ACTION OF
GRIGNARD REAGENTS
ON BENZANTHRONE

THE ACTION OF CERTAIN GRIGNARD REAGENTS ON BENZANTHRONE

A Thesis

by

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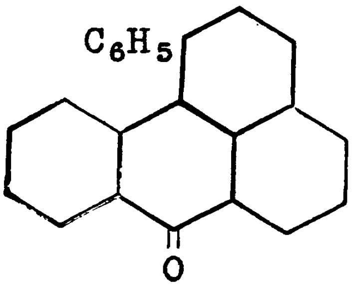
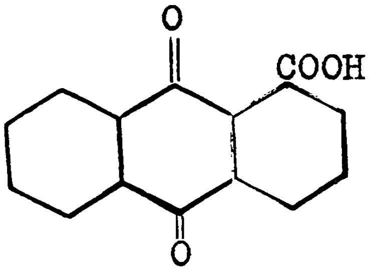
Introduction

Although the action of the Grignard reagent on anthrone and anthraquinone has been known for many years, it is only recently that any study has been made of its reaction with benzanthrone. The published work presents conflicting evidence. Clar (1) described a phenylbenzanthrone obtained by the action of phenylmagnesium bromide on the ketone. Without giving any experimental data, he made the statement that it was oxidized to anthraquinone-α-carboxylic acid (II). If true this would indicate that the phenyl group must be in the benzo ring (*), and accordingly he represented the substance by (I)



(I)



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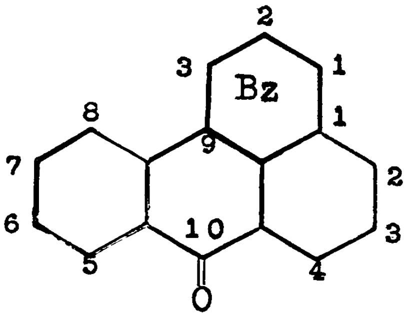

(A)

He also obtained a ketone by the action of benzylmagnesium chloride on benzanthrone. The product was assigned the formula (III), because when passed over platinized

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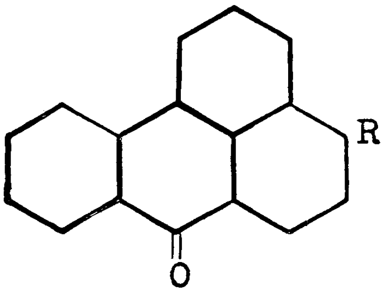
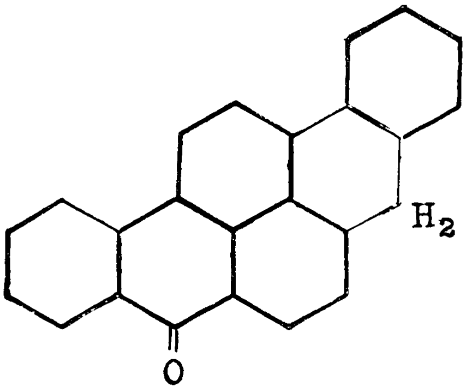
(*) The numbering of the benzanthrone nucleus used in this thesis is that due to Scholl, illustrated in formula (A).

charcoal at 300°, it gave a substance which appeared to be identical with the 4,5,8,9-dibenzo-10-keto-3-hydropyrene (IV) of Dziewonski and Moszew (2).



$R = CH_2C_6H_5$

(III)

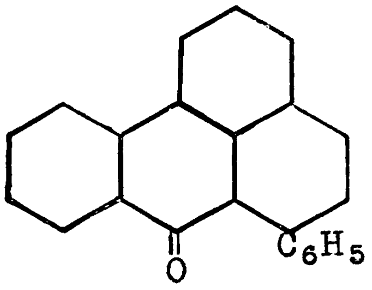


(IV)

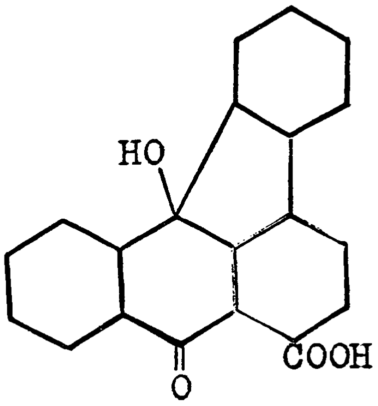
Nakanishi (3), working independently, obtained a phenylbenzanthrone to which he assigned formula (I), and similarly with little experimental detail given, claimed the acid (II) was its oxidation product. Both of these authors overlooked the fact that all three possible Bz-phenylbenzanthrones were known, and different from their substance (4).

Charrier and Ghigi (5) obtained a phenylbenzanthrone by the same reaction, which possessed the same physical properties, but noted that the acid obtained on oxidation did not analyze for anthraquinone-α-carboxylic acid. Their analytical values corresponded to a formula containing one phenyl group in addition to the anthraquinone nucleus.

They gave the formulas (V) and (VI) to the phenylbenzanthrone and its oxidation product respectively.



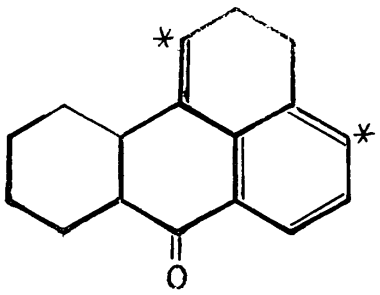
(V)



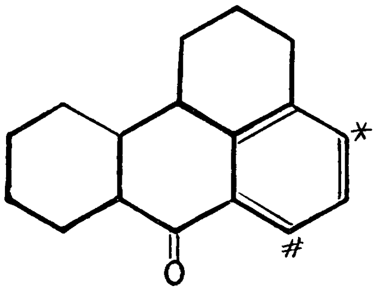
(VI)

Formula (VI) was written to explain the fact that on reduction the acid did not form the red vat which is characteristic of anthraquinone derivatives.

In spite of the conflicting views, the evidence of all three authors is in agreement in that the product is not a carbinol, as would be formed by 1,2-addition to the carbonyl group. Clar's structures (I) and (III) both involve 1,6-addition of the Grignard reagent to a conjugated system. No authentic case of this was known at the time the work was done. Formula (V) requires 1,4-addition to a system involving an unsaturated linkage in an aromatic ring. Such reactions are relatively uncommon. The bond structure essential to benzanthrone in order that such 1,6-addition should be possible is indicated in (VII). The positions marked (*) are in completely conjugated 1,6-relationship to the carbonyl group. Formula (V) if correct. would mean that the bond system of (VIII) was present, where the position (#) is in conjugated 1,4-relationship to the doubly-bound oxygen. The latter formula would also allow Clar's 1,6-addition of benzylmagnesium chloride at (*).



(VII)



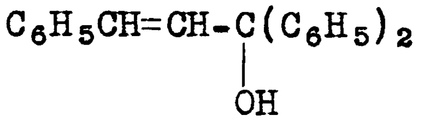
(VIII)

It becomes of great importance therefore, to determine exactly the nature of the products, because the results may then be used to show the bond structure of the polynuclear system in benzanthrone. Further, if this is really an instance of 1,6-addition of the Grignard reagent , it should be checked, for there is only one authentic example of this at the present time.

These possibilities were carefully considered in arranging the experimental work described in this thesis. Before discussing the results obtained and their interpretation, it is essential to consider previous work that may have a possible relation to the problem in hand.

The first topic will be 1,4-addition of the Grignard reagent to unsaturated systems involving the carbonyl group, and the factors that favor 1,2- or 1,4-addition to such systems. The alternative mechanism of 1,2-addition to the $C=C$ linkage will be discussed in the light of recent work, after which the types of reaction obtained with a number of unsaturated ketones containing ring systems will be reviewed.

Only four years after V. Grignard's original paper, Kohler (6) announced the discovery of 1,4-addition of phenylmagnesium bromide to benzalacetophenone. The product obtained after decomposition of the magnesium complex was at first thought to be diphenyl styryl carbinol (IX), though it gave neither esters nor ethers. It was later found to be the ketone (X), readily forming a phenylhydrazone and an oxime.



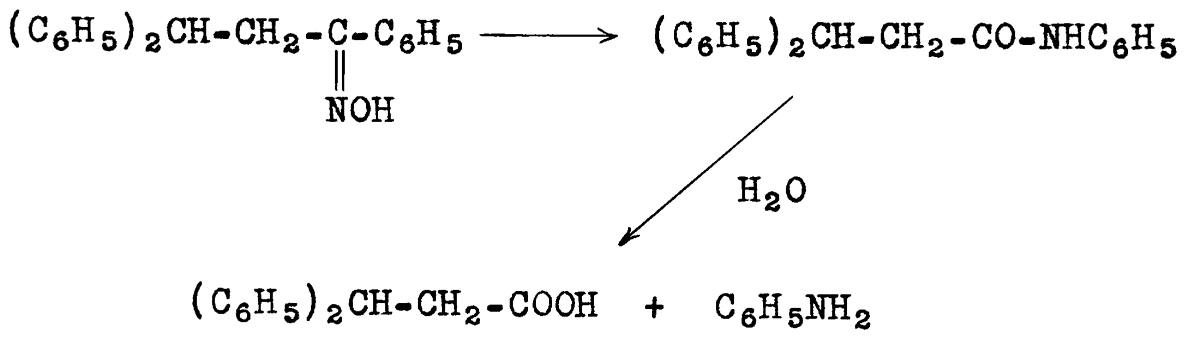
$$C_6H_5CH{=}CH{-}\underset{\displaystyle OH}{\underset{|}{C}}(C_6H_5)_2$$

(IX)

$(C_6H_5)_2CH{-}CH_2{-}CO{-}C_6H_5$

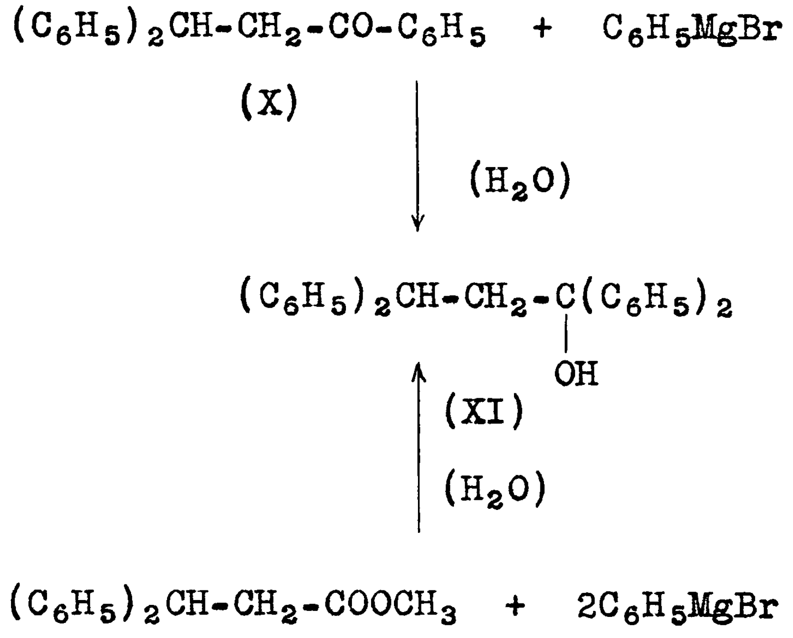
(X)

The oxime inderwent the Beckmann rearrangement to yield an anilide which was hydrolyzed to aniline and β,β-diphenylpropionic acid.



$$(C_6H_5)_2CH\text{-}CH_2\text{-}\underset{\underset{NOH}{\|}}{C}\text{-}C_6H_5 \longrightarrow (C_6H_5)_2CH\text{-}CH_2\text{-}CO\text{-}NHC_6H_5 \xrightarrow{H_2O} (C_6H_5)_2CH\text{-}CH_2\text{-}COOH + C_6H_5NH_2$$

