristic green colour of dinitrogen trioxide was not observed at any stage.

General Technique of Addition of Dinitrogen Tetroxide to Olefins - The apparatus used is shown in fig. 15. The dinitrogen tetroxide in a diluent gas is led into the reaction vessel containing the olefin dissolved in an inert solvent. The temperature and duration of the addition may be varied, the usual conditions being a two-hour addition period, at 0°.

Addition of Dinitrogen Tetroxide to Cyclohexene - Cyclohexene (6g.), carefully purified by distillation from cupric stearate to remove peroxides, was dissolved in carbon disulphide (200ml.) and dinitrogen tetroxide (6g.) added in a nitrogen stream over one hour at 2°. The solvent was removed, the oil hydrolysed by dioxane:water, and recovered, light absorption : ν 3400, 1640, and 1557cm.$^{-1}$, indicating the presence of dinitro-, nitro-alcohol and nitro-nitrate adducts. Similar reaction mixtures when treated *in situ* with dry ammonia, gave the expected precipitate of ammonium nitrate, but only partial conversion to 1-nitro*cyclo*hexene was achieved, light absorption : ν 3400, 1557, and 1520cm.$^{-1}$, indicating presence of the nitro-alcohol. On chromatography on silica, the dinitro-, nitro-nitrate, and nitro-olefin adducts were eluted by petrol:benzene, and the nitro-alcohol by benzene:chloroform.

Addition to Oleic Acid and to Methyl Oleate - Oleic acid was purified by the method of Brown and Shinowara,[234] and methyl oleate was prepared by treatment of the acid obtained with methanol and sulphuric acid, followed by distillation at reduced pressure. The additions were performed as for *cyclo*hexene and are detailed in table V. The light absorption of the adducts is given in table VI (after esterification with diazomethane). The esterified adducts were chromatographed on silica, as reproducible results could not be obtained with alumina. Petrol:benzene was used to elute the dinitro-, nitro-nitrate, and nitro-olefin adducts, which eluted as one fraction. Elution with benzene: chloroform afforded the nitro-alcohol free from any contaminant, as an oil n_D^{25} 1.463.

Action of Ammonia on a Methyl Oleate-Dinitrogen Tetroxide Adduct - Methyl Oleate (6g,) in dry ether (250ml.) was treated in the usual manner with dinitrogen tetroxide (2g.) and dry ammonia passed in with stirring until precipitation was complete. The solution was evaporated down to yield an oil, light absorption : ν 3400, 1557 and 1520cm.$^{-1}$, indicating the presence of nitro-alcohol and nitro-olefin. The oil was chromatographed on silica to give the nitro-olefin (3g.) n_D^{25} 1.4607, light absorption indicating a fairly pure sample. The later fractions afforded the nitro-alcohol, n_D^{25} 1.4631, free from any other type of adduct.

Addition of Dinitrogen Tetroxide to Elaidic Acid - Elaidic acid (6g.), purified by recrystallisation from ethyl alcohol, was treated in petrol (250ml.) at 0° under nitrogen with dinitrogen tetroxide (2g.) over a period of two hours. After the completion of the addition, nitrogen was passed for an hour, then the crystalline precipitate (1.1g.) was filtered off, the filtrate affording no further precipitate on cooling. The filtrate was evaporated down and the resulting oil hydrolysed with dioxane:water, and recovered (7g.). The solid, the dinitro-acid, crystallised from methanol as flat plates m.p. 89-90° (Found : C, 57.8; H, 8.9; N, 7.1; $C_{18}H_{34}N_2O_6$ requires C, 57.8; H, 9.1; N, 7.5%), light absorption : ν 1710 and 1557cm.$^{-1}$ A further small amount of solid separated from the oily remainder, and was identified as stearic acid by mixed m.p. and elemental analysis (probably present as impurity in the starting material). The oil remaining was esterified with diazomethane and a portion (5g.) was chromatographed on silica (100g.). A mixture of dinitro-, nitro-nitrate and nitro-olefin adducts (2.1g.) was eluted with petrol:benzene, light absorption: ν 1640, 1557, and 1520cm.$^{-1}$, with $\varepsilon_{1557cm.^{-1}}$ greater than $\varepsilon_{1640cm.^{-1}}$. The nitro-alcohol (2.5g.) was eluted with benzene:chloroform, light absorption: ν 1557 and 3400cm.$^{-1}$

