Dyes and Pigments **9** (1988) 1–20

Meerwein Arylation Reactions of Olefins with Anthraquinone Diazonium Hydrogen Sulfates: Formation of New Carbon Bonds at the Carbon Atoms C-1 and at C-1,5 of the Anthraquinone System

Claus D. Weis

Research and Development, Dyestuffs and Chemicals Division,
Ciba–Geigy Ltd, Basel, Switzerland

(Received 5 March 1987; accepted 23 March 1987)

SUMMARY

A survey is presented of Meerwein arylation reactions involving the arylation of olefins with anthraquinone diazonium hydrogen sulfate. These reactions comprise an experimentally limited and special section of the otherwise broad applicability and scope of Meerwein reactions. The combinations of the anthraquinone system with olefins having from two to five carbon atoms are attained by using experimental conditions which differ markedly from those patterned after the general performance of Meerwein reactions. The best results are obtained in using diazonium hydrogen sulfates, in contrast to the generally and most conveniently used hydrogen chloride salts. The preferred solvents are methanol or dimethyl methylphosphonate (DMMP). The latter solvent in particular greatly facilitates the arylations of 2-methylene-glutaronitrile, allows one to perform a one-pot synthesis of 2-methoxy-benzanthrone, and also enhances the double Meerwein arylations of 1,5-disubstituted anthraquinones. Many further ring-closure reactions of the intermediates thus obtained are reported, yielding condensed heterocyclic aromatic compounds.

1 INTRODUCTION

The Meerwein arylation reaction is the metal-catalyzed arylation of olefinic compounds with aryldiazonium salts, occurring with the formation of a new carbon–carbon bond and the simultaneous evolution of nitrogen. The

Dyes and Pigments 0143-7208/88/$03·50

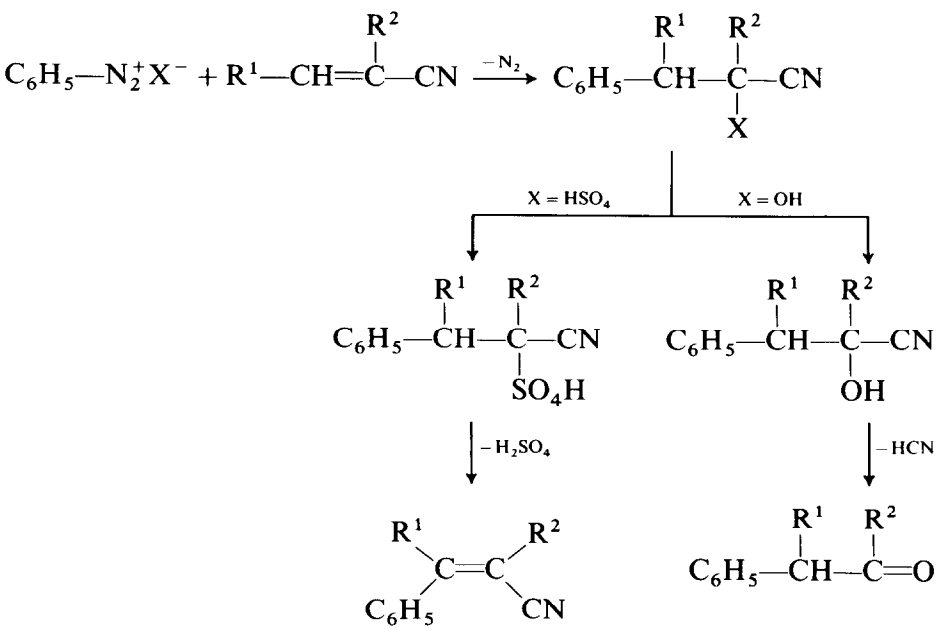
thermally initiated decomposition of the reactive intermediate complex which consists of the diazonium salt, the unsaturated compound and the copper salt leads to addition of the aryl residue onto the α-carbon atom of the olefin, and the remaining anion is added to the β-carbon atom.

$$\text{Ar-N}_2^+\text{X}^- + \text{R}^1\text{—CH=CR}^2\text{R}^3 \xrightarrow{\text{CuX}_n} \text{Ar—CHR}^1\text{—CR}^2\text{R}^3\text{X} + \text{X} + \text{N}_2$$

(X = halogen, hydrogen sulfate)

Olefins which are most suitable in undergoing this transformation are always activated either by electron-withdrawing substituents or by conjugation with unsaturated functional groups. Occasionally under the reaction conditions an elimination of elements of hydrogen halide, water or sulfuric acid, with the simultaneous formation of the unsaturated compound, or subsequent transformations, may occur, the results of which then depend on the electrophilic character of the anion. Thus, several distinct further reactions of the primary adduct may ensue which depend largely on the substituents attached to the olefin. This choice of different reaction sequences does not lead solely to olefins but gives rise to cyanohydrins or to ketones also. The different reaction paths which emerge from this consideration are illustrated in Scheme 1.

This somewhat unusual course of Meerwein reactions, encompassing the entire scope of these reactions, becomes more important when, in arylation



Scheme 1

reactions, the hydrogensulfate moiety is used as the anion. This becomes of considerable synthetic importance in those reactions in which anthraquinone diazonium hydrogen sulfate is reacted with olefins. The hydrogensulfate anion is exchanged in the course of the redox-modulated reaction[1,2] by the stronger nucleophilic hydroxy- or methoxy-anion radical.

Whilst the Meerwein reaction in its diverse experimental applications has been thoroughly discussed in various articles,[1-3] much less attention has been focused on the particular type of the reaction which involves reactions of anthraquinone diazonium salts with olefins, and there are only a limited number of publications reporting the synthetic possibilities for the preparation of 1-mono- and 1,5-di-substituted anthraquinones. In particular, some special cyclization reactions may be accomplished with the derivatives thus prepared, and they may serve as precursors for the synthesis of tri- tetra- and penta-cyclic compounds. Some of the more recent developments in this area are included in this review.

Nearly all investigations of the Meerwein reaction have been performed with diazonium hydrogen halides, and only a more limited number have been carried out using the diazonium hydrogen sulfate or the nitrate.[2] Either these attempts failed or the expected products were isolated only in very low yields.[2] The collected results taken from the literature survey were discussed in connection with the general mechanism, and it was concluded that in anions with a relatively large diameter, such as the bisulfate or the nitrate ions, the tendency to form covalent bonds is far less pronounced than in the anions of halogens.[2]

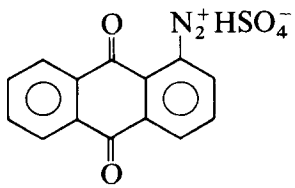
The formation of a carbon–carbon linkage between the anthraquinone moiety and an aliphatic substituent can be particularly well achieved by means of a Meerwein reaction. These reactions form the topic of this present review and results are collected from currently available literature.