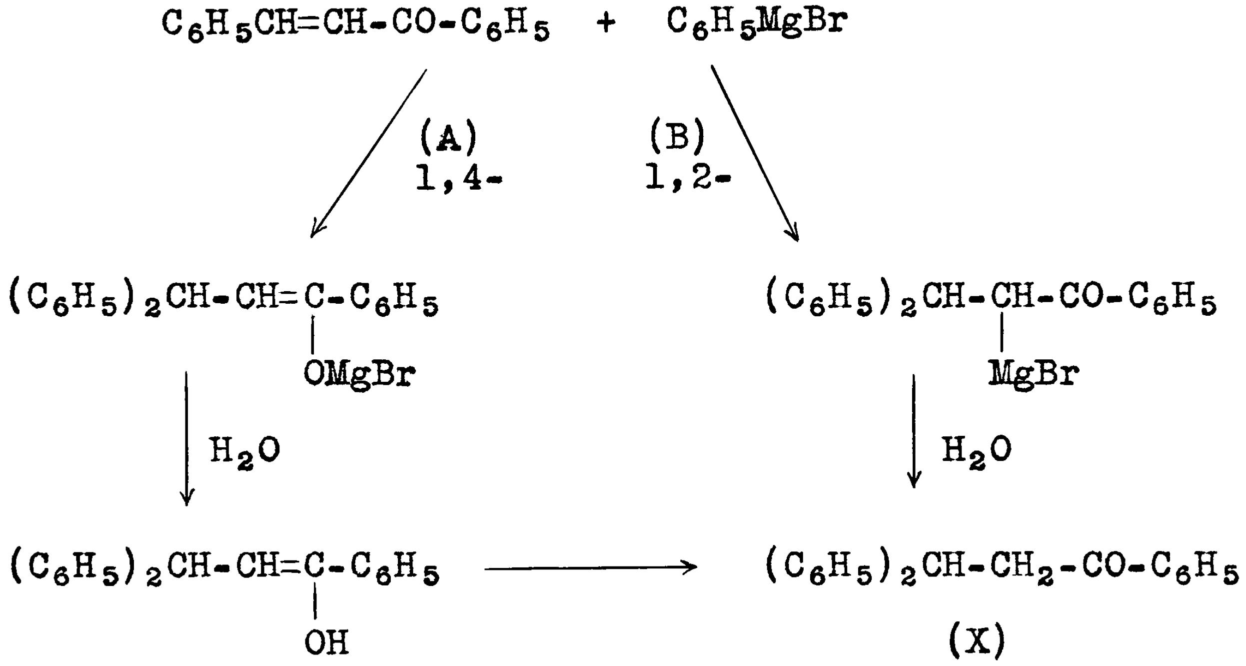
The production of this acid clearly showed that the position taken by the entering phenyl group was on the carbon atom of the original ketone in the beta position, referred to the carbonyl group. It was finally shown that the addition of another molecule of phenylmagnesium bromide to (X) produced a substance (XI) identical with the product obtained by the action of phenylmagnesium bromide on the methyl ester of β,β-diphenylpropionic acid.



$$\underset{(X)}{(C_6H_5)_2CH\text{-}CH_2\text{-}CO\text{-}C_6H_5} + C_6H_5MgBr \xrightarrow{(H_2O)} \underset{(XI)}{(C_6H_5)_2CH\text{-}CH_2\text{-}\underset{\underset{OH}{|}}{C}(C_6H_5)_2} \xleftarrow{(H_2O)} (C_6H_5)_2CH\text{-}CH_2\text{-}COOCH_3 + 2C_6H_5MgBr$$

With the use of formula (X), based upon these (and other) considerations, Kohler was able to explain all the reactions of the new substance.

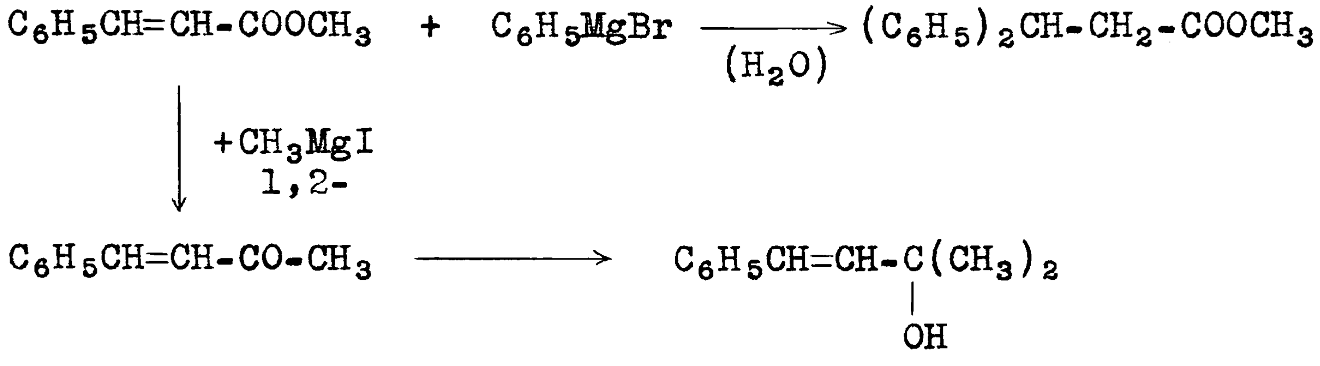
The mechanism of the reaction could be written two ways.



For reasons to be discussed later, the reaction (A) was favored by Kohler.

This was the first of a brilliant series of papers by the same author in which the action of various Grignard reagents on a great variety of α,β-unsaturated ketones was described.

Methyl cinnamate (7) was found to undergo 1,4-addition with several Grignard reagents, including phenylmagnesium bromide, whereas, with methylmagnesium iodide 1,2-addition took place.



$$C_6H_5CH{=}CH{-}COOCH_3 \quad + \quad C_6H_5MgBr \xrightarrow[(H_2O)]{} (C_6H_5)_2CH{-}CH_2{-}COOCH_3$$

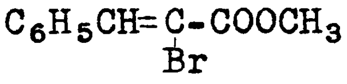
$$\Big\downarrow {\scriptstyle +CH_3MgI \atop 1,2-}$$

$$C_6H_5CH{=}CH{-}CO{-}CH_3 \longrightarrow C_6H_5CH{=}CH{-}\underset{\displaystyle OH}{\underset{|}{C}}(CH_3)_2$$

(XII) (XIII)

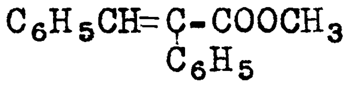
The reaction as ordinarily carried out yielded the unsaturated carbinol (XIII), but by running a reverse Grignard the isolation of the ketone (XII) was accomplished. Hence this case differed from the previous one, in that the type of reaction obtained depended on the Grignard reagent used.

α-Bromo- (XIV) (8) and α-phenylcinnamic ester (XV) (9) reacted in a similar manner.



$$C_6H_5CH{=}\underset{Br}{C}{-}COOCH_3$$

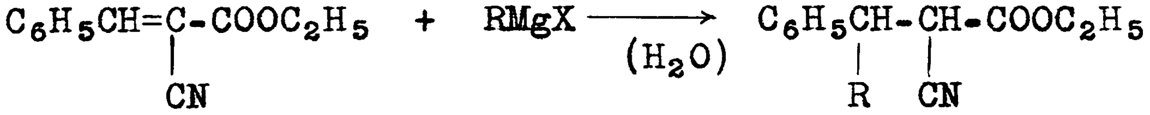
(XIV)



$$C_6H_5CH{=}\underset{C_6H_5}{C}{-}COOCH_3$$

(XV)

α-Cyanocinnamic ester (XVI) (10) gave only 1,4-addition with all types of Grignard reagents.



$$C_6H_5CH{=}\underset{\displaystyle CN}{\underset{|}{C}}{-}COOC_2H_5 \quad + \quad RMgX \xrightarrow[(H_2O)]{} C_6H_5\underset{\displaystyle R}{\underset{|}{CH}}{-}\underset{\displaystyle CN}{\underset{|}{CH}}{-}COOC_2H_5$$

(XVI)

The cyano group on the α-carbon atom, like the neighboring phenyl radical in benzalacetophenone, seemed to hinder

1,2-addition to the carbonyl group, in such cases 1,4-addition was found.

In Table I are given the percentages of 1,2- and 1,4-addition products found,using the reagents phenylmagnesium bromide and ethylmagnesium bromide on α,β-unsaturated aldehydes and ketones (11). Special quantitative methods were devised for measuring the relative amounts of 1,2- and 1,4-addition products formed, since it was found that in many cases both types of products were produced simultaneously. In every case the percentage of 1,4-addition is shown, and the amount of 1,2-addition product is obtained by subtracting this from 100.

TABLE I

Substance	With C_2H_5MgBr	With C_6H_5MgBr
a) $C_6H_5CH=CH-CO-CH_3$	60	12
b) $C_6H_5CH=CH-CO-CH_2CH_3$	71	40
c) $C_6H_5CH=CH-CO-CH(CH_3)_2$	100	88
d) $C_6H_5CH=CH-CO-C(CH_3)_3$	100	100
e) $C_6H_5CH=CCH_3-CO-C_6H_5$	100	100
f) $CH_3CH=CH-CO-CH_3$	75	40
g) $(CH_3)_2C=CH-CO-CH_3$	0	0
h) $CH_3CH=CH-CO-C_6H_5$	100	100
i) $CCl_3CH=CH-CO-C_6H_5$	—	95

Substance	With C_2H_5MgBr	With C_6H_5MgBr
j) $C_6H_5CH{=}CH{-}CO{-}C_6H_5$	99	94
k) $C_6H_5CCH_3{=}CH{-}CO{-}C_6H_5$	44	41
l) $(C_6H_5)_2C{=}CH{-}CO{-}C_6H_5$	18	0
m) $(C_6H_5)_2C{=}CC_6H_5{-}CO{-}C_6H_5$	—	—

Kohler found that while aldehydes gave 1,2-addition only, to form unsaturated carbinols, ketones generally gave both unsaturated carbinols and saturated ketones.

It has very recently been shown (12), that crotonaldehyde gives a saturated aldehyde with t-butylmagnesium chloride. This is the only instance known in which 1,4-addition has been observed.

The activity of the carbonyl group is one important factor, and it is of interest to compare the rate of addition of the Grignard reagent to other known addition reactions of this group. Some of these are summarized in Table II. The first column gives the percentage of sodium bisulfite addition-product formed in forty minutes, the second the percentage of oxime formed in ten minutes, the third that of phenylhydrazone formed in one hour, and the last the percentage of tertiary alcohol obtained by treating the benzal derivatives of the same substances (i.e. (a),(b), (c) and (d), Table I) with phenylmagnesium bromide.

TABLE II

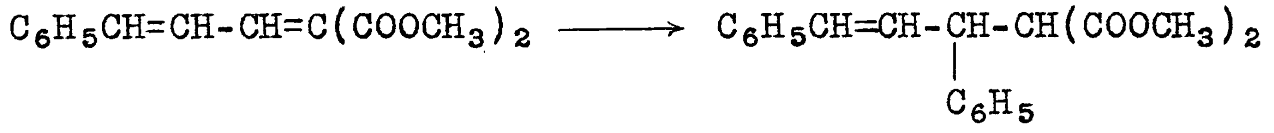
Substance	1	2	3	4
CH_3-CO-CH_3	53.6	45.1	66	88
CH_3-CO-C_2H_5	29.1	36.3	52	60
CH_3-CO-CH(CH_3)$_2$	9.4	31.4	15	12
CH_3-CO-C(CH_3)$_3$	5.6	12.9	3	0

It is seen that with the diminution of the activity of the carbonyl group, as shown by the decreased rate of formation of the oxime etc., the amount of 1,2-addition product obtained falls off correspondingly.

However, the reactivity of this group is not the only important factor, though it does directly affect the rate of formation of the tertiary alcohol. Branching of the chain at the other end of the conjugated system has a powerful "blocking effect" on the amount of 1,4-addition taking place. This is clearly shown by a comparison of (f) and (g) in Table I, and by (j),(k),(l) and (m). In the four last mentioned substances, the carbonyl groups might be expected to be about equally active, but the addition of the Grignard reagent shows wide variations, it is very sensitive to slight changes in structure. In some instances hindrance to both types of addition is prohibitive; in the case of tetraphenylpropenone (m, Table I) no reaction took place under the experimental conditions employed.