Reactions of the Adducts

a) Splitting of the Nitro-alcohol Adduct of **Methyl Oleate** - The nitro-alcohol (0.2g.) was dissolved in dilute sodium hydroxide solution and stirred at room temperature for eight hours. The solution was acidified at 0° with dilute hydrochloric acid, and ether extracted, and the extract separated into a neutral and an acidic fraction. The neutral fraction afforded an oil, light absorption : ν 1557cm.$^{-1}$, indicating a nitroalkane, and absence of any aldehyde; the acid fraction, after esterification with diazomethane, had light absorption : ν 3400, 1740, and 1557cm.$^{-1}$ (presence of ester and nitro groups, with some unreacted nitro-alcohol). From the intensities of the nitro absorptions, the larger content appeared to be in the neutral fraction. No 2:4-dinitrophenylhydrazone could be isolated, and no crystallisation of either oil was achieved.

b) Attempted Conversion of the Nitro-alcohol to the Nitro-Olefin Adduct.- The nitro-alcohol (1.5g.) was treated with acetic anhydride (0.6g.) in pyridine (5ml.), and the solution was maintained at 100° for one hour, allowed to stand for two hours, then poured on to chipped ice. The resulting neutral oil had light absorption : ν 1740cm.$^{-1}$, absence of hydroxyl absorption. The oil was heated for two hours with solid anhydrous potassium carbonate (0.2g.) at 100°, then ether extracted. The extract afforded an oil, light absorption : ν 1740 and 1557cm.$^{-1}$(small), indicating decomposition of the nitro-acetate.

c) Attempted Preparation of the Nitro-olefin - A mixture (0.5g.) of nitro-olefin, nitro-nitrate and dinitro- adducts was treated in ether with dilute sodium hydroxide with effective stirring for six hours. The ether layer was separated, the aqueous layer acidified with dilute acid, and ether extracted. The combined extracts afforded an oil, the light absorption of which was relatively unchanged, apart from hydrolysis of the ester. The action of alcoholic alkali also failed to achieve appreciable change in the light absorption of the oily mixture.

d) Reduction of Impure Nitro-olefin - The impure nitro-olefin (1.4g.) in dry ether (100ml.) was added over one hour to a stirred solution of lithium aluminium hydride (0.5g.) in dry ether (100ml.) in a three-necked r.b. flask, equipped with a reflux condenser, dropping funnel and stirrer, protected by silica drying tubes. The solution was refluxed for an additional ninety minutes, then worked up by addition of dilute sulphuric acid after excess lithium aluminium hydride had been decomposed by addition of water(care). The ether extract afforded an oil which had light absorption: ν 3400cm.$^{-1}$, absence of any absorption attributable to nitro group. Preparation of the benzoyl derivative afforded an oil, light absorption : ν 1735cm.$^{-1}$, indicating only presence of benzoate. Lassaigne test indicated almost complete absence of nitrogen content. Apparently the nitro group has been removed from the molecule by hydrogenolysis.

Addition of Dinitrogen Tetroxide to Petroselinic Acid.

a) Petroselinic acid (5g.) was saturated with dinitrogen tetroxide according to the procedure of Vil'yams and Vasil'ev.[56] The crystalline precipitate (1.28g.) was filtered off, and the recovered oil had n_D^{20} 1.4650 after hydrolysis with dioxane:water, light absorption : ν 3400, 1640 (large), 1557cm.$^{-1}$, indicating presence of nitro-alcohol and nitro-nitrate adducts. The crystalline precipitate was separated into two compounds by their differing solubilities in methanol. The first (0.6g.) crystallised from methanol as fluffy plates m.p. 126-127° (Found : C, 57.8; H, 9.0; n, 7.4; $C_{18}H_{34}N_2O_6$ requires C, 57.8; H, 9.1; N, 7.5%), light absorption : ν 1710, 1557cm.$^{-1}$, indicating a dinitro-acid. The second (0.65g.) crystallised from aqueous methanol as plates m.p. 90-92° (Found C, 58.0; H, 8.9; N, 7.4; $C_{18}H_{34}N_2O_6$ requires C, 57.8; H, 9.1; N, 7.5%), light absorption : ν 1710, 1555cm.$^{-1}$, indicating a dinitro-acid.