1.1 Anthraquinone diazonium salts

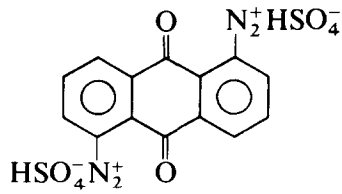
1-Aminoanthraquinones have been diazotized by a number of methods.[1-3] However, the anthraquinone diazonium hydrogen sulfate is the preferred salt to be used for those Meerwein reactions which will be discussed subsequently. The preparation of **1** was accomplished either by adding a solution of sodium nitrite to a solution of 1-aminoanthraquinone in concentrated sulfuric acid or, alternatively, the sulfuric acid solution of the amine was diazotized by adding a 40% solution of nitrosyl sulfuric acid to it.[4]

Similarly, the preparation of 1,5-anthraquinone-bis(diazonium hydrogen sulfate) was best effected when using the latter method. The yield was nearly quantitative.[5,6]

The isolation of either one of these diazonium salts was achieved by adding their acidic solution to an excess of water, whereupon crystals precipitated. The crude 1-anthraquinonediazonium hydrogen sulfate was obtained free of inorganic salts by sufficient washing with cold water, followed by methanol and ether. This gave a largely anhydrous product which was finally dried over diphosphorus pentoxide. It forms yellow crystals which melt with decomposition at 159°C.



1



2

The corresponding 1,5-anthraquinone bis(diazonium hydrogen sulfate), **2**, was obtained in the form of yellow crystals which decompose at 155°C. This diazonium salt proved to be stable over a period of two years if stored in dark (blackened) flasks. However, decomposition becomes apparent after a few hours when the crystalline compound is exposed to bright daylight.[5]

The synthesis of 1-anthraquinone diazonium hydrogen chloride has also been reported. Since it is very water-soluble, it may be prepared by adding a saturated aqueous solution of sodium chloride to a concentrated aqueous solution of the hydrogen sulfate salt.[7,8]

1.2 Solvents and catalysts

The effect of using various solvents and catalysts is an important factor with respect to the yield of products[9] and also to the accompanying unwanted substitution products which are often associated with and traced back to the concomitantly occurring Sandmeyer reactions.[1,2,5] However, Meerwein reactions involving anthraquinone diazonium hydrogen sulfate occur generally only when the reaction is performed in methanol, dimethyl methylphosphonate or acetic acid as solvent.

More recent investigations have been concerned with the action of catalysts in a particular type of Meerwein reaction which has been carried out with 1,5-anthraquinone bis(diazonium hydrogen sulfate).[5] These reactions have been coined 'internal Meerwein reactions' but they seem to be restricted to those reactions which involve bisdiazonium salts of anthraquinone.

The utilization of various catalysts gave only very modest increases—no more than 10–15%—in the yield of products. Generally, however, the use of

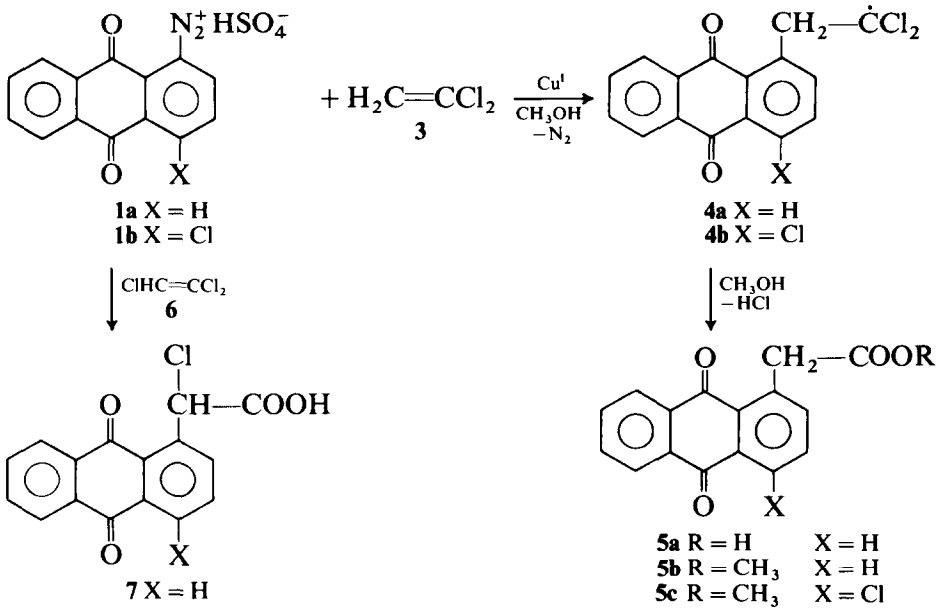
copper(I) salts furnished very good results with respect to the purity and the yields of isolated products.[4]

2 THE COMBINATION OF ANTHRAQUINONE SYSTEMS WITH COMPOUNDS HAVING TWO CARBON ATOMS

2.1 The arylation of chlorinated ethylenes: synthesis of 1-anthraquinoneacetic acid and its derivatives

A very simple and elegant synthesis of 1-anthraquinone acetic acid (**5a**) and its methyl ester (**5b**), respectively, was achieved by the arylation of 1,1-dichloroethylene (**3**) with 1-anthraquinone diazonium hydrogen sulfate (**1a**) (Scheme 2). When the diazonium salt was allowed to react with an elevenfold excess of 1,1-dichloroethylene in the presence of catalytic quantities of copper(I) chloride using anhydrous methanol as solvent, 1-anthraquinone-acetic acid methyl ester (**5b**) was formed in 98% yield.[10] The reaction could alternatively be performed in aqueous acetone and this enabled the carboxylic acid (**5a**) to be isolated in 65% yield.

The patent specification which reports this reaction claims the remarkably high yield of 99% of **5b**. It may be presumed that this nearly quantitative yield is attributable to the high ratio 1:16 of diazonium salt concentration to



Scheme 2

olefin. The excess of 1,1-dichloroethylene was distilled from the reaction mixture during the course of the work-up procedure.

The 4-chloroanthraquinone diazonium hydrogen sulfate (**1b**) is the only substituted anthraquinone derivative of this type which was reported to react with 1,1-dichloroethylene yielding 4-chloroanthraquinone-1-acetic acid methyl ester (**5c**) in 96% yield.[11]

The method in this experimentally convenient form is, however, only applicable when using low-boiling olefinic products. Another surprising feature is the apparently complete absence of products stemming from the Sandmeyer reactions, in particular the hydrogen-transfer reaction which would ultimately lead to anthraquinone. However, this seems to be an effect which became apparent in many—although not all—arylations of olefins with anthraquinone diazonium hydrogen sulfate and which might be due to the built-in quinone system, and its redox modulating effect.