The author concludes that the relative amounts of unsaturated carbinol and saturated ketone formed in any particular case depend on the rates of two competing reactions 1,2- and 1,4-addition. These rates are largely dependent on steric influences such as branching of the chain, but are little affected by polarity. The radical in the RMgX compound is also an important factor, aliphatic radicals tending to give more 1,4-addition than do aromatic radicals such as C_6H_5. This is clearly shown in Table I. Temperature has relatively little effect on the result other than to influence the rate of reaction. (Cf.p.21)

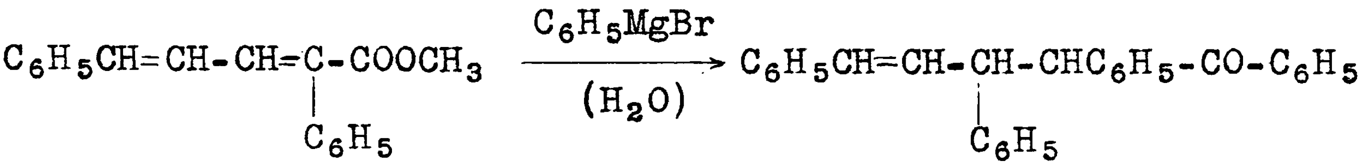
Longer conjugated systems where, theoretically, 1,6-addition is possible have been found to give 1,2- and 1,4-addition. Reimer (13) added phenylmagnesium bromide to cinnamylidene malonic ester (XVII), and obtained (XVIII) by 1,4-addition.



$$C_6H_5CH{=}CH{-}CH{=}C(COOCH_3)_2 \longrightarrow C_6H_5CH{=}CH{-}\underset{C_6H_5}{\underset{|}{CH}}{-}CH(COOCH_3)_2$$

(XVII) (XVIII)

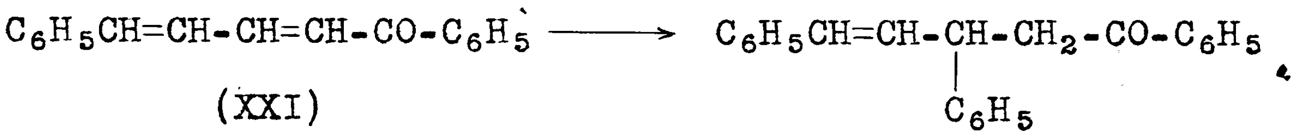
Methyl α-phenylcinnamylidene acetate (XIX) (14) reacted stepwise, first 1,2- and then 1,4-, to give the ketone (XX).



$$C_6H_5CH{=}CH\text{-}CH{=}\underset{\displaystyle C_6H_5}{C}\text{-}COOCH_3 \xrightarrow[(H_2O)]{C_6H_5MgBr} C_6H_5CH{=}CH\text{-}\underset{\displaystyle C_6H_5}{CH}\text{-}CHC_6H_5\text{-}CO\text{-}C_6H_5$$

(XIX) (XX)

Kohler (15) showed that cinnamylidene acetophenone (XXI) gave only 1,4-addition products with the Grignard reagent.

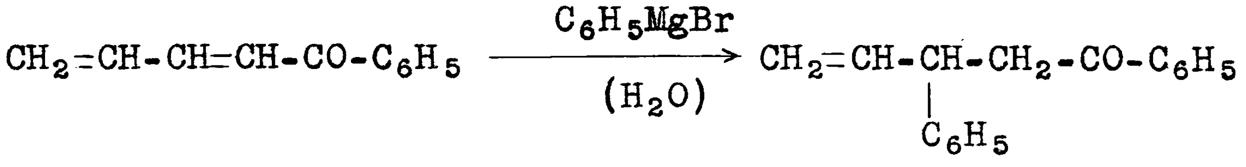


$$C_6H_5CH{=}CH\text{-}CH{=}CH\text{-}CO\text{-}C_6H_5 \longrightarrow C_6H_5CH{=}CH\text{-}\underset{\displaystyle C_6H_5}{CH}\text{-}CH_2\text{-}CO\text{-}C_6H_5$$

(XXI)

$+C_6H_5MgBr$

More recently Kohler and Butler (16) have investigated a similar system (XXII) which offers no hindrance to 1,6-addition. It gave only the ketone (XXIII), formed by 1,4-addition of phenylmagnesium bromide. The authors conclude that, as no 1,6-addition took place even in this favorable case, for some reason inherent in the nature of conjugated systems, 1,4-addition is easier than 1,6-addition.(*)

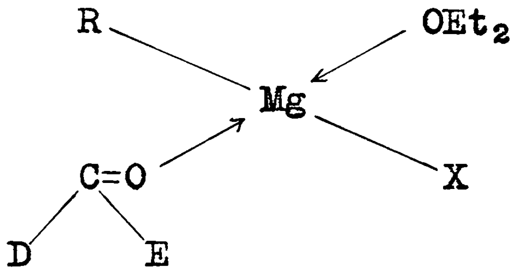


$$CH_2{=}CH\text{-}CH{=}CH\text{-}CO\text{-}C_6H_5 \xrightarrow[(H_2O)]{C_6H_5MgBr} CH_2{=}CH\text{-}\underset{\displaystyle C_6H_5}{CH}\text{-}CH_2\text{-}CO\text{-}C_6H_5$$

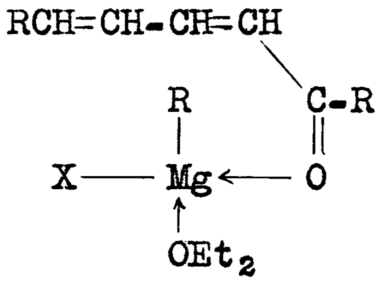
(XXII) (XXIII)

(*) The formation of 1,4-addition products is not confined to the Grignard reagent, but the literature is too voluminous to be included here. It is sufficient to note that 1,4-addition results even when 1,6- is possible.

In an attempt to explain some abnormal reactions of benzylmagnesium chloride, Johnson (20) has presented an hypothesis which assumes that a coordination compound is first formed from the Grignard reagent and the unsaturated substance. For example the coordination compound (A) would be formed from the ketone D-CO-E and the Grignard reagent.



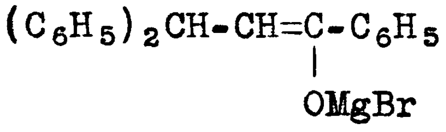
(A)



(B)

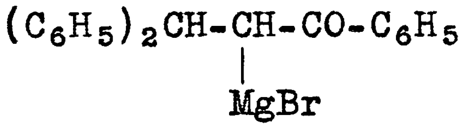
Now, supposing a similar coordination compound (B) to be formed from the Grignard reagent and an unsaturated ketone, and using the commonly accepted valence angles, it is seen that the radical R is nearer in space to the fourth carbon atom than to the sixth, therefore 1,4-addition would seem more probable than 1,6-addition.

As previously mentioned, Kohler showed that the mechanism of the Grignard reaction with α,β-unsaturated ketones was through 1,4-addition, the formula of the magnesium complex obtained from phenylmagnesium bromide and benzalacetophenone being (XXIV). If the mechanism were direct addition to the ethylenic linkage, the complex would correspond to (XXV).



$(C_6H_5)_2CH\text{-}CH{=}\underset{\underset{\displaystyle OMgBr}{|}}{C}\text{-}C_6H_5$

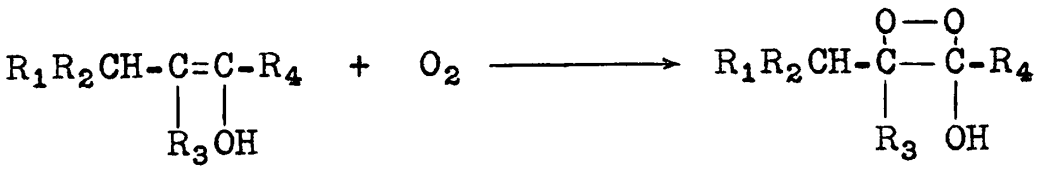
(XXIV)



$(C_6H_5)_2CH\text{-}\underset{\underset{\displaystyle MgBr}{|}}{CH}\text{-}CO\text{-}C_6H_5$

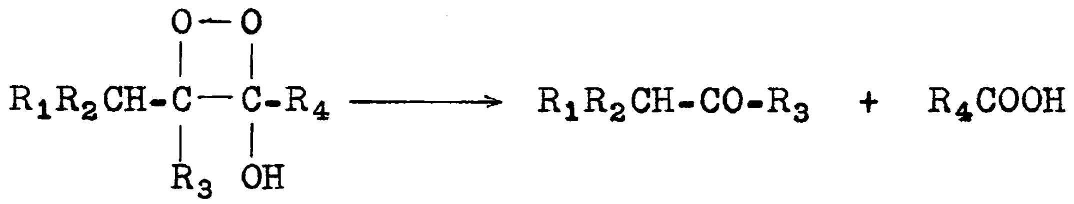
(XXV)

However an intermediate of formula (XXV) would be a Grignard reagent itself, and react as an RMgX compound with saturated ketones and esters. Several of the metallic derivatives found in these reactions were investigated, but in no case was any reaction observed. Recently a reaction between this complex and a compound containing an active carbonyl group has been found (17), but it proceeded much less readily than do the reactions of the Grignard reagent itself. This indirectly favored structure (XXIV). Treatment with benzoyl chloride, at first believed to be a useful reagent for distinguishing between the two possibilities, was later proved to be unreliable (18). The presence of the double bond in (XXIV) could be shown by the instant decolorization of bromine. In cases where there was a hydrocarbon residue on the carbon in the ∝-position to the carbonyl group, a stable peroxide was formed if the solution, after decomposition of the magnesium complex, was chilled and aerated.



$$R_1R_2CH\text{-}\underset{\underset{\displaystyle R_3}{|}}{C}{=}\underset{\underset{\displaystyle OH}{|}}{C}\text{-}R_4 + O_2 \longrightarrow R_1R_2CH\text{-}\underset{\underset{\displaystyle R_3}{|}}{\overset{O\,-}{C}}-\underset{\underset{\displaystyle OH}{|}}{\overset{O}{C}}\text{-}R_4$$

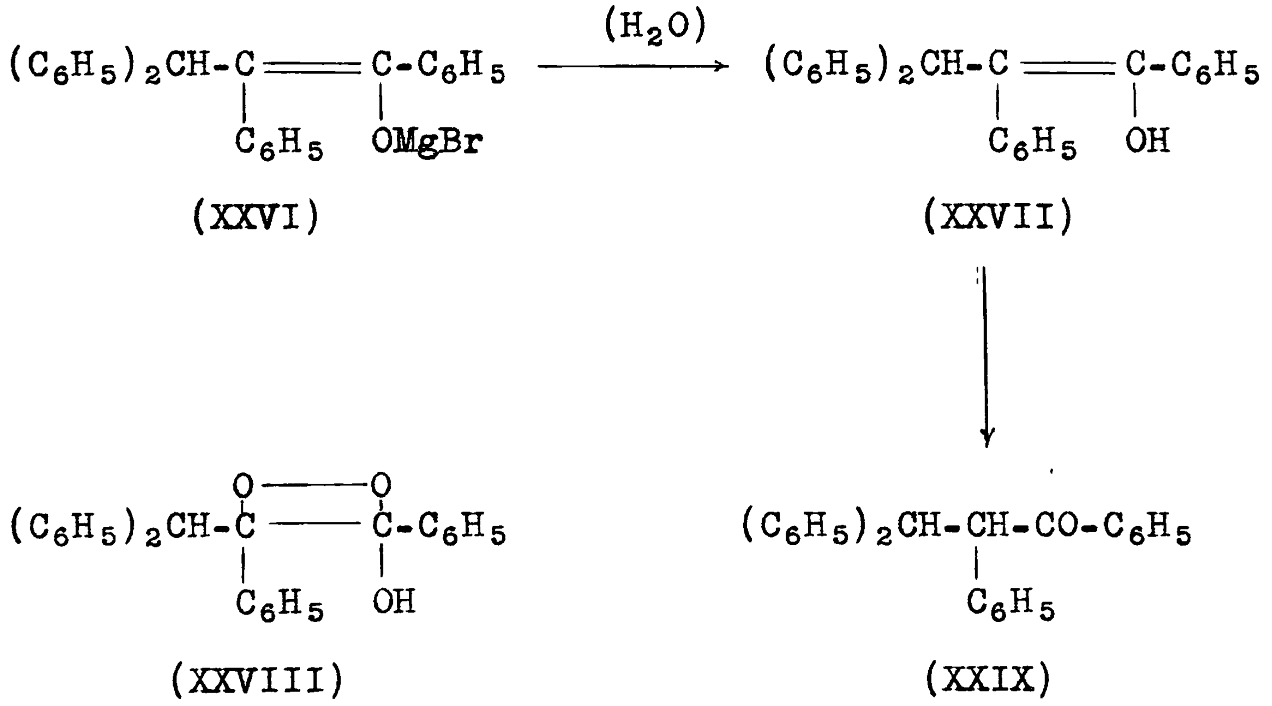
The peroxide decomposed on heating strongly, according to the equation:



$$R_1R_2CH\text{-}\overset{\displaystyle O-}{\underset{\displaystyle R_3}{C}}\!-\!\overset{\displaystyle O}{\underset{\displaystyle OH}{C}}\text{-}R_4 \longrightarrow R_1R_2CH\text{-}CO\text{-}R_3 + R_4COOH$$

When there was no substituent on the ∝-carbon, rearrangement to the keto form was too rapid to permit of peroxide formation.