b) Petroselinic acid (4.5g.) in petrol (250ml.) was treated at 0° under nitrogen with dinitrogen tetroxide (1.5g.) over thirty minutes. The crystalline precipitate was filtered off (0.7g.), and the recovered oil was hydrolysed with dioxane: water, and set aside. The precipitate was separated into two components by their solubility differences in methanol, the first (300mg.) m.p. 127°, crystallised from cold methanol, and the second (350mg.) m.p. 90-92°, from aqueous methanol. The light absorption of both compounds was the same: ν 1710, 1557cm.$^{-1}$, indicating the composition of a dinitro-acid. The hydrolysed oil partly solidified, yielding crude petroselidinic acid (2.8g.), crystallising from methanol as small prisms m.p. 50-52°, undepressed on admixture with petroselidinic acid m.p. 54°.[227] The recovered oil(2g.) had light absorption : ν 3400, 1710, 1640 and 1557cm.$^{-1}$, indicating the presence of nitro-alcohol and nitro-nitrate adducts.

Addition of Dinitrogen Tetroxide to Petroselidinic Acid

Petroselidinic acid (2g.), purified by crystallisation from ethanol (m.p. 50-52°), was treated in petrol (250ml.) with dinitrogen tetroxide (1g.) under nitrogen at 0° over a period of two hours. The crystalline precipitate (0.6g.) was filtered off, and the solid separated into its two components as described in the case of addition to the cis-acid, by treatment with methanol. On evaporation of the mother liquors, a small amount of oil was obtained, light absorption : ν 1740, 1557cm.$^{-1}$, indicating that esterification had taken place (esterification with methanol, catalysed possibly by nitrous acid). The remainder of the adduct (1.3g.), after hydrolysis and esterification with diazomethane, was chromatographed on silica (30g.). The nitro-nitrate (0.4g.) n_D^{25} 1.462, was eluted with petrol:benzene (2:1), and the nitro-alcohol (0.82g.) n_D^{25} 1.463, with chloroform:methanol (1:1).

Preparation of the Methyl Esters of the Dinitro-acids

The dinitro-acid m.p. 127° (50mg.) was esterified with diazomethane, filtered, the solvent removed, and a solid obtained on standing, crystallising from ethanol as flat plates m.p. 47-48° (Found : C, 58.9; H, 8.7; N, 6.8; $C_{19}H_{36}N_2O_6$ requires C, 58.8; H, 9.3; N, 7.2%), light absorption : ν 1740 and 1555cm.$^{-1}$, indicating a pure dinitro-ester. The solid obtained on filtering the original reaction solution was polymeric, m.p. 127°, M (Rast), ca. 3000, insoluble in all solvents.

The dinitro-acid m.p.92° (50mg.) was esterified with diazomethane in ether, and the solution evaporated to give an oil n_D^{25} 1.463. The oil was distilled in vacuo to give a fraction b.p. 195-205°(bath temp.)/10^{-4}mm., (Found : C, 66.6; H, 9.8; N, 4.1; $C_{19}H_{35}NO_4$ requires C, 66.9; H, 10.3; N, 4.1%), light absorption : ν 1740, 1520cm.$^{-1}$, absence of nitro absorption, λmax. 245 mμ (ε 3800), indicating a nitro-olefin.

Attempted Preparation of the Nitro-olefin - The dinitro-acids and the nitro-nitrate ester were treated separately with aqueous alcoholic sodium hydroxide at room temperature overnight. After acidification, oils were obtained in all cases, light absorption: ν 1710, 1555(small), and 1520cm.$^{-1}$ (small), indicating incompleteness of reaction, accompanied by splitting , with removal of the nitro content.

Addition of Dinitrogen Tetroxide to Erucic Acid - Erucic acid (10g.), purified by crystallisation from ethanol at low temperature, was treated in petrol (250ml.) with dinitrogen tetroxide (3g.) under nitrogen at 0° over one hour. The precipitate (3.3g.) was filtered off, and on concentration of the filtrate a further amount of solid (2.3g.) was obtained. The light absorption : ν 965cm.$^{-1}$, virtual absence of nitro absorption, indicated the solid to be brassidic acid, and on recrystallisation from methanol, brassidic acid m.p. 58° was obtained. From the residues, behenic acid (0.1g.) m.p. 72-75°, was isolated (probably present as impurity in the starting material. The filtrate was evaporated, and the resulting oil hydrolysed and esterified, light absorption : ν 3400, 1640, and 1555cm.$^{-1}$, indicating presence of nitro-alcohol and nitro-nitrate adducts. Occasionally higher-melting crystalline material precipitated along with the brassidic acid, and crystallised from methanol m.p. 89-90°, (Found : C, 64.8; H, 9.7; N, 5.3; $C_{22}H_{42}N_2O_6$ requires C, 61.4; H, 9.7; N, 6.5%), light absorption : ν 1710 and 1555cm.$^{-1}$, indicative of a dinitro-acid. No further characterisation of this product was attempted.