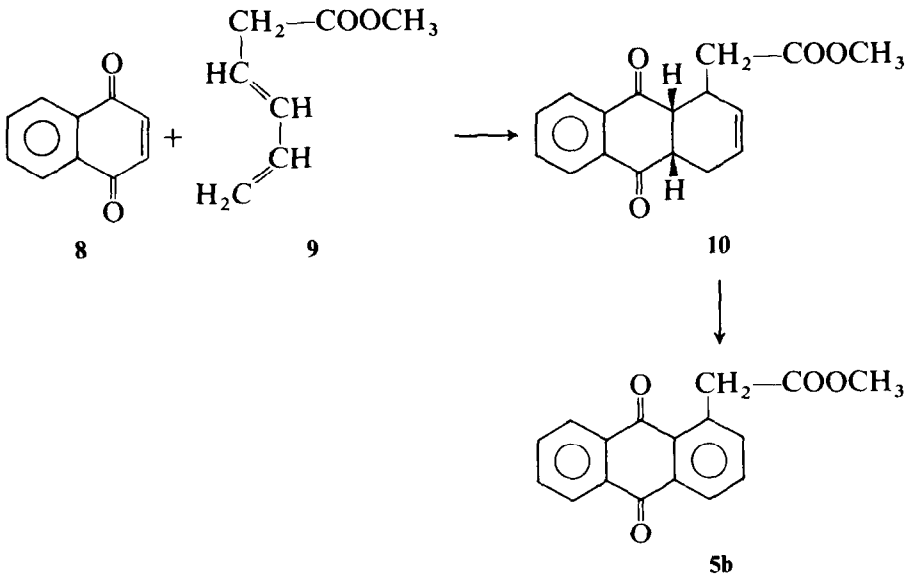
Similarly, when the analogous arylation of 1,1,2-trichloroethylene (**6**) with **1a** was performed in acetic acid as solvent, the formation of 1-anthraquinone-1-chloroacetic acid (**7**) was observed in 74% yield.[10] The formation of the acid **5a** or the ester **5b** occurs presumably via **4a** involving an anion radical. This reacts subsequently with alcohol or with water and provides either the acid or the ester after the hydrolysis of the chlorinated part of the molecule.

2.2 Alternative synthesis of 1-anthraquinoneacetic acid

Several alternative procedures have been described for the preparation of 1-anthraquinoneacetic acid and of its methyl ester, respectively.

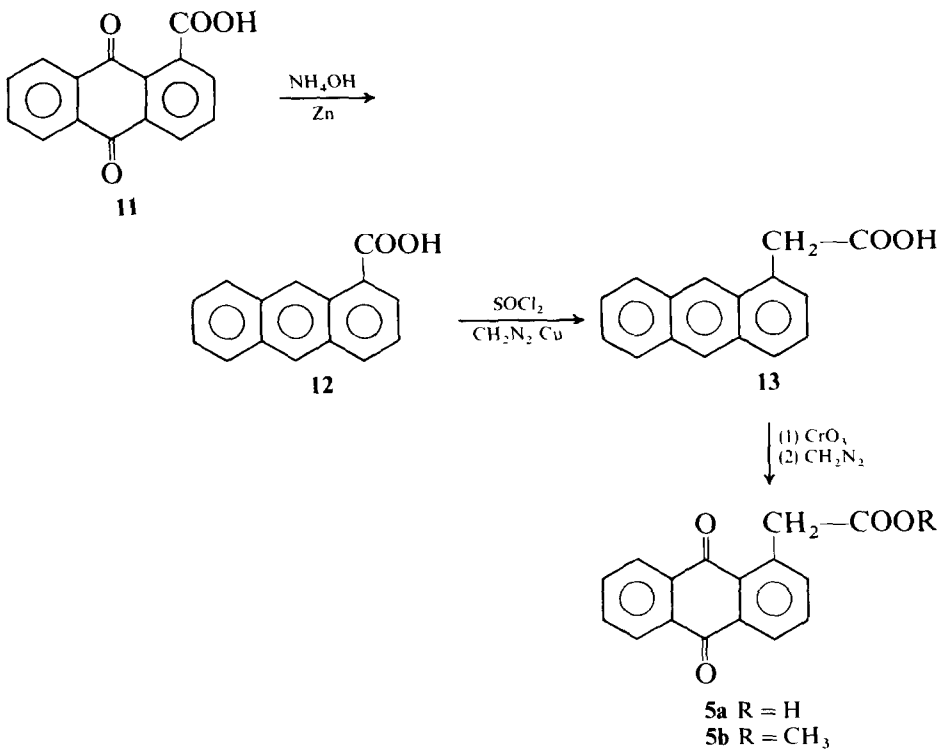
Thus, the Diels–Alder reaction of 1,4-naphthoquinone (**8**) and hexadiene-3,5-carboxylic acid methyl ester (**9**) in refluxing ethanol yields 1,4,9a,10a-tetrahydroanthraquinone-1-acetic acid methyl ester (**10**)[12–15] (Scheme 3). The stereochemical assignments of the structure of **10** were determined by X-ray analysis.[16] The tricyclic compound **10** was readily oxidized to **5b** by passing a current of air through the methanolic solution.

Another method for the preparation of **5b**[17] used 1-anthraquinone-carboxylic acid (**11**) as the starting material (Scheme 4). The keto groups of the anthraquinone moiety were initially reduced with zinc and 15% aqueous ammonia in order to obtain the parent hydrocarbon, 1-anthracenecarboxylic acid (**12**). The subsequent extension of the carbon chain by one additional methylene unit was accomplished using the Arndt–Eistert method employing diazomethane. This yielded 1-anthracene-acetic acid (**13**). The final oxidation of **13** with chromic oxide yielded the known acid **5a** which was then treated with diazomethane to obtain the methyl ester **5b**.



8 **9** **10** **5b**

Scheme 3



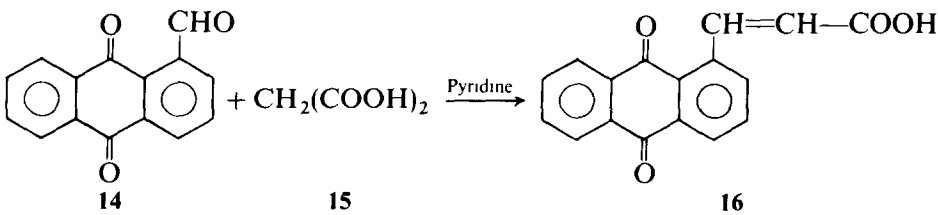
11 **12** **13**

5a R = H
5b R = CH_3

Scheme 4

A chromatographic method for the determination of the acid **5a** has also been developed,[18] since the compound has been detected in the alkaline pulp mass produced in the paper-manufacturing industry.

Acrylic esters and acrylonitrile do not undergo the Meerwein reaction with **1** under any conditions, although they are known to belong to the most reactive of olefinic substrates. Therefore, the usual method which has been worked out for the preparation of 1-anthraquinoneacrylic acid (**16**) employed the condensation of 1-anthraquinonealdehyde (**14**) with malonic acid (**15**) in pyridine solution[19] (Scheme 5). A series of esters, namely the methyl, ethyl, hydroxyethyl and the propyl esters, were prepared from the acid **16** via the carboxylic acid chloride, which was then reacted with the respective alcohol.



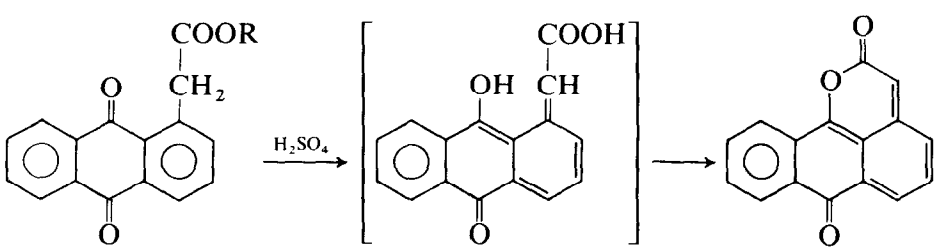
14 **15** **16**

Scheme 5

2.3 Pyroneanthrone (2*H*,7*H*-dibenzo[*de*,*h*]chromene-2,7-dione)

1-Anthraquinoneacetic acid and its methyl ester not only served as suitable starting materials for the synthesis of the pyroneanthrone (**18**), but were also employed in the synthesis of the aza-2-hydroxybenzanthrone system (**23**).