From the product of the reaction between benzaldesoxybenzoin and phenylmagnesium bromide (XXVI) (19) a peroxide of the structure (XXVIII) was obtained. The enol (XXVII) could be isolated in the pure state, and its gradual rearrangement to the keto form (XXIX) studied.



$$(C_6H_5)_2CH\text{-}\underset{\displaystyle C_6H_5}{C}=\underset{\displaystyle OMgBr}{C}\text{-}C_6H_5 \xrightarrow{(H_2O)} (C_6H_5)_2CH\text{-}\underset{\displaystyle C_6H_5}{C}=\underset{\displaystyle OH}{C}\text{-}C_6H_5$$

$$(C_6H_5)_2CH\text{-}\underset{\displaystyle C_6H_5}{\overset{\displaystyle O-}{C}}\!-\!\underset{\displaystyle OH}{\overset{\displaystyle O}{C}}\text{-}C_6H_5 \qquad (C_6H_5)_2CH\text{-}\underset{\displaystyle C_6H_5}{CH}\text{-}CO\text{-}C_6H_5$$

Fuson and his co-workers (21) have shown that dibenzalacetone (XXX) reacts with phenylmagnesium bromide in two steps.

$$C_6H_5CH{=}CH\text{-}CO\text{-}CH{=}CHC_6H_5 \xrightarrow[(H_2O)]{C_6H_5MgBr} (C_6H_5)_2CH\text{-}CH_2\text{-}CO\text{-}CH{=}CHC_6H_5$$

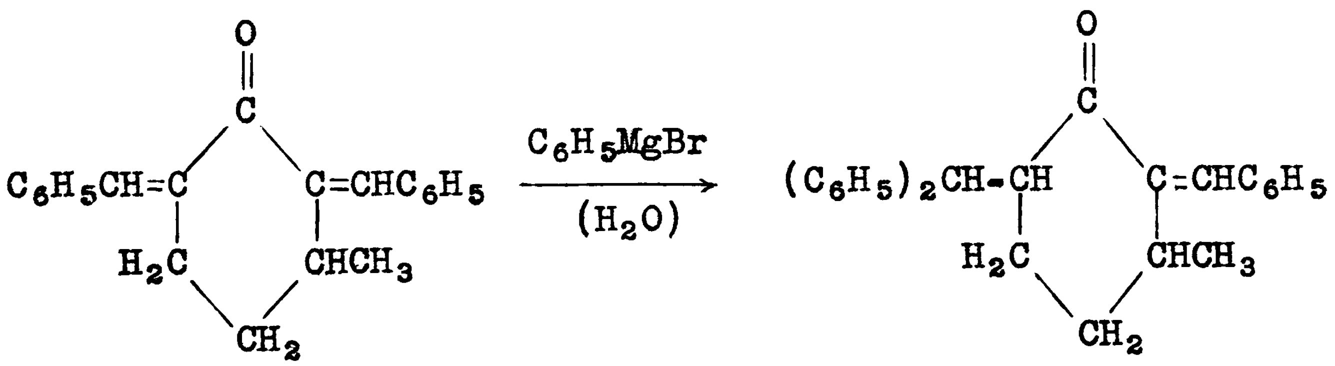
(XXX) (XXXI)

$$(C_6H_5)_2CH\text{-}CH_2\text{-}CO\text{-}CH{=}CHC_6H_5 \longrightarrow (C_6H_5)_2CH\text{-}CH_2\text{-}CO\text{-}CH_2\text{-}CH(C_6H_5)_2$$

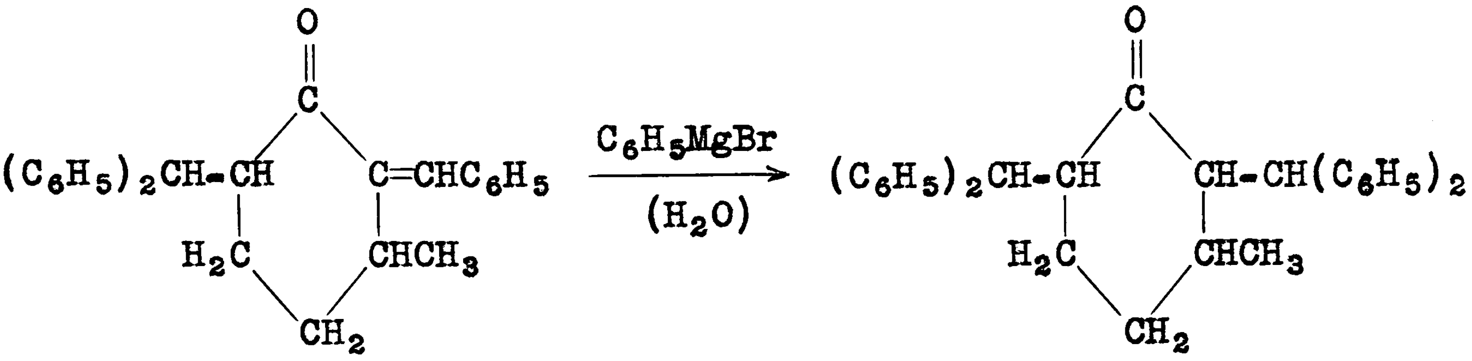
(XXXI) (XXXII)

The fact that this could not be carried out by a single step, even with a large excess of the Grignard reagent, showed that the carbonyl group must have been involved in the reaction, i.e., that it was really 1,4-addition to the conjugated system $C{=}C{-}C{=}O$, and not direct addition to the ethylenic linkage.

The cyclic ketone 2,6-dibenzal-3-methyl-cyclohexanone-1 (XXXIII) (22) reacted with phenylmagnesium bromide in two stages to give the products (XXXIV) and (XXXV).



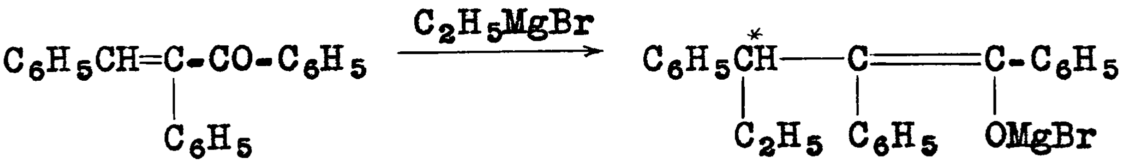
(XXXIII) (XXXIV)



(XXXIV) (XXXV)

In both cases peroxides were readily obtainable. The carbon atoms 3,4 and 5 in the ring constitute the hydrocarbon residue. This compound (XXXIII) is really a di-α-substituted dibenzalacetone.

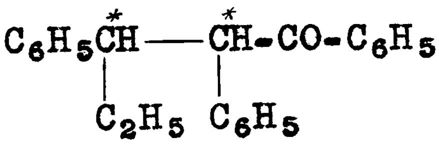
Further evidence of a stereochemical nature, showed that the magnesium residue was attached to oxygen as in (XXIV); this was obtained from the reaction of ethylmagnesium bromide on the stereoisomers benzaldesoxybenzoin and iso-benzaldesoxybenzoin (XXXVI) (19). The magnesium complex from either gave the same compound with acid chlorides, making it seem probable that there was only one addition compound formed(XXXVII).



$$C_6H_5CH{=}\underset{C_6H_5}{C}\text{-}CO\text{-}C_6H_5 \xrightarrow{C_2H_5MgBr} C_6H_5\underset{C_2H_5}{\overset{*}{CH}}-\underset{C_6H_5}{C}=\underset{OMgBr}{C}\text{-}C_6H_5$$

(XXXVI) (XXXVII)

Two substances One substance

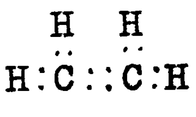


$$C_6H_5\underset{C_2H_5}{\overset{*}{CH}}-\underset{C_6H_5}{\overset{*}{CH}}\text{-}CO\text{-}C_6H_5 \quad \text{(XXXVIII)}$$

Hydrolysis of (XXXVII) gave rise to two ketones (XXXVIII) both previously known, The relative amounts of either depended entirely on the method of hydrolysis; in favorable conditions only 0.5 percent of the higher-melting isomer was obtained. Kohler inferred that only one substance was formed directly from (XXXVII), and that the small amount of the other found was produced by transformation of the lower-melting isomer. This seemed very probable, as it was found that the latter passed into the other form very readily under the experimental conditions.

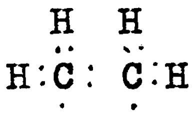
The magnesium compound (XXXVII) contained one asymmetric carbon atom (*), and the final ketone contained two. The fact that one isomer was produced in much greater amounts than the other, indicated that these two centres of asymmetry could not have been formed simultaneously, but one after the other as in the mechanism shown. The presence of the first asymmetric carbon atom had a directing influence on the configuration of the second one. The author called this a case of asymmetric synthesis. If the formation of the magnesium complex were by direct addition to the ethylenic linkage, the two centres of asymmetry should have been formed simultaneously, and equal amounts of the two isomers of (XXXVIII) should have been found under the most favorable conditions of hydrolysis.

From time to time, papers have appeared in which addition of the Grignard reagent to the C=C linkage was claimed. In a series of papers (23-27) Gilman has described the results of experiments undertaken to determine whether the Grignard reagent ever adds to ethylenic double bonds. A large number of suitable compounds were treated with various RMgX compounds, in some cases in solvents of higher boiling point than diethyl ether, but no reaction was observed. Using the reagent ethylmagnesium bromide in solutions of known concentration, (23) the amount remaining unchanged at the end of the experiment could be easily determined by measuring the volume of ethane evolved on decomposing the magnesium compound with dilute sulfuric acid. Although such quantitative experiments were carried out with a large number of unsaturated hydrocarbons, in no case was any reaction detected. Gilman concluded from this that the electronic structure of the ethylenic double bond was represented by (A) or (B) rather than by the polar form (C), as this last would be expected to react with the polar Grignard reagent.



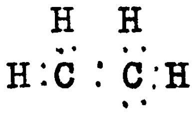
$$\mathrm{H}:\overset{\mathrm{H}}{\overset{..}{\mathrm{C}}}::\overset{\mathrm{H}}{\overset{..}{\mathrm{C}}}:\mathrm{H}$$

(A)



$$\mathrm{H}:\underset{\cdot}{\overset{\mathrm{H}}{\overset{..}{\mathrm{C}}}}:\;\underset{\cdot}{\overset{\mathrm{H}}{\overset{..}{\mathrm{C}}}}:\mathrm{H}$$

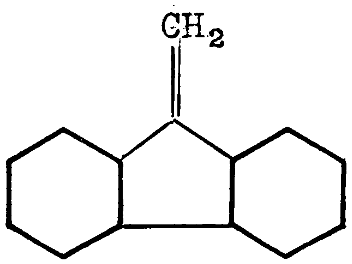
(B)



$$\mathrm{H}:\overset{\mathrm{H}}{\overset{..}{\mathrm{C}}}\;:\;\underset{..}{\overset{\mathrm{H}}{\overset{..}{\mathrm{C}}}}:\mathrm{H}$$

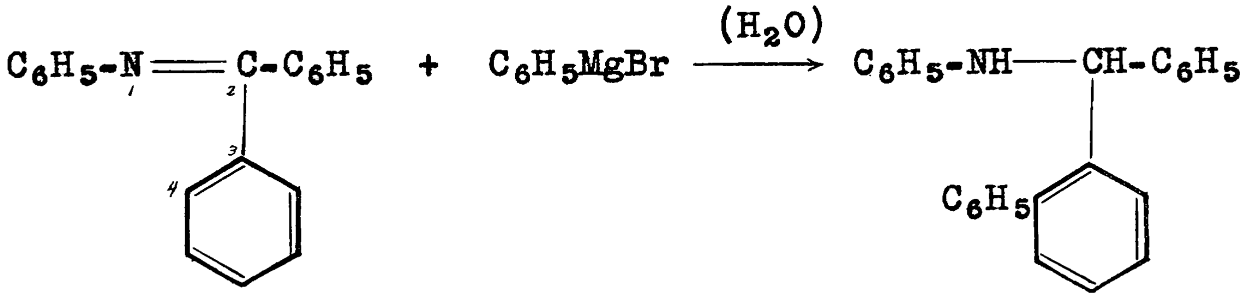
(C)

Wieland and Kraus (28) have shown that the very active double bond in (XXXIX) does not react with the Grignard reagent.