<u>Addition of Dinitrogen Tetroxide to Brassidic Acid</u> - Brassidic acid (3g.) m.p. 58-59°, purified by recrystallisation from ethanol, was treated in petrol:ether (300ml.) with dinitrogen tetroxide (1.5g.) under nitrogen at 0° over a total period of four hours. The solution was then allowed to warm to room temperature, and stood overnight. The precipitate (0.18g.) was filtered off, and on cooling, a further amount (0.4g.) was obtained, separable by treatment with methanol into two components. The first (0.22g.) crystallised from methanol as plates m.p. 90-91°, identical

with the first crystalline precipitate, (Found : C, 61.5; H, 8.8; N, 6.1; $C_{22}H_{42}N_2O_6$ requires C, 61.4; H, 9.7; N, 6.5%), light absorption : ν 1710 and 1555cm.$^{-1}$, indicating a dinitro-acid. On esterification of the acid with diazomethane, the dinitro-ester crystallised as plates from methanol m.p. 43-44°, (Found : C, 62.3; H, 9.7; N, 5.8; $C_{23}H_{44}N_2O_6$ requires C, 62.2; H, 9.9; N, 6.3%). The second (0.15g.) was obtained from the mother liquors, crystallising from methanol as plates m.p. 74-75° and was identified as behenic acid by formation of the solid ester (m.p. 51-54°) by treatment with diazomethane. (Methyl behenate has m.p. 54°[235]). The filtrate was evaporated to yield an oil which, after hydrolysis and esterification, was chromatographed on silica. The first fraction, eluted with petrol:benzene (1:1) had light absorption : ν 1740, 1640, 1555 and 1520cm.$^{-1}$, with $\varepsilon_{1555cm.^{-1}}$ greater than $\varepsilon_{1640cm.^{-1}}$, indicating the presence of dinitro-acid, as well as nitro-nitrate and nitro-olefin adducts. From the optical densities of the absorptions, the nitro-nitrate was estimated to be formed in 10-15% yield. The nitro-alcohol ester had n_D^{25} 1.462 (eluted with benzene: chloroform). Earlier runs worked up immediately after completion of addition invariably afforded mainly unchanged brassidic acid.

Addition of Dinitrogen Tetroxide to Undecylenic Acid - Undecylenic acid (5g.), purified by crystallisation from hexane at -10°, was treated in petrol (250ml.) with dinitrogen tetroxide (3g.) under nitrogen at 5° over a period of two hours. The solution was then evaporated down and the resulting oil stored for a period of four weeks. No satisfactory crystalline deposit having resulted, the oil was esterified with diazomethane, light absorption : ν 3400, 1740, 1640, 1557 and 1520cm.$^{-1}$ (small), indicating the presence of nitro-alcohol, nitro-nitrate, probably dinitro- and a small amount of nitro-olefin. No absorption at 890cm.$^{-1}$ was observed, indicating absence of the $CH_2{=}C(NO_2)R$ group. The oil was chromatographed on silica (90g.) to yield the following fractions :

a) 3.1g., eluted by petrol:benzene 3:1, light absorption : ν 1740, 1640, 1555, 1520cm.$^{-1}$, indicating a mixture of nitro-nitrate, nitro-olefin and dinitro- adducts.

b) 0.9g. , eluted by benzene:petrol 2:1, light absorption : ν 1740 and 1555cm.$^{-1}$, (1640 and 1520cm.$^{-1}$ absorption is small), indicating impure dinitro-adduct.

c) 2.1g., eluted by benzene:chloroform 2:1, light absorption : ν 3400, 1740, and 1555cm.$^{-1}$, indicating pure nitro-alcohol.

d) 1.9g., eluted with chloroform, light absorption : ν 3400, 1720(broad) and 1555cm.$^{-1}$, indicating an acidic nitro-alcohol adduct(probably from incomplete esterification).