The pyroneanthrone (**18**) was formed in 97% yield (Scheme 6) when **5a** was stirred in concentrated sulfuric acid at room temperature, whilst the methyl ester **5b** was heated to 40–45°C for 3 h to achieve the cyclization to **18** in 94% yield.[20,21] It has the structure of a lactone, and it is presumed that the



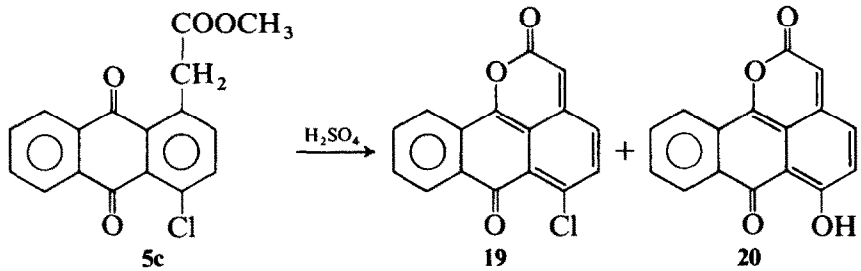
5a R = H
5b R = CH_3

17 **18**

Scheme 6

acid **5a** undergoes a 1,5-hydrogen shift from the methylene to the carbonyl group, first with the intermediate formation of the anthrol **17** which then reacts with the carboxyl function to yield **18**.

This method, using concentrated sulfuric acid to effect the ring closure, has also been applied to substituted anthraquinone derivatives (Scheme 7), 4-chloro-1-anthraquinoneacetic acid methyl ester (**5c**), for example, yielding

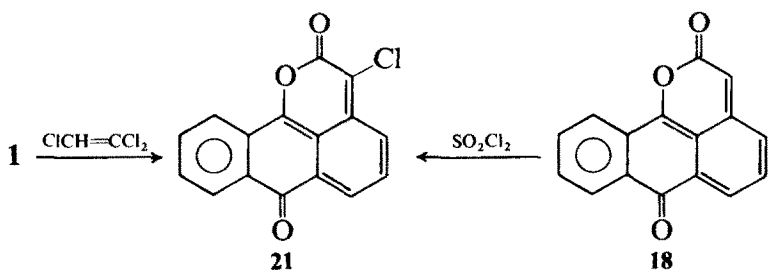


5c **19** **20**

Scheme 7

a mixture of 75% of the 6-chloropyroneanthrone (**19**) and 20% of 6-hydroxypyroneanthrone (**20**), both of which could be separated by chromatography on silica gel. The latter compound was formed in nearly quantitative yield when the ring closure was carried out in sulfuric acid at 45°C.

The previously-mentioned reaction of **1** with 1,1,2-trichloroethylene (**6**) in acetic acid may also be performed under conditions which yield directly 3-chloro-pyroneanthrone (**21**) without initially having to isolate compound **7**, and subsequently to cyclize it (Scheme 8). The chlorination of **18** with sulfuryl chloride also gave 3-chloropyroneanthrone in 94% yield.[20]



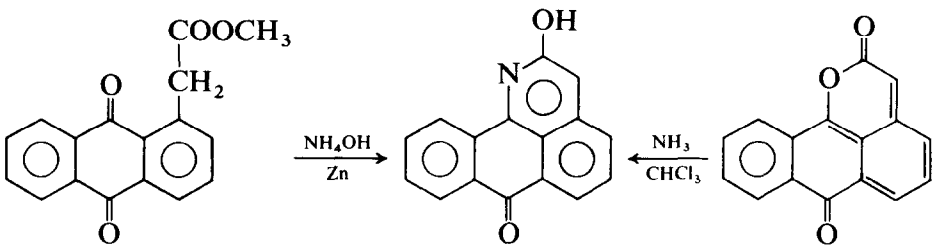
21 **18**

Scheme 8

In addition to the use of sulfuric acid in effecting the ring closure of **5a** to the lactone **18**, acetic anhydride or phosphorus pentoxide in organic solvents have also been used successfully.[20,21]

2.4 1-Aza-2-hydroxybenzanthrone (2-hydroxy-7*H*-dibenzo[*de,h*]quinolin-7-one)

The addition of pyroneanthrone (**18**) to a solution of ammonia in chloroform gives 1-aza-2-hydroxybenzanthrone (**22**) in a yield of 48%[20] (Scheme 9). An alternative method for the synthesis of **22** relied on the reduction of 1-anthraquinoneacetic acid methyl ester (**5b**) using zinc in a solution of methanolic sodium hydroxide in the presence of a large excess of aqueous ammonia, yielding **22** in 90% yield.[22]



5b **22** **18**

Scheme 9

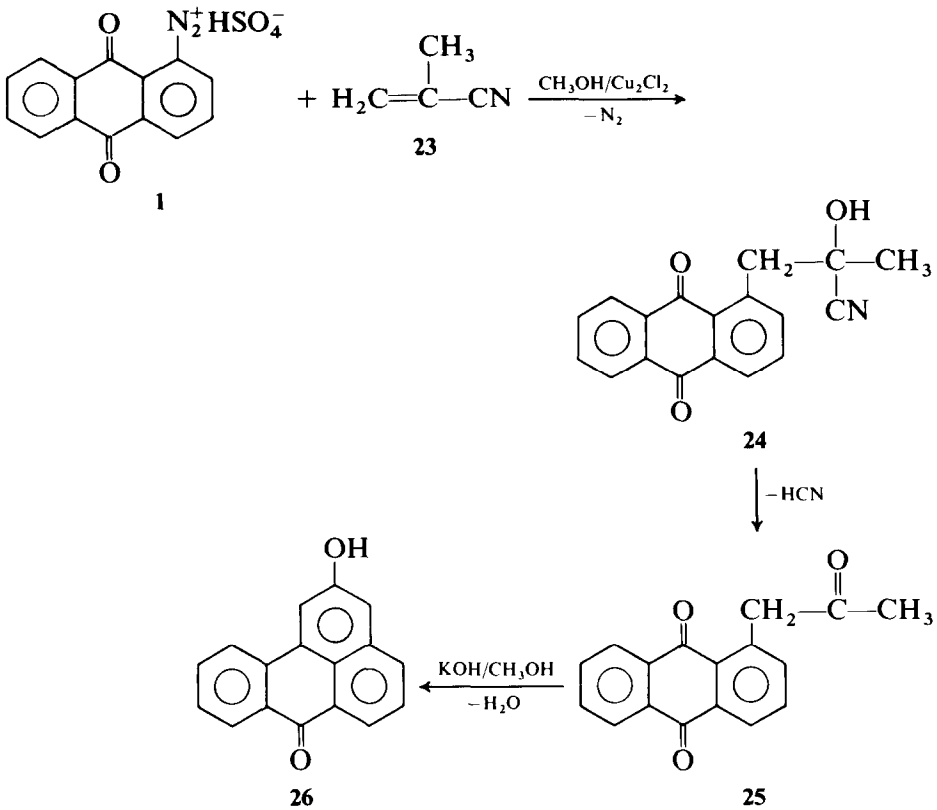
3 THE COMBINATION OF ANTHRAQUINONE SYSTEMS WITH COMPOUNDS HAVING THREE CARBON ATOMS

The Meerwein reaction of 1-anthraquinone diazonium hydrogen sulfate (**1**) with olefins having a linear sequence of three carbon atoms yields 1-substituted anthraquinone derivatives which readily undergo a further cyclization reaction involving the adjacent carbonyl group. Only one example, however, of this reaction type has been reported thus far.