(XXXIX)

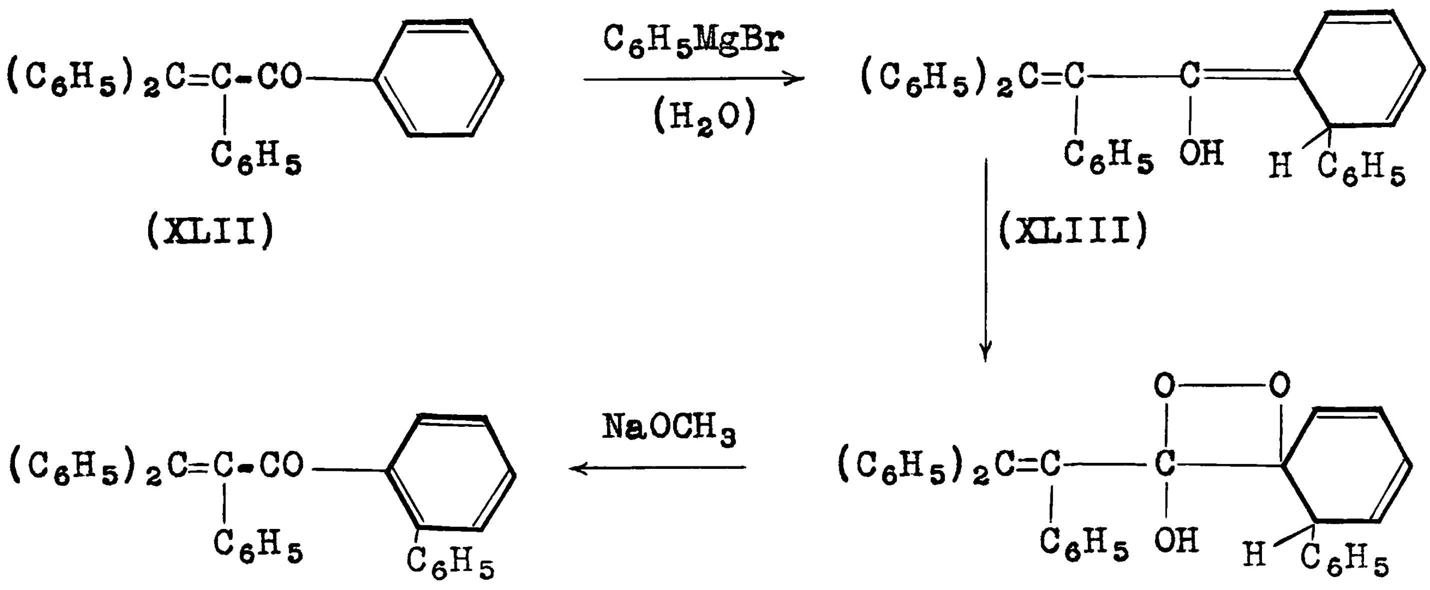
Gilman and his co-workers (29) discovered a new type of 1,4-addition of the Grignard reagent. Benzophenone anil (XL) and phenylmagnesium bromide reacted to give the substance (XLI).



(XL) (XLI)

This was the first example of 1,4-addition to a system which included a double bond in an aromatic ring.

Kohler and Nygaard (30) discovered a similar reaction between tetraphenylpropenone (XLII) and phenylmagnesium bromide. This had been tried before, but under the experimental conditions employed had failed to react (11). By using a "forced" reaction however, the reaction proceeded to give a tarry product from which the peroxide (XLIV), formed by the action of oxygen, could be isolated in small yield. Evidently the enol (XLIII) was the intermediate. The peroxide, under the influence of sodium methylate gave the ketone (XLV)

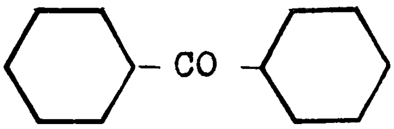


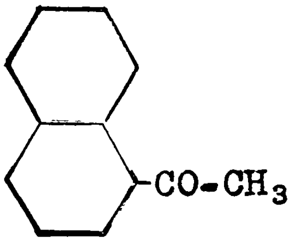
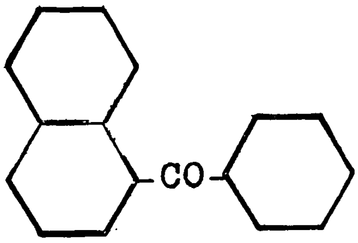
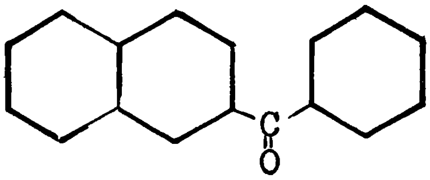
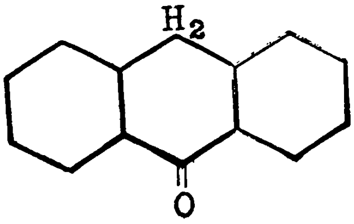
(XLII) (XLIII) (XLIV) (XLV)

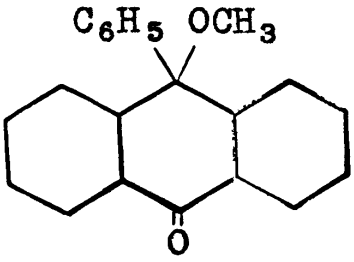
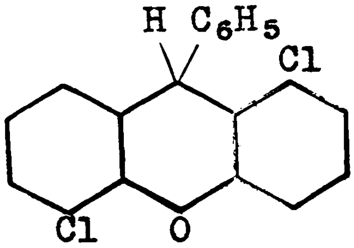
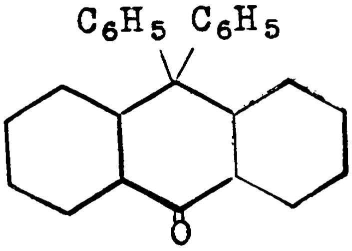
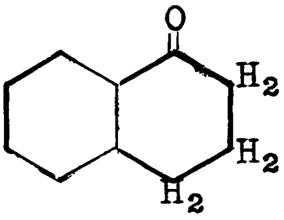
It should be noted that in both cases where addition took place to the system including the aromatic ring, the final product had an aromatic structure, the intermediate dihydro compound being unstable as would be expected. Also the yields were under 50 percent of the theoretical.

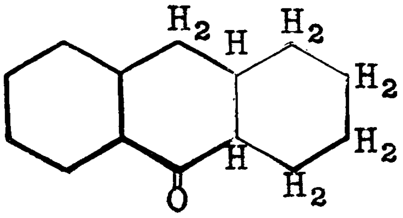
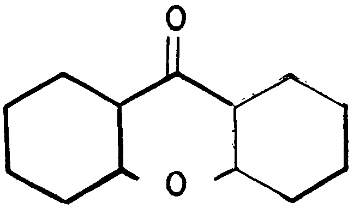
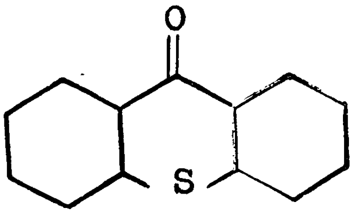
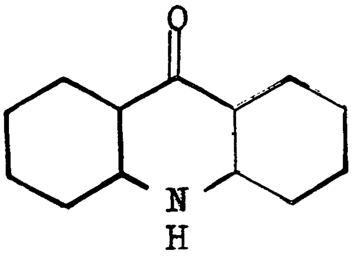
The type of addition obtained by the action of the Grignard reagent on a number of aromatic ketones and quinones is conveniently summarized in Tables III-VII.

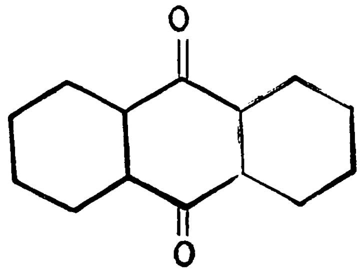
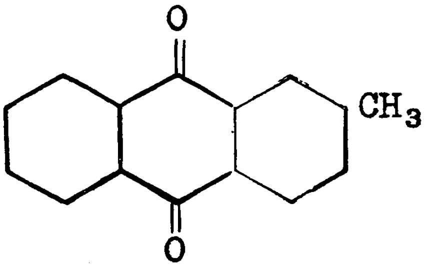
TABLE III

Substance	R, in RMgX	Addition	References
 (XLVI) Benzophenone	Benzyl	1,2-	(31)
	Ethyl	1,2-	(32)
	α-Naphthyl	1,2-	(33)

Substance	R, in RMgX	Addition	References
 (XLVII) α-Naphthyl methyl ketone	Methyl	1,2-	(34)
 (XLVIII) α-Naphthyl phenyl ketone	Phenyl	1,2-	(35)
 (XLIX) β-Naphthyl phenyl ketone	Phenyl	1,2-	(36)
 (L) Anthrone	Methyl	1,2-	(37)
	Ethyl	1,2-	(37)
	n-Propyl	1,2-	(37)
	n-Butyl	1,2-	(37)

Substance	R, in RMgX	Addition	References
 (LI) 9-Phenyl-9-methoxy anthrone	Methyl	1,2-	(38)
 (LII) 1,5-dichloro-9-phenyl anthrone	Alkyls	1,2-	(39)
 (LIII) 9,9-diphenyl anthrone	Phenyl	1,2-	(40)
 (LIV) α-Tetralone		1,2-	

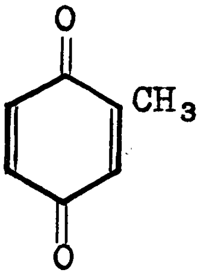
Substance	R, in RMgX	Addition	References
 (LV) Hexahydroanthrone	Benzyl	1,2-	(41) (42)
 (LVI) Xanthone	Phenyl	1,2-	(43)
 (LVII) Thioxanthone	Phenyl	1,2-	(43)
 (LVIII) Acridone	Phenyl	1,2-	(44)

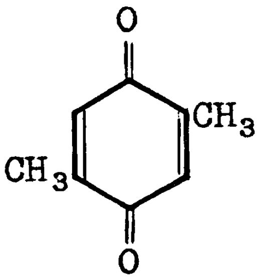
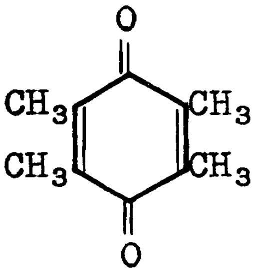
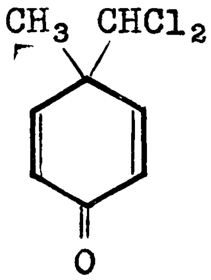
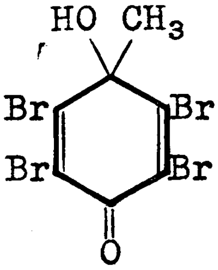
Substance	R, in RMgX	Addition	References
 (LIX) Anthraquinone	p-Anisyl	1,2-	(45)
	Phenyl	1,2-	(46)
	Ethyl	1,2-	(47)
	Alkyls	1,2-	(38)
 (LX) β-Methyl anthraquinone	Phenyl	1,2-	(48)

It is to be noted that all the above compounds gave i,2-addition products only.

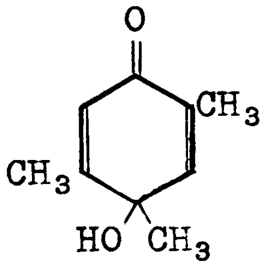
With the simpler quinones a greater variety of products was found.