No successful separation was achieved on rechromatography of the first fraction. The nitro-alcohol fractions crystallised on standing and had m.p. 55-56° (ether:petrol), (Found : C, 55.0; H, 8.8; N, 5.5; $C_{12}H_{23}NO_5$ requires C, 55.2; H, 8.8; N, 5.4%), light absorption : ν 3400, 1740, and $1555cm.^{-1}$ Light absorption of the fractions containing appreciable absorption at $1520cm.^{-1}$ (nitro-olefin), showed no peak at $890cm.^{-1}$, but absorption at $965cm.^{-1}$ (trans-olefin) was present.

Reactions of the Nitro-Alcohol Ester

a) Splitting - The nitro-alcohol (0.44g.) was treated at 80° for one hour with an aqueous alcoholic solution (25ml.) of sodium hydroxide (0.2g.). The red solution was acidified at 0° and ether extracted. The action of the base would be expected to split the the nitro-alcohol ester into two fragments, an aldehyde (probably converted to the acid) and a nitro compound. The oil obtained afforded no precipitate with the 2:4-dinitrophenylhydrazine reagent, although a marked intensification of colour was observed. Light absorption : ν $1710cm.^{-1}$, indicated the presence of an acid with little nitro content remaining. Attempts to detect formaldehyde or nitromethane were unsuccessful.

b) Oxidative Splitting. - The nitro-alcohol was treated as above with base, and the recovered product shaken for an hour with alkaline potassium permanganate at room temperature. After acidification and ether extraction, a yellow solid was obtained, light absorption : ν 1710cm.$^{-1}$, indicating an acid free from nitro content. After recrystallisation from ether:petrol, the solid had m.p..120-130°, undepressed on admixture with a genuine sample of sebacic acid. The solid appeared difficult to purify further.

c) Dehydration - No dehydration was achieved on treating the nitro-alcohol in refluxing benzene with a trace of p-toluenesulphonic acid.

d) Reaction with Paraformaldehyde - The nitro-alcohol (0.2g.) was dissolved with paraformaldehyde (0.07g.) in 95% ethanol (3ml.) containing potassium hydroxide (1g. per 200ml.). The flask was stoppered and stood overnight. After working up by dilution with water and ether extraction, the product was separated into a neutral and an acid fraction by bicarbonate extraction. The neutral fraction afforded no trace of the expected tri(hydroxymethyl)nitromethane, light absorption : ν 1740, 3400cm.$^{-1}$(small), and no nitro absorption, indicating an ester. The acid fraction consisted of unchanged nitro-alcohol acid, the light absorption indicating predominance of acid. Attempts to identify the neutral ester by hydrolysis were unsuccessful.

Addition of Dinitrogen Tetroxide to Undecylenic Acid in Presence of Excess Iodine

Dinitrogen tetroxide (2.5g.) was added slowly over three hours under nitrogen to a stirred solution of undecylenic acid (5g.) and iodine (9g.) in ether (250ml.) at 0°. Stirring under nitrogen was continued for a further hour, then the solution was treated with sodium thiosulphate solution to remove excess iodine. After washing with water, the ether extract afforded a colourless oil (10g.). Light absorption : ν 1640 and 1555cm.$^{-1}$, indicating nitrate and nitro absorption, and a Beilstein test gave a positive result. A similar run at 20° furnished the same result. Part (1g.) of the oil was chromatographed on silica (30g.) and eluted with chloroform:methanol. A pink colour (iodine?) was observed on the column, and the light absorption of the recovered fractions indicated little separation. The fractions all afforded a positive Beilstein test.

Addition of Dinitrogen Tetroxide to Acenaphthylene

- Dinitrogen tetroxide (4.5g.) was added slowly over two hours under nitrogen to a stirred solution of acenaphthylene (6g.) in ether (300ml.) at 0°. After addition, stirring was continued for a further hour. The solution was evaporated to small volume and the solid depositing was filtered off. The first crop (1.06g.) was an amorphous brown powder, light absorption : ν 1555cm.$^{-1}$, indicating a nitro-compound, and the second (1.79g.) crystallised from benzene as plates m.p. 160-161° (Found : C, 58.9; H, 3.1; N, 11.4; $C_{12}H_8N_2O_4$ requires C, 59.0; H, 3.4; N, 11.5%; $C_{12}H_6N_2O_4$ requires C, 59.5; H, 2.5; N, 11.6%), light absorption : ν 1520cm.$^{-1}$, λmax. 290 and 349 mμ (ε 8900 and 11,700 respectively), indicative of a nitro group or groups substituted in an aromatic ring. The mother liquors afforded only intractable gums and the products were not further investigated.

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