3.1 The arylation of methacrylonitrile: synthesis of 2-hydroxybenzanthrone and 2-methoxybenzanthrone

The arylation of methacrylonitrile (**23**) with **1** has attracted considerable interest and much attention has been devoted to this reaction, since it is a new synthesis of benzanthrone which makes use of the Meerwein arylation and which does not rely on the classical method of preparation.

The reaction of dry **1** with methacrylonitrile (**23**) in the presence of copper(I) chloride gave 1-(2-oxopropyl)anthraquinone (**25**) in good yield (Scheme 10). However, this compound was not isolated, but retained in solution and subsequently cyclized by adding a solution of potassium hydroxide in methanol to yield 2-hydroxybenzanthrone (**26**) in 74% yield.[23]



Scheme 10

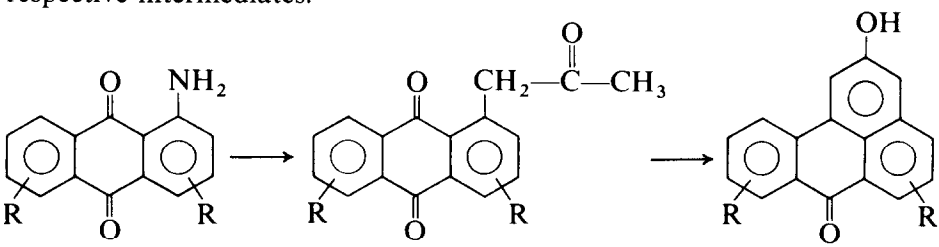
This reaction was envisaged as proceeding via the transient cyanohydrin **24**, which easily released hydrogen cyanide on attempts to isolate it, thus yielding the ketone **25**. Using different reaction conditions it is sometimes feasible to isolate a cyanohydrin which is attached to an anthraquinone moiety, but such compounds are not very stable, and are prone to release hydrogen cyanide and convert to the corresponding ketone. Some examples will be presented subsequently which deal with the Meerwein reactions of 2-methyleneglutaronitrile and the 2-methyleneglutaric acid ester, respectively (see Sections 4.1 and 4.3).

The ketone **25** can be isolated using a different work-up procedure, after completion of the first step of the reaction. It was obtained in the form of white crystals, but it has attracted no further attention from the synthetic point of view, although the two reactive sites of its molecule, the keto and the nitrile functions, may be used to construct a large number of heterocyclic compounds.

Therefore it became an easily feasible task to attach a chain consisting of three carbon atoms to the anthraquinone system. Although this reaction

was performed in methanol as solvent, i.e. under conditions which are normally employed for the Sandmeyer reaction and which one might have expected to lead to the almost exclusive formation of anthraquinone and of 1-methoxyanthraquinone, the only compound isolated was 1-(2-oxopropyl)anthraquinone (**25**), this being the only product formed in the Meerwein process.

Similarly, various substituted 1-aminoanthraquinones (**27a–27e**) were also subject to the diazotization and cyclization reactions and yielded a series of substituted benzanthrones (**29a–29e**)[23] (Scheme 11). An appropriate work-up procedure would very likely also enable the isolation to be effected of the corresponding 1-(oxopropyl)anthraquinones (**28a–28e**) as the respective intermediates.

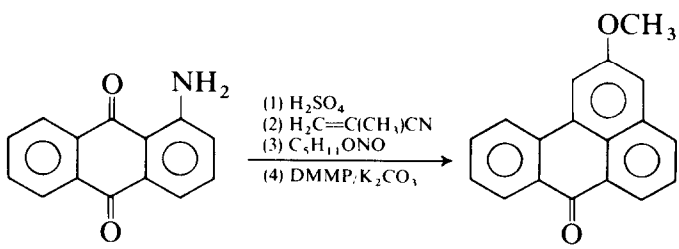


27a–27e **28a–28e** **29a–29e**

a: R = 4-Hydroxy-
b: R = 5-Hydroxy-
c: R = 5-Chloro-
d: R = 6,7-Dichloro-
e: R = 5-Benzoylamino-

Scheme 11

An interesting variation of the original experimental method of this benzanthrone synthesis has been described in a recently issued patent specification.[24] A Meerwein reaction of **1** with methacrylonitrile was used to achieve the formation of a new carbon bond at the carbon atom C-1 of the anthraquinone (Scheme 12). However, the primary step, the formation of the hydrogen sulfate salt obtained from 1-aminoanthraquinone and concentrated sulfuric acid, was carried out in dimethyl methylphosphonate as the



30

Scheme 12

solvent. Dimethyl methylphosphonate is rather inert towards hydrolysis promoted by mineral acids as long as the mixtures are maintained at ambient temperatures. Subsequently, methacrylonitrile and copper(I) chloride were added to the suspension and the diazotization and the coupling process were initiated and performed at 55–60°C by slow addition of isopentyl nitrite. Methyl nitrite may be used with equal success.[24] Those diazotizations which use isopentyl nitrite as the reagent often require an initial reaction temperature of 55–70°C and then proceed with a rather violent exothermic evolution of nitrogen which may require external cooling. Excellent yields are observed and the usual 'diazo-tars' are virtually absent.

The excess sulfuric acid was then neutralized by addition of potassium carbonate and the 2-hydroxybenzanthrone (**26**) formed was methylated with the excess of dimethyl methylphosphonate still present in the reaction mixture. This method furnished 2-methoxybenzanthrone (**30**) of excellent purity in a yield of 73%. Apparently all of the deeply coloured by-products formed in this reaction sequence remained in the filtrate which consisted largely of aqueous dimethyl methylphosphonate.

An alternative synthesis of 2-methoxybenzanthrone (**30**) may be carried out by using a separately prepared **1**, which is then suspended in dimethyl methylphosphonate and subjected to the same sequence of reactions as reported above. This method also furnished 2-methoxybenzanthrone of high purity.

The last step of this reaction sequence, leading to 2-methoxybenzanthrone, essentially describes the methylation of a phenol with dimethyl methylphosphonate in the presence of an alkali carbonate. This methylation technique has been extensively applied to phenols and more generally to acidic compounds, as has been amply demonstrated with many examples.[25]

This direct one-pot synthesis of 2-methoxybenzanthrone bears a very significant implication concerning future reactions involving aminoanthraquinones. It became obvious that the diazotizations of 1-aminoanthraquinone and the subsequent arylation of an olefin with a diazonium salt formed *in situ* may be carried out successfully in an aprotic solvent. Furthermore, it seemed noteworthy to confirm that the reaction sequence involving the formation of the amine hydrogen sulfate and the addition of isopentyl nitrite could also be carried out in dimethyl methylphosphonate without interference by processes such as the hydrolysis of the methylphosphonate.