TABLE IV

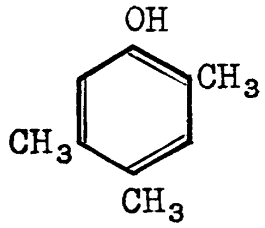
Substance	R, in RMgX	Addition	References
 (LXI) p-Toluquinone	Methyl	1,2- 1,4-	(49) (50)

Substance	R, in RMgX	Addition	References
 (LXII) p-Xyloquinone	Methyl	1,2- 1,4-	(50)
 (LXIII) Duroquinone	Phenyl	1,2- 1,4-	(51)
 (LXIV) 4-Methyl-4-dichloromethyl-cyclohexadienone-1	Methyl	1,2-	(52)
 (LXV) Tetrabrom toluquinol	Ethyl	1,2-	(53)

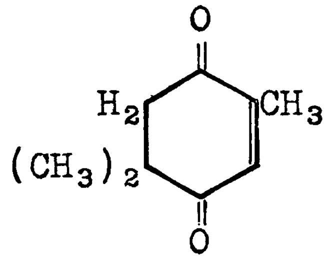
With quinones of this type the reactions were very involved, several products being formed simultaneously. For example, p-xyloquinone (LXII) yielded the following substances with methylmagnesium iodide:



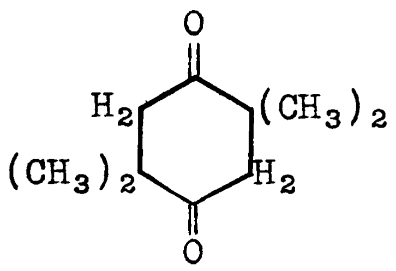
(A)



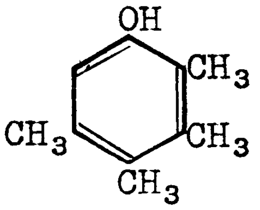
(B)



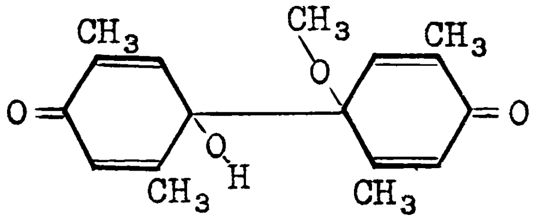
(C)



(D)



(E)

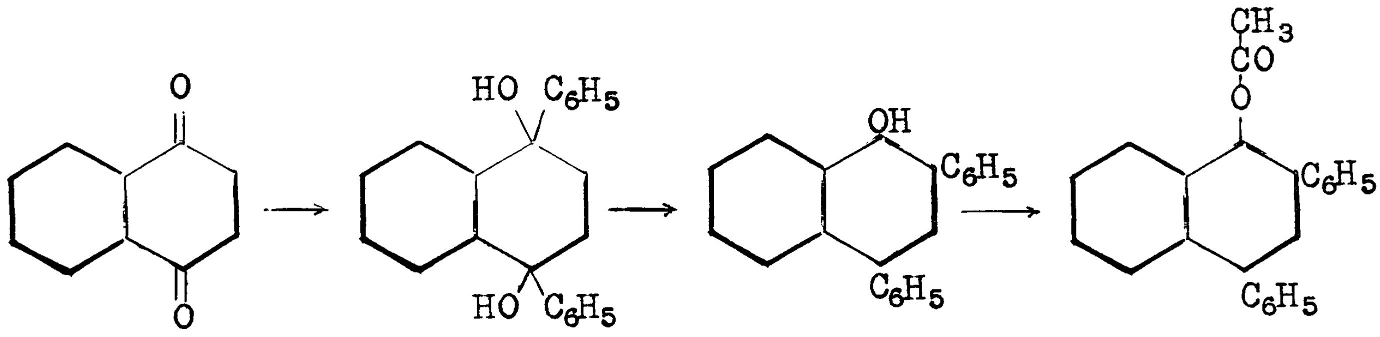


(F)

(A) was formed by 1,2-addition; (B) by reduction of (A). (C) and (D) were produced by 1,4-addition of one and two molecules of the reagent respectively. (E) was the result of 1,2- and 1,4-addition followed by loss of water to form an aromatic ring. (F) could not be accounted for by either type of addition. Bamberger considered it to be formed by the union of one molecule of methylmagnesium iodide and two of the quinone, in a manner analogous to bimolecular reduction, e,g. of acetone to give pinacol.

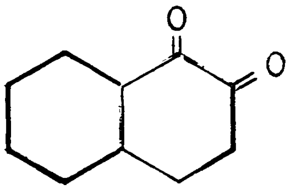
Though the reaction yielded the above six solids, only 25 percent of the starting material was accounted for. The remainder of the product consisted of uncrystallizable tars and oils that resisted all attempts at separation and identification. This is typical of the reactions of quinones with many reagents.

Franssen (54) reported that α-naphthoquinone (LXVI) reacted with phenylmagnesium bromide to give a substance having unusual properties, but for which he wrote the structure of a diol (LXVII). The supposed diol could be neither acetylated nor methylated, but when heated with acetic anhydride and sulfuric acid, lost a molecule of water to give an acetate of a new substance. These reactions were written as outlined below.

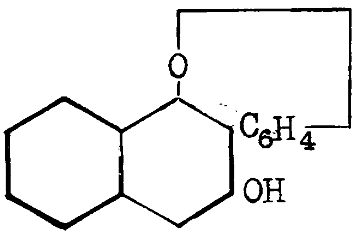


(LXVI) (LXVII)

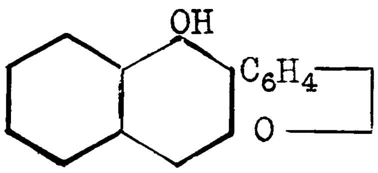
β-Naphthoquinone (LXVIII) (55) gave even more peculiar results, the final product being formulated as (LXIX) or (LXX).



(LXVIII)

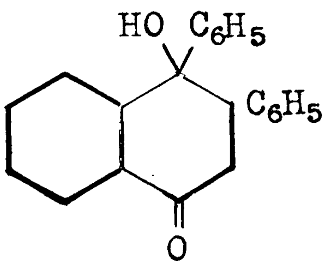


(LXIX)

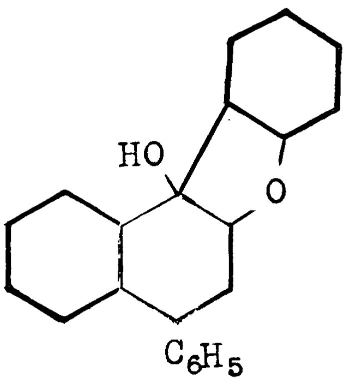


(LXX)

None of the structures was proved conclusively. In these two papers the authors postulated a shift of the phenyl or hydroxyl group, but ignored the possibility of 1,4-addition to the conjugated system. If the latter had occurred, the products might have structures (LXXI) and (LXXII) respectively, and the peculiar properties would be in better accord with what one would predict.



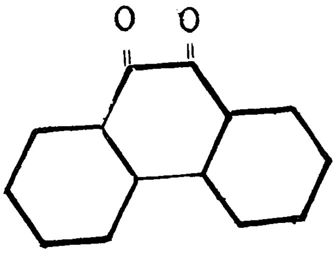
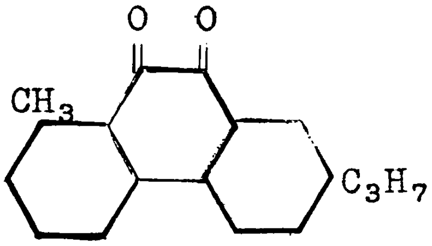
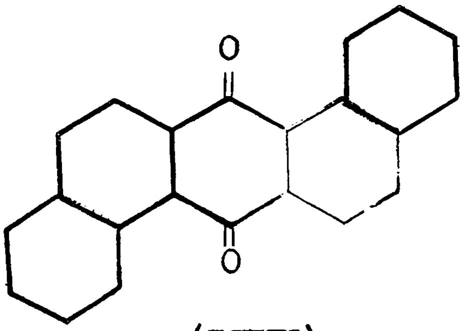
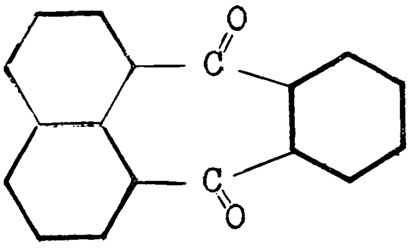
(LXXI)



(LXXII)

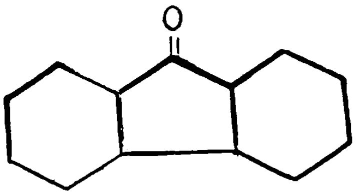
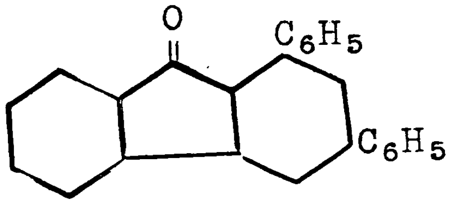
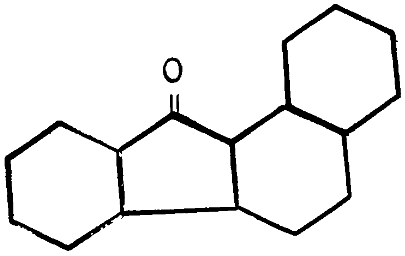
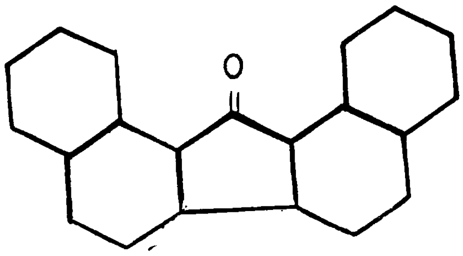
Only a few polynuclear quinones have been treated with the Grignard reagent. The results are summarized in Table V.

TABLE V

Substance	R, in RMgX	Addition	References
 (LXXIII) Phenanthrenequinone	Ethyl	1,2-	
	n-Propyl	1,2-	(56)
	Benzyl	1,2-	
	Phenyl	1,2-	(57)
 (LXXIV) Retenequinone	Phenyl	1,2-	(58)
	Benzyl	1,2-	
	p-Tolyl	1,2-	
 (LXXV) 1,2,5,6-dibenz-anthraquinone	Methyl	1,2-	(59)
	n-Butyl	1,2-	
	Benzyl	1,2-	
 (LXXVI) Peri-phthaloyl-naphthalene	Ethyl	1,2-	(60)

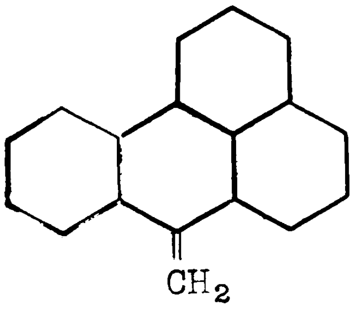
Most of the polynuclear ketones used have been fluorenones, Table VI.

TABLE VI

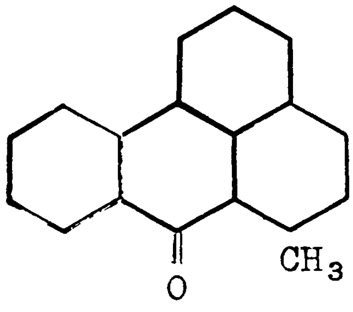
Substance	R, in RMgX	Addition	References
 (LXXVII) Fluorenone	Phenyl	1,2-	(61)
	Benzyl	1,2-	
	⍺-Naphthyl	1,2-	(62)
	Methyl	1,2-	
	Ethyl	1,2-	
 (LXXVIII) 1,3-diphenyl-fluorenone	Phenyl	1,2-	(63)
 (LXXIX) Chrysofluorenone	Phenyl	1,2-	(36)
 (LXXX) Naphthofluorenone	Phenyl	1,2-	(64)

As previously mentioned (pages 1-3), Clar (1) and Nakanishi (3) both claimed 1,6-addition of phenylmagnesium bromide to benzanthrone and wrote the substituent in the Bz-3-position. Clar also treated benzanthrone with α-naphthylmagnesium bromide and by analogy named the substance Bz-3-α-naphthylbenzanthrone. Nakanishi obtained a ketone by the action of n-butylmagnesium bromide and likewise located the group in the Bz-3-position.

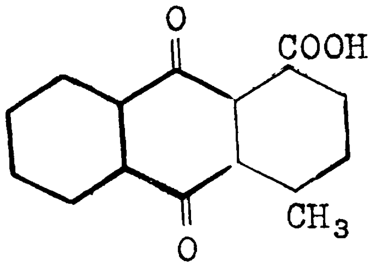
Charrier and Ghigi (5), using methylmagnesium iodide obtained two compounds to which they assigned the structures (LXXXI) and (LXXXII). The formula of the methylbenzanthrone (LXXXII) was definitely proved by oxidizing it to the previously known acid (LXXXIII).