Thus four different reaction steps may be combined and performed as a one-pot synthesis: (a) the formation of the amine hydrogen sulfate; (b) the diazotization and arylation of the olefin; (c) the ring closure to the benzanthrone; and (d) the methylation of the phenolic hydroxyl group.

Further applications of dimethyl methylphosphonate as solvent and as a reagent may be found in Section 5 and in the appropriate literature.[5,25-28]

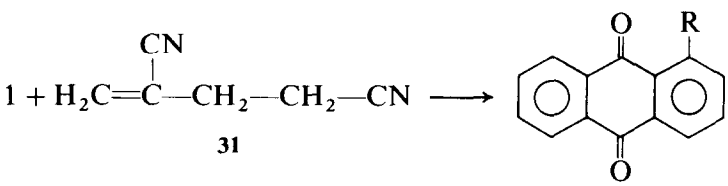
4 THE COMBINATION OF ANTHRAQUINONE SYSTEMS WITH COMPOUNDS HAVING FIVE CARBON ATOMS

The arylation of an olefinic compound consisting of four carbon atoms in a linear sequence would be the logical extension of the previously described reactions. However, this reaction has not yet been realized, presumably because the appropriate olefin is not a readily available compound.

The arylation of an olefin consisting of five carbon atoms using anthraquinone diazonium hydrogen sulfate can easily be performed.

4.1 The arylation of 2-methyleneglutaronitrile

Although the carbon double bond of 2-methyleneglutaronitrile (**31**) is far less reactive towards nucleophilic substitution than that of acrylonitrile, the Meerwein reactions with **1** succeeded when methanol or dimethyl methylphosphonate was used as the solvent[26] (Scheme 13). The reaction of **1** with 2-methyleneglutaronitrile (**31**) in methanol in the presence of catalytic amounts of copper(I) chloride produced a mixture consisting of 76% of the cyanohydrin (**32**), 5% of the cyanoketone (**33**), and 20% of anthraquinone. A similar result was obtained using dimethyl methylphosphonate as solvent



31 **32–35**

32 R = $-CH_2-C(OH)(CN)-CH_2-CH_2-CN$

33 R = $-CH_2-CO-CH_2-CH_2-CN$

34 R = $-CH_2-C(Cl)(CN)-CH_2-CH_2-CN$

35 R = $-CH_2-CO-CH_2-CH_2-COOH$

Scheme 13

yielding 76% of **32**, 1·8% of **33**, and 10% of anthraquinone, indicating a slight reduction in the quantity of anthraquinone formed when dimethyl methylphosphonate was used as solvent. On the other hand, the addition of one mole of copper(II) chloride provided the only source of chloride anions[9] when the reaction was performed in acetonitrile and thus furnished 1-anthraquinone-2-chloro-2,4-dicyanobutane (**34**) in a modest yield of 24%.

The cyanohydrin **32** slowly released hydrogen cyanide during the process of crystallization from ethanol. This reaction could be catalyzed by addition of basic aluminium oxide and was then preferably carried out in a higher-boiling solvent such as toluene, whereby the ketone **33** was obtained in 98% yield.

This reaction sequence permitted the synthesis of an anthraquinone derivative having a linear aliphatic chain of five carbon atoms. The ketone **33** may require some further attention because it features two important functional groups which bear inherently the possibility for the synthesis of new functional derivatives of anthraquinones.

Hydrolysis of the nitrile **33** with concentrated sulfuric acid furnished the γ-ketocarboxylic acid **35**.[26]

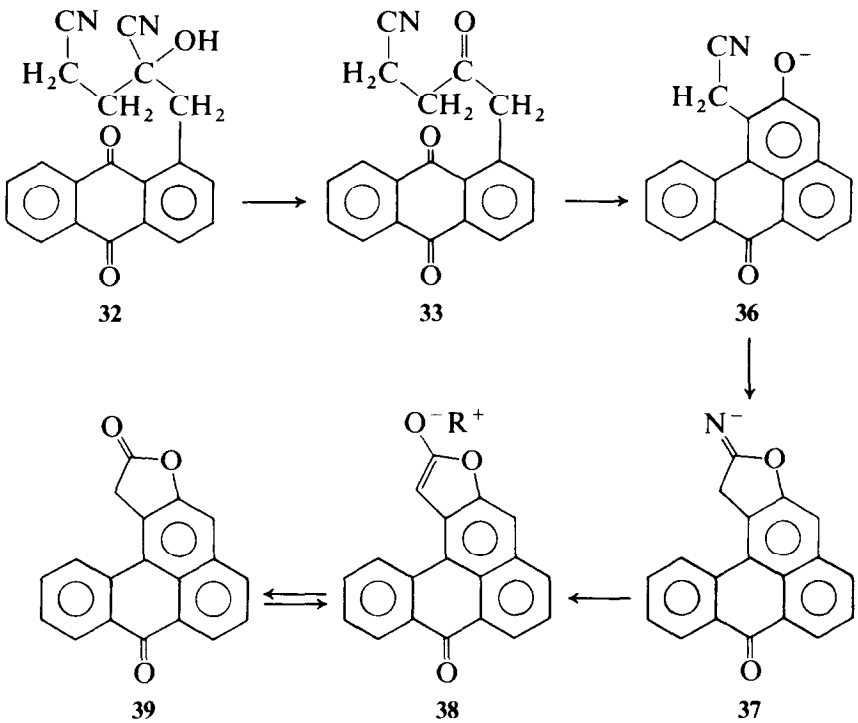
4.2 The synthesis of an enolizable benzanthrone lactone (1*H*-anthra[1,9-*e*,*f*]benzo[*b*]furan-2,8-dione)

The similarity of the structure of the cyanoketone **33** to that of 1-acetonylanthraquinone (**25**) gave rise to the surmise that a ring closure analogous to the one which proceeded to yield benzanthrone might also be performed with **33**.[26]

Addition of sodium methylate to a suspension of **33** in dimethylformamide (Scheme 14) effected a neat ring closure with formation of the anion **36**. Alternatively, the crude mixture of **32** and of **33** may also be subject to the same reaction with equal success. However, the reaction was not terminated at this stage, but the anion **36** attacked the nitrile group and formed, via **37**, the anion of the lactone **38** (R = Na), from which the lactone **39** (1*H*-anthra[1,9-*e*,*f*]benzo[*b*]furan-2,8-dione) was then precipitated after the addition of mineral acid.

The behaviour of the γ-lactone ring of **39** on addition of alkali is substantially different from that of an ordinary γ-lactone which has the lactone ring attached to an aromatic system, as for example the 2*H*-benzofuran-2-one.

Whilst the lactone ring of the latter compound is readily opened in an alkaline medium forming the salt of the α-hydroxyphenylacetic acid, the addition of potassium methylate or of sodium methylate to a solution of **39**



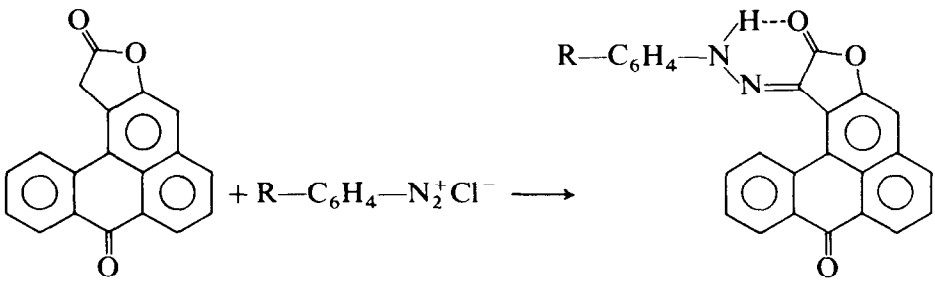
Scheme 14

in dimethylsulfoxide gave rise to the formation of an intense blue coloured solution, from which the alkali salts of 8-oxoanthra[1,9-*e*,*f*]benzo[*b*]-2-furanolate (**39**) were isolated as violet amorphous materials. Addition of tetrabutylammonium fluoride trihydrate precipitated the tetrabutylammonium salt of **38** ($R = (C_4H_9)_4N$) as deep blue crystals which could be recrystallized from acetonitrile. The structure could be inferred from the NMR spectrum and from the results of the nuclear Overhauser effect.[26]

Apparently this represents the first case of a compound in which a γ-lactone attached to a polycyclic system upon addition of alkali tends to enolize and thus becomes part of the entire aromatic system instead of undergoing the usual ring-opening reaction with formation of the carboxylic acid salt.

Some γ-lactones are known to undergo facile coupling reactions with diazonium compounds to give bright-coloured azo dyestuffs.[29,30]

The methylene group of the lactone **39** also reacted with aromatic diazonium salts yielding yellow to red coloured azo derivatives (**40a–40f**) (Scheme 15). The structures of **40a–40f** were confirmed by their analytical and their spectral data. Nearly all of these compounds were very insoluble in



39

40a–40f

a: R = H
b: R = 4-Cl
c: R = 4-NO_2
d: R = 4-SO_3Na
e: R = 4-OCH_3
f: R = 3,4-$(NO_2)_2$

Scheme 15

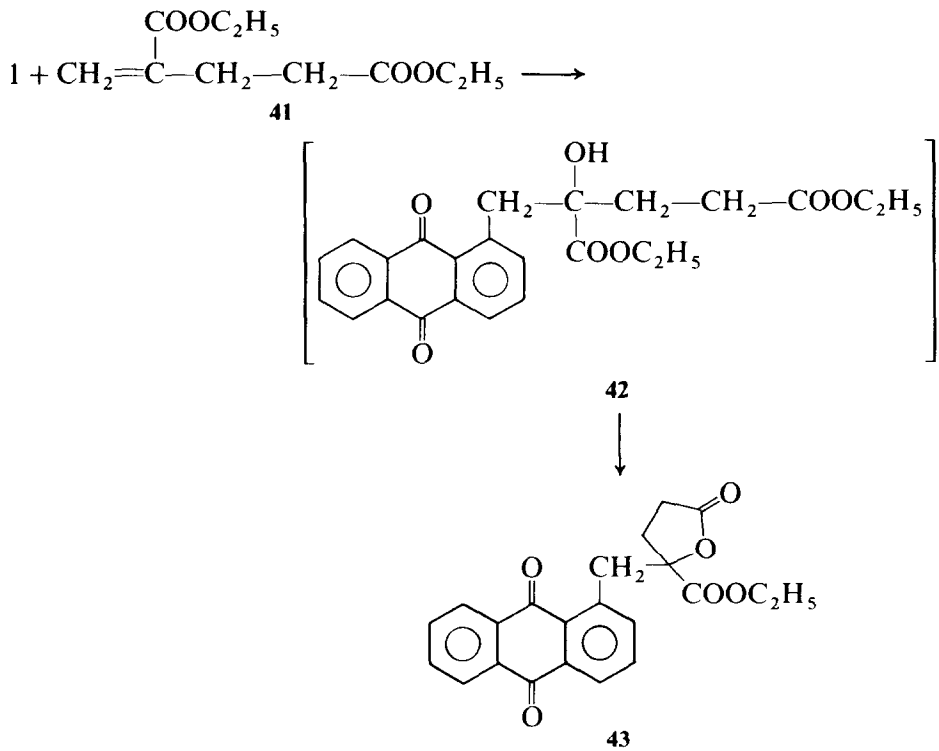
solvents which are suitable for obtaining NMR spectra. The *p*-methoxy derivative, however, proved to have a solubility sufficient for obtaining the NMR spectral data.[26]

Although the Meerwein reaction of 2-methyleneglutaronitrile with **1** furnished **32** in good yields, the reaction failed entirely when using the diazonium salts of substituted derivatives of 1-aminoanthraquinone, for example those with halogen, hydroxy or methoxy substituents. This is surprising since it has been reported that the arylation of methacrylonitrile using substituted derivatives of **1** yielded readily the corresponding 2-hydroxybenzanthrone under comparable experimental conditions.[23]

4.3 The arylation of 2-methyleneglutaric acid diethyl ester

The Meerwein reaction of 2-methyleneglutaric acid diethyl ester (**41**) with **1** proceeded in the first step in a manner similar to that described above for 2-methyleneglutaronitrile. The initially formed product, however, underwent subsequent ring closure to form a lactone (Scheme 16).

The reaction was carried out as described for 2-methyleneglutaronitrile in methanol to yield first the normal coupling product, **42**. The two reactive groups, viz., the hydroxy and the ethyl ester functions, gave rise to an immediate cyclization to the lactone **43**. The structure of **43** was verified by the data of the IR and the NMR spectra. Although the structural prerequisites are given for a ring closure between the carbonyl oxygen of the quinone moiety and the methylene group to form the benzanthrone system, the activation of the methylene group is apparently still insufficient. Only an adjacent keto group, as in **25**, enhanced the tendency for the ring closure.