(LXXXI)



(LXXXII)

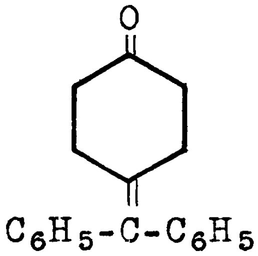
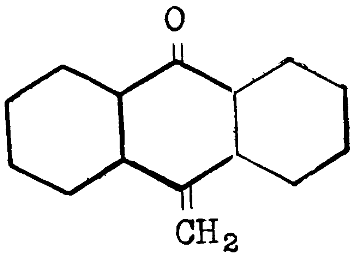


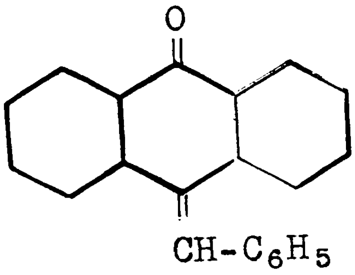
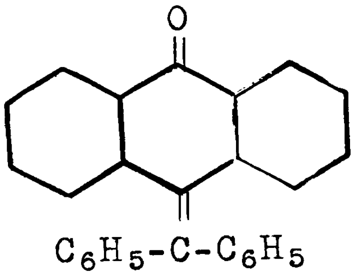
(LXXXIII)

The authors found methyl alcohol which they failed to recognize as a usual by-product in the preparation of methylmagnesium iodide, and proposed a complicated mechanism to account for its presence. They were apparently unacquainted with the behavior of conjugated systems towards the Grignard reagent, as their mechanism involved addition of methylmagnesium iodide to the carbonyl group with subsequent shift of the methyl radical to position-4. They also postulated direct addition to the ethylenic linkage between positions 3 and 4, which in view of all modern work is very improbable. Using ethylmagnesium bromide they obtained a ketone only, and by analogy with their methyl compound, wrote its formula as 4-ethylbenzanthrone.

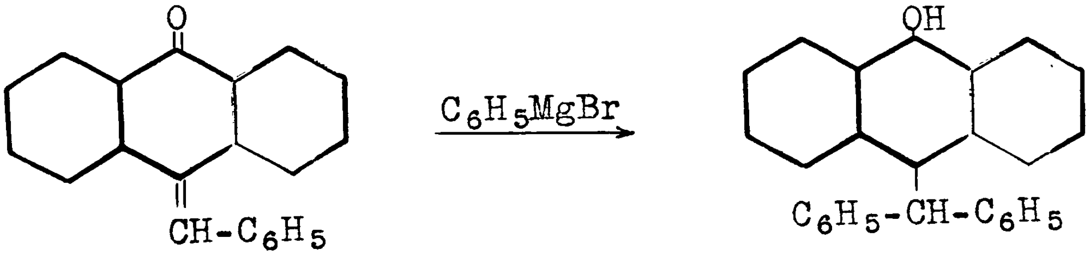
The results recorded, as obtained with fuchsone and some closely related substances, are shown in Table VII

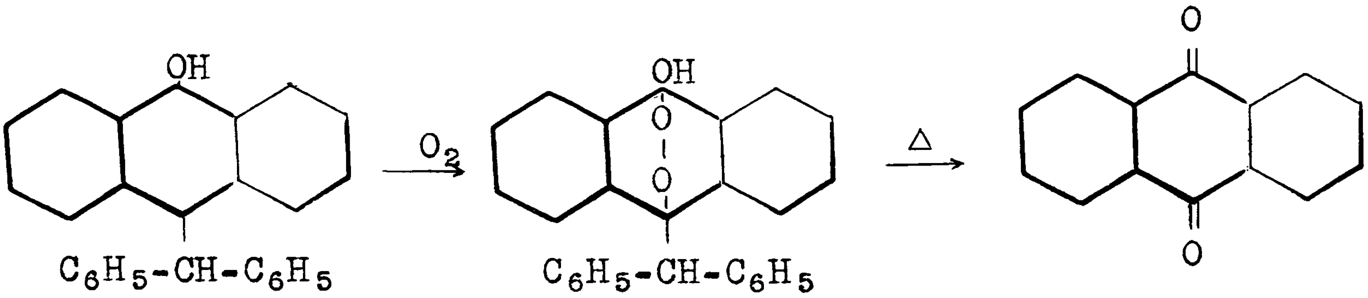
TABLE VII

Substance	R, in RMgX	Addition	References
 (LXXXIV) Fuchsone	Methyl	1,6-	(65)
 (LXXXV) Methylene anthrone	Phenyl	1,6-	(66) (67)

Substance	R, in RMgX	Addition	References
 (LXXXVI) Benzalanthrone	Phenyl	1,6-	(66) (67)
 (LXXXVII) Anthrafuchsone	Phenyl	1,2-	(67)

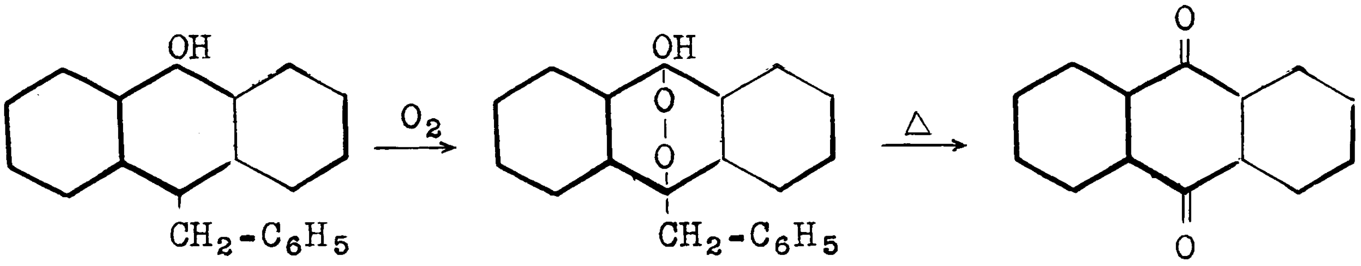
Bergmann (67) who first described the action of phenylmagnesium bromide on benzalanthrone and methyleneanthrone, was able to isolate only anthraquinone from the reaction mixture. This surprising result was explained by Julian (66) who showed that it was probably a case of primary 1,6-addition with subsequent peroxide formation and cleavage.





+ $(C_6H_5)_2CHOH$

Julian was unable to isolate the intermediate peroxide in this instance, but a similar reaction with methylene-anthrone gave the peroxide (LXXXIX). The structure of the latter compound was proved by its decomposition to yield anthraquinone (LIX) and benzyl alcohol (XC). Later he also isolated the first magnesium-free product (LXXXVIII). This is the only example of 1,6-addition of the Grignard reagent to a conjugated system which has been established by conclusive evidence.

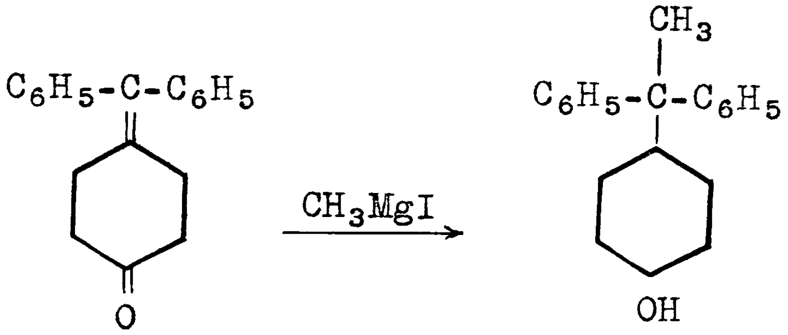


(LXXXVIII) (LXXXIX) (LIX)

+ $C_6H_5-CH_2OH$

(XC)

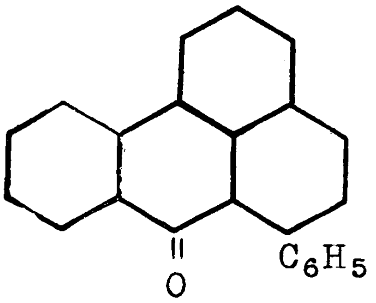
Baeyer and Villiger (65) claimed to have obtained the substance (XCI) by the action of methylmagnesium iodide on fuchsone (LXXXIV), though no proof of structure was given. If true, this would be the first case of 1,6-addition of the Grignard reagent.



(LXXXIV) (XCI)

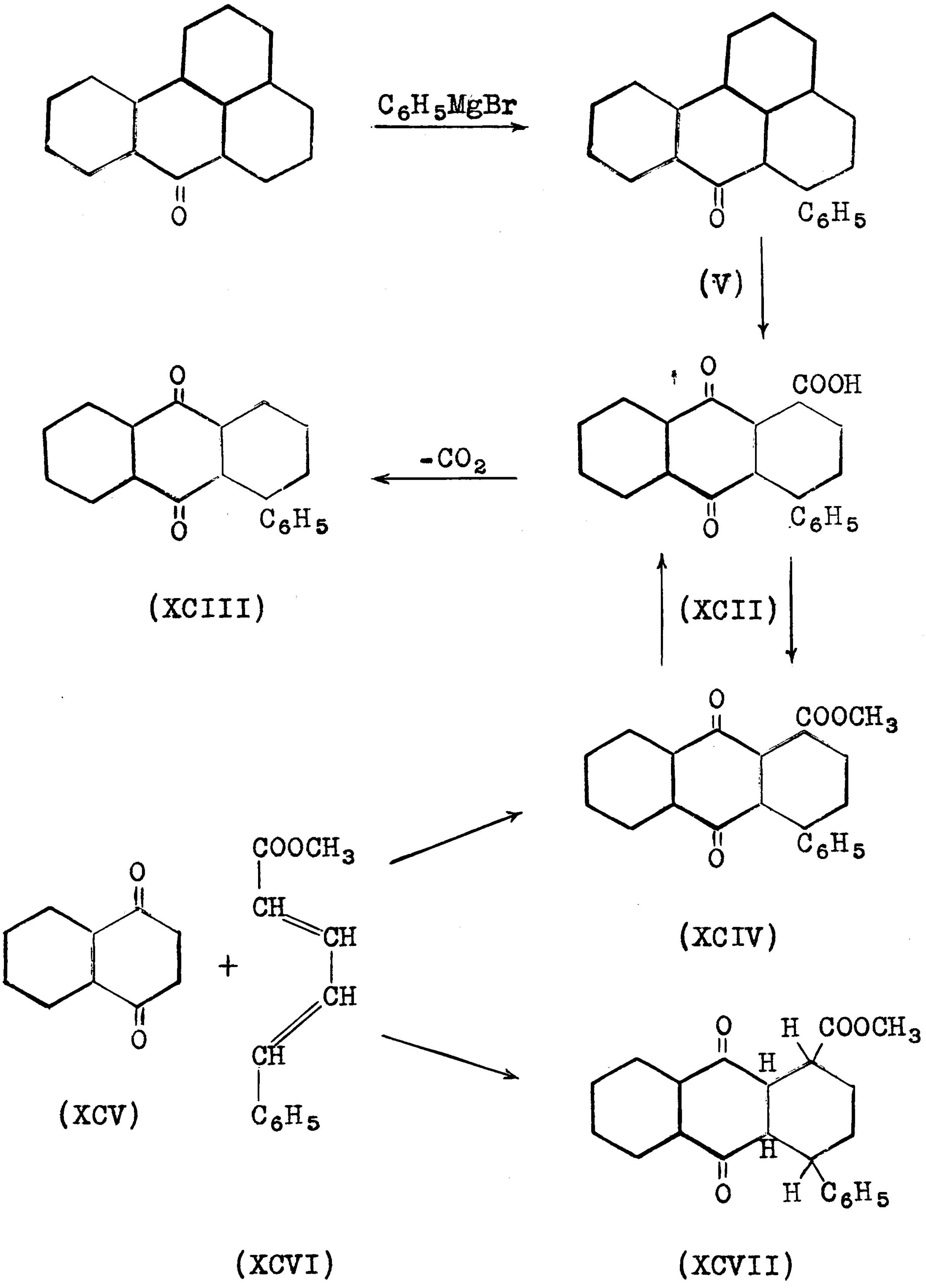
Outline of the Work

As outlined in the Introduction, the structure of the ketone resulting from the action of phenylmagnesium bromide on benzanthrone has never been conclusively demonstrated. Actually it is 4-phenylbenzanthrone (V). The evidence is as follows: oxidation by permanganate gave the acid (XCII), which was decarboxylated by heating with quinoline and copper powder to give α-phenylanthraquinone (XCIII). This showed beyond a doubt that the phenyl group had entered one of the three unsubstituted α-positions in benzanthrone. The methyl ester (XCIV) prepared from the silver salt of the acid (XCII) and methyl iodide, proved to be identical with the ester obtained by the diene synthesis from α-naphthoquinone (XCV) and cinnamylidene acetic ester (XCVI). The synthetic ester was readily hydrolyzed to the acid (XCII). Therefore the phenyl group in both the acid (XCII) and the phenylbenzanthrone (V) must be in position-4. These results are summarized in Flow-sheet I.