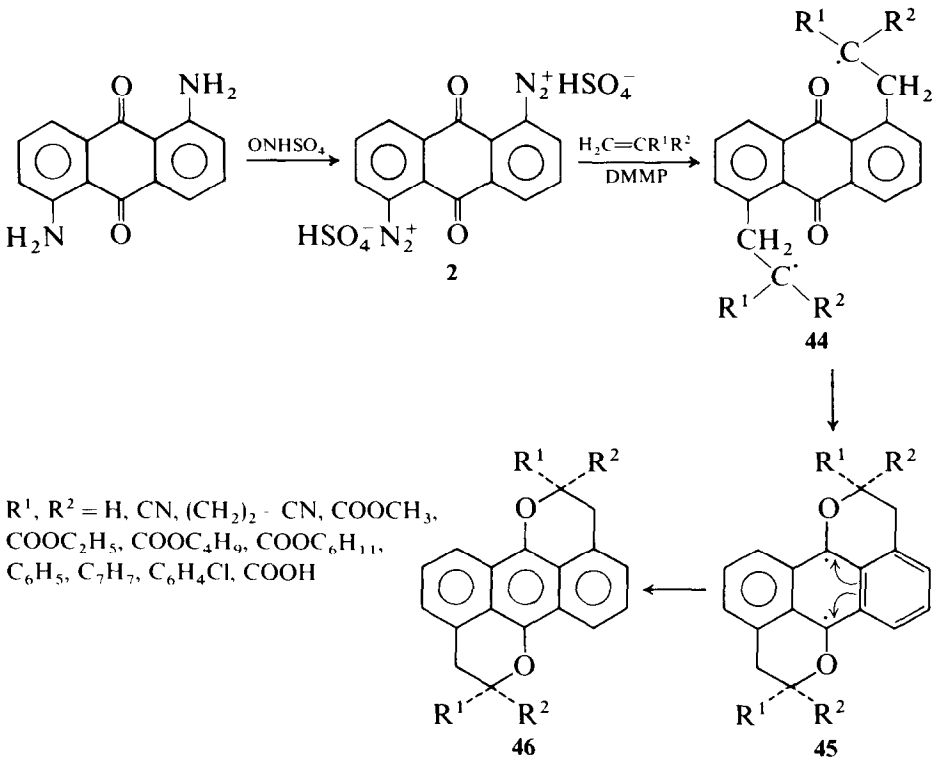


Scheme 16

5 DOUBLE MEERWEIN ARYLATIONS OF OLEFINIC COMPOUNDS WITH 1,5-ANTHRAQUINONE BIS(DIAZONIUM HYDROGEN SULFATE). SYNTHESIS OF ANTHRA[9,10-*b*,*c*:10,5-*b*,*c*]TETRAHYDRODIPYRANS

The modern ideas of the interpretation of the Meerwein reaction as a redox-modulated one-electron transfer process gained considerable support when it was applied to the quinone system of anthraquinone, and further from the subsequent results obtained in the studies of intramolecular Meerwein reactions[5] involving olefins and the 1,5-anthraquinone bis(diazonium hydrogen sulfate) (**2**).

Reactions of **2** with sufficiently activated olefins such as acrylonitrile, methacrylonitrile, acrylic esters, styrene or α-methylstyrene furnished derivatives of the new heterocyclic system anthra[9,10-*b*,*c*:10,5-*b*,*c*]tetrahydrodipyran (**46**)[5] (Scheme 17). The isolation of the derivatives succeeded best when the reactions were performed in dimethyl methylphosphonate as solvent, and again in the presence of catalytic quantities of copper(I) salts.[5] No products at all or only very low yields (< 5%) were



Scheme 17

obtained when dimethyl methylphosphonate was substituted by another solvent. The proof of structure and the stereochemical assignments for some of these compounds were carried out by an X-ray analysis, and gained further support by the ^{1}H- and the ^{13}C-NMR spectra. The mechanism which was proposed to explain the formation of these pentacyclic structures is detailed in Scheme 17. It may be presumed that from a charge transfer complex, formed from the olefin–metal salt–diazonium cation, one electron is transferred to the diazonium cation, giving rise to a radical which then loses nitrogen. The aryl radical formed attacks the olefin and forms an aliphatic radical (**44**) which then forms a new bond with the oxygen atom of the built-in quinone system (**45**). In this formulation, the electron required for the reduction of the quinone system (**45** → **46**) originates from the reaction system itself, and does not have to be generated by an outside source, as is the case in the arylations of the benzoquinones.[2]

These internal arylation reactions are typical examples of Meerwein reactions which proceed only in a very narrow, selected range of experimental conditions with satisfactory yields and seem to be largely determined by the proper choice of solvent.

REFERENCES

1. C. S. Rondestvedt, Jr, *Organic Reactions*, **11**, 189 (1960).
2. C. S. Rondestvedt, Jr, *Organic Reactions*, **24**, 225 (1976).
3. A. V. Dombrowskii, *Russ. Chem. Reviews*, **53**, 943 (1984); translation from *Uspekii Khim.*, **53**, 1625 (1984).
4. E. Mueller, ed., *Methoden der Organischen Chemie (Houben-Weyl)*, **10** (3), p. 24, Stuttgart, Georg Thieme Verlag (1978).
5. H. Fritz, G. Rihs, P. Sutter and C. D. Weis, *J. Heterocyclic Chem.*, **18**, 1571 (1981).
6. R. Stoll, *Monatsh. Chem.*, **32**, 1051 (1911).
7. A. Schaarschmidt, *Ber. Deutsche Chem. Ges.*, **49**, 2678 (1916).
8. Ref. 4, p. 20.
9. M. P. Doyle, B. Siegfried, R. C. Elliot and J. F. Dellaria, Jr, *J. Org. Chem.*, **42**, 2431 (1977).
10. Montecatini Edison S.p.A. (G. Ribaldone, V. Gallarte and G. Borsotti), German Offen. 2 323 543 (1973); *Chem. Abstr.*, **80**, 61068b (1974).
11. M. V. Gorelik, M. V. Kazankov and M. I. Bernadskii, *Zhur. Org. Khim.*, **14**, 1535 (1978); English translation, p. 1433.
12. G. Boffa, G. Pieri and N. Mazzafero, *Gazz. Chim. Ital.*, **102**, 697 (1972).
13. G. P. Chiusoli, M. Dubini, M. Ferrario and F. Gurrieri, *J. Chem. Soc. (C)*, 2889 (1968).
14. Montecatini Edison S.p.A. (M. Ferrari), Ital. Patent 848 909 (1969).
15. Montecatini Edison S.p.A. (G. Boffa and G. P. Chiusoli), Ital. Patent 860 016 (1969).
16. G. Bocelle, L. Cavalca, P. Scarabotto and C. D. Andreetiti, *Gazz. Chim. Ital.*, **101**, 735 (1971).
17. Y. R. Mednis and R. E. Valter, *Izv. Akad. Nauk. Latv. SSSR., Ser. Khim.*, 88 (1976); *Chem. Abstr.*, **85**, 32962m (1976).
18. B. F. Nielson and O. Samuelson, *J. Wood Chem. Technol.*, **2**, 47 (1982).
19. Z. D. Huang and W. X. Yua, *Hua Hsueh Hsueh Pao.* **39**, 165 (1981); *Chem. Abstr.*, **95**, 150 250 (1981).
20. M. V. Gorelik, M. V. Kazankov and M. I. Bernadskii, *Zhur. Org. Khim.*, **12**, 2041 (1976); English translation, p. 1988.
21. M. V. Gorelik, M. V. Kazankov and M. I. Bernadskii, *Zhur. Org. Khim.*, **14**, 1535 (1978); English translation, p. 1433.
22. Montedison S.p.A., German Offen., 2 434 466 (1973).
23. Montedison S.p.A., German Offen., 2 627 867 (1975); *Chem. Abstr.*, **86**, 91746n (1977).
24. Ciba-Geigy, European Patent Appln 50872 (1982); *Chem. Abstr.*, **97**, 146 216 (1981).
25. P. Sutter and C. D. Weis, *Phosphorus and Sulfur*, **4**, 335 (1978).
26. P. Sutter and C. D. Weis, *J. Heterocyclic Chem.*, **24**, 69 (1987).
27. H. Fuhrer, P. Sutter and C. D. Weis, *J. Heterocyclic Chem.*, **16**, 1121 (1979).
28. P. Sutter and C. D. Weis, *J. Heterocyclic Chem.*, **17**, 493 (1980).
29. F. Korte and K. H. Büchel, *Angew. Chem.*, **71**, 715 (1979).
30. G. F. Duffin and J. D. Kendall, *J. Chem. Soc.*, 3470 (1955).