(V)

FLOW-SHEET I


C_6H_5MgBr
C_6H_5
(V)
COOH
$-CO_2$
C_6H_5
(XCIII)
(XCII)
$COOCH_3$
C_6H_5
(XCIV)
$COOCH_3$
CH
CH
CH
CH
C_6H_5
(XCV)
+
H $COOCH_3$
H
H
H C_6H_5
(XCVI)
(XCVII)

It is to be noted that two products were obtained by the diene synthesis, the anthraquinone derivative (XCIV) and a lower-melting ester, which analyzed for the intermediate tetrahydro compound (XCVII). The relatively small amount of the latter was probably due to the oxidizing action of α-naphthoquinone at the high temperature employed, which removed the hydrogens to give the anthraquinone derivative (XCIV); such easy oxidation is characteristic of this type of compound in the diene synthesis using quinones as one component.

Chromic acid oxidation of 4-phenylbenzanthrone proceeded with some difficulty to give an acid (m.p.288-90 dec.) previously described by Clar (1) and Nakanishi (3) both of whom called it anthraquinone-α-carboxylic acid (II). Our analysis of this substance gave values agreeing with those for (XCII) rather than anthraquinone-α-carboxylic acid. This is in accord with Charrier and Ghigi (5) whose values obtained by analysis of the sodium salt showed the presence of the additional phenyl group. Having checked these results no attempt was made to determine the nature of the product, to which Charrier and Ghigi had assigned the structure (VI). Since the three acids all melt with decomposition over practically the same range, the methyl esters of each were prepared and found to be different.

For convenience in comparing these substances, the melting points of the three acids and their esters are shown in the following Table.

TABLE VIII

Acid II	Me ester	Acid XCII	Me ester XCIV	CrO_3 acid	Me ester
286-8°d.	188-90°	288-90d.	197-8°	286-8°d.	216-7°

The oxidation of 4-phenylbenzanthrone was also carried out by a third method described by Charrier and Ghigi (68). They found that when benzanthrone was oxidized by permanganate in a copper vessel lined with tin, the benzo ring remained intact and instead of the usually expected acid (II) a derivative of biphenyl was produced. 4-Phenylbenzanthrone was oxidized in a similar manner but, in our hands, yielded only the acid (XCII).

Other phenylbenzanthrones mentioned in the literature are the three Bz-phenyl compounds (4) and the 7-phenylbenzanthrone which Scholl and Seer (69) obtained by ring closure from xenyl α-naphthyl ketone.

Fuson has recently shown (70) that aluminium chloride and benzene act like phenylmagnesium bromide in addition to conjugated systems of double linkages. With these reagents, benzanthrone gave no reaction, other than the formation of a halochromic salt, even when heated to the boiling point of benzene for several hours.

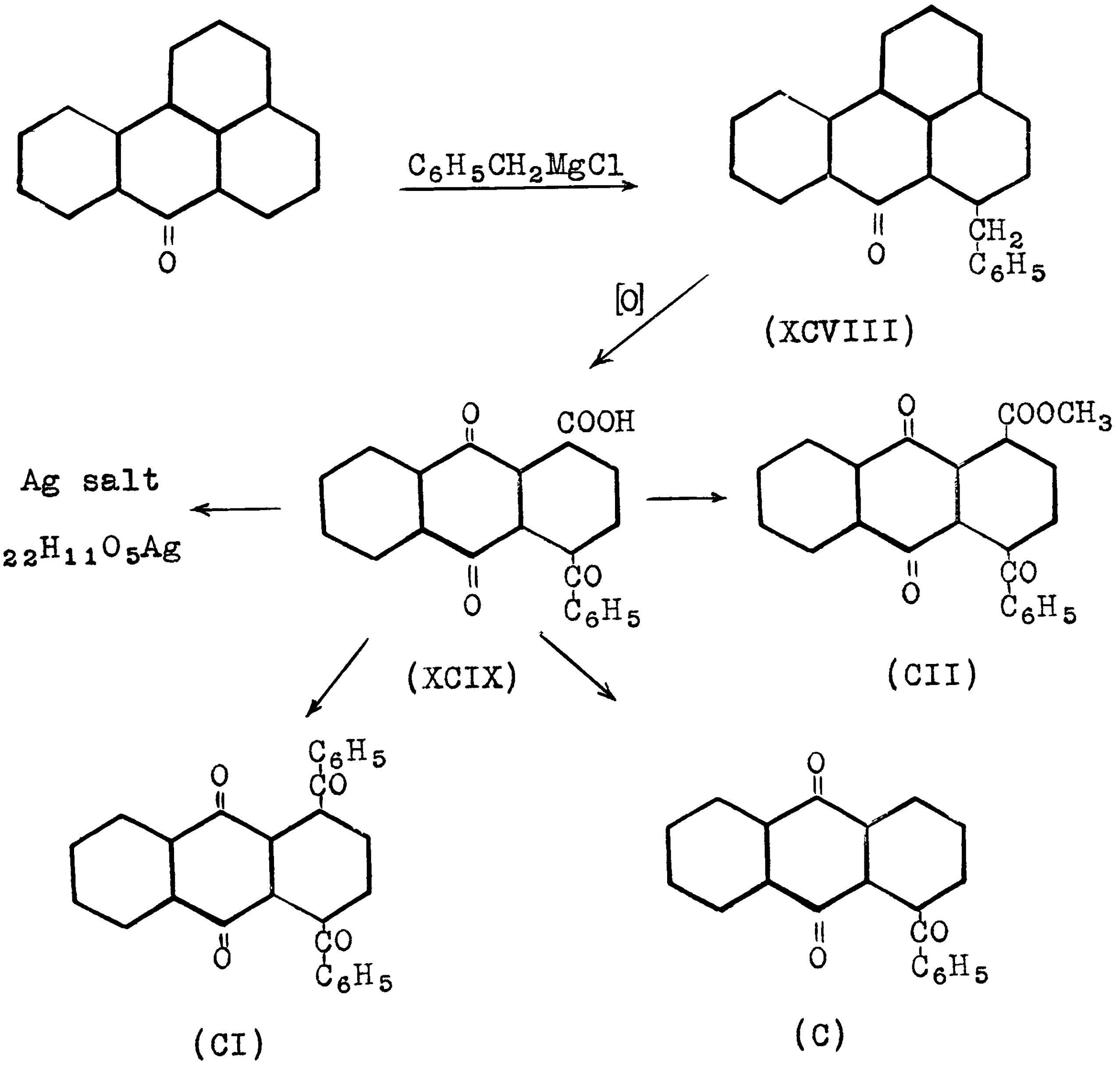
The action of benzylmagnesium chloride on benzanthrone gave a substance (m.p. 135°) which Clar had previously obtained and named 2-benzylbenzanthrone (pp.1-2). Actually it has been proved to be 4-benzylbenzanthrone (XCVIII). Chromic acid oxidized it readily to the acid (XCIX). The latter with alkaline hydrosulfite gave a red solution which was decolorized on shaking with air, showing that it was an anthraquinone derivative. In concentrated sulfuric acid it formed a light yellow solution which slowly assumed an intense green color on the addition of a little copper powder. Dilution with water caused the immediate precipitation of a bulky violet-blue substance. This test indicated that the benzoyl group was in the α-position of the anthraquinone nucleus. This was confirmed by decarboxylating the acid to α-benzoylanthraquinone (C), identical with an authentic specimen.

The silver salt was prepared in the usual manner, and its analysis agreed with the theoretical values for the formula (XCIX).

The methyl ester (CII) was obtained by the use of dimethyl sulfate, after attempts to make it by refluxing the acid in methyl alcohol containing hydrogen chloride had failed.

The acid chloride was prepared by the use of thionyl chloride. In a Friedel and Craft reaction with benzene it yielded a dibenzoylanthraquinone (CI) having physical properties identical with those described by Scholl and Meyer (71) for their 1,4-dibenzoylanthraquinone. The carboxyl and benzoyl groups are therefore in the positions shown in (XCIX). These results are summarized in the following Flow-sheet.

FLOW-SHEET II

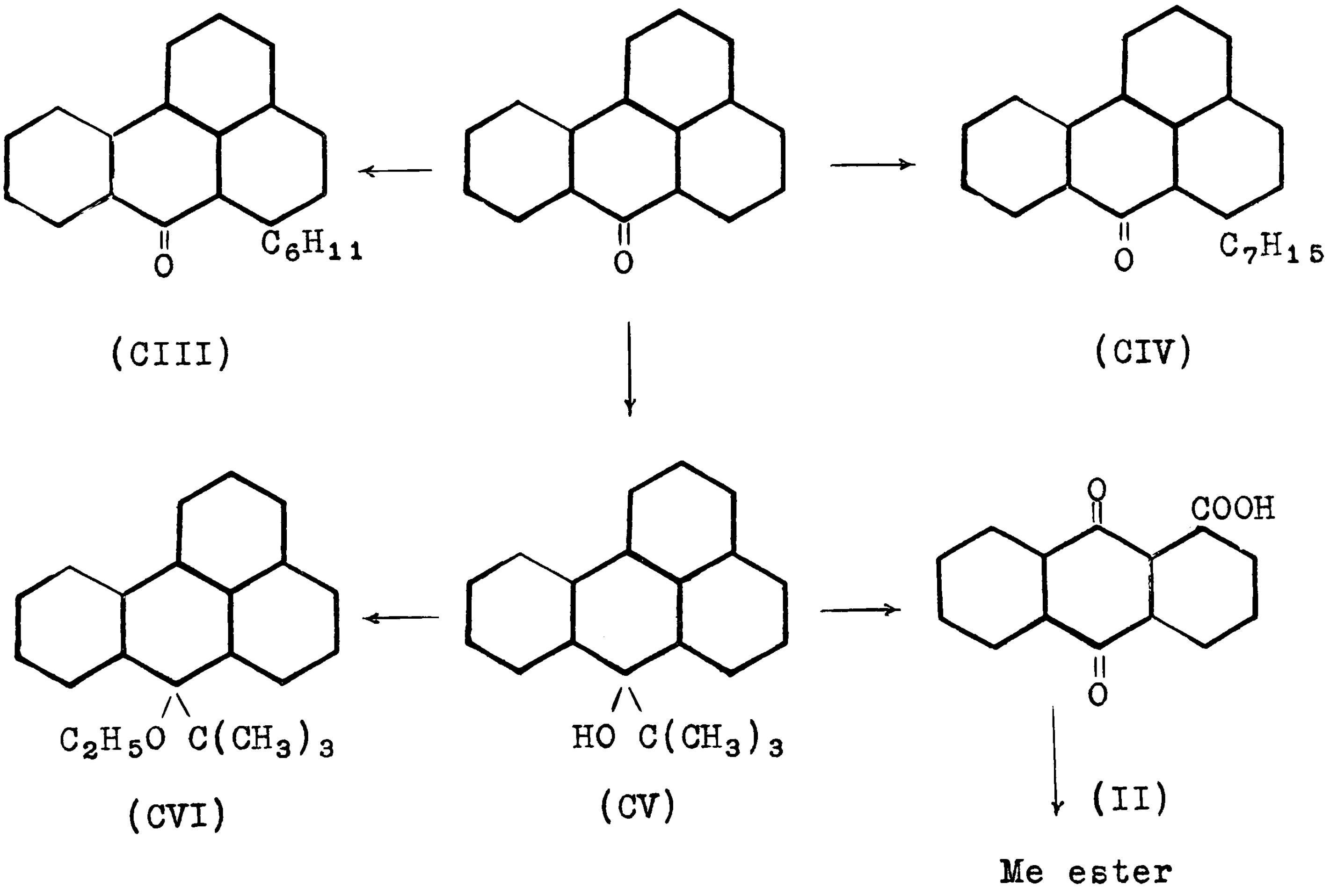


Bz-1-benzylbenzanthrone is the only isomer mentioned in the literature. Its properties and method of preparation are entirely different.

Cyclohexylmagnesium chloride and n-heptylmagnesium bromide likewise gave ketones with benzanthrone which by analogy have been assigned formulas (CIII) and (CIV) respectively.

t-Butylmagnesium chloride , on the other hand, gave the carbinol 10-t-butyl-benzanthrenol-10 (CV). Chromic acid oxidized this to anthraquinone-α-carboxylic acid (II), identified by preparing the methyl ester and comparing it with a known specimen.

FLOW-SHEET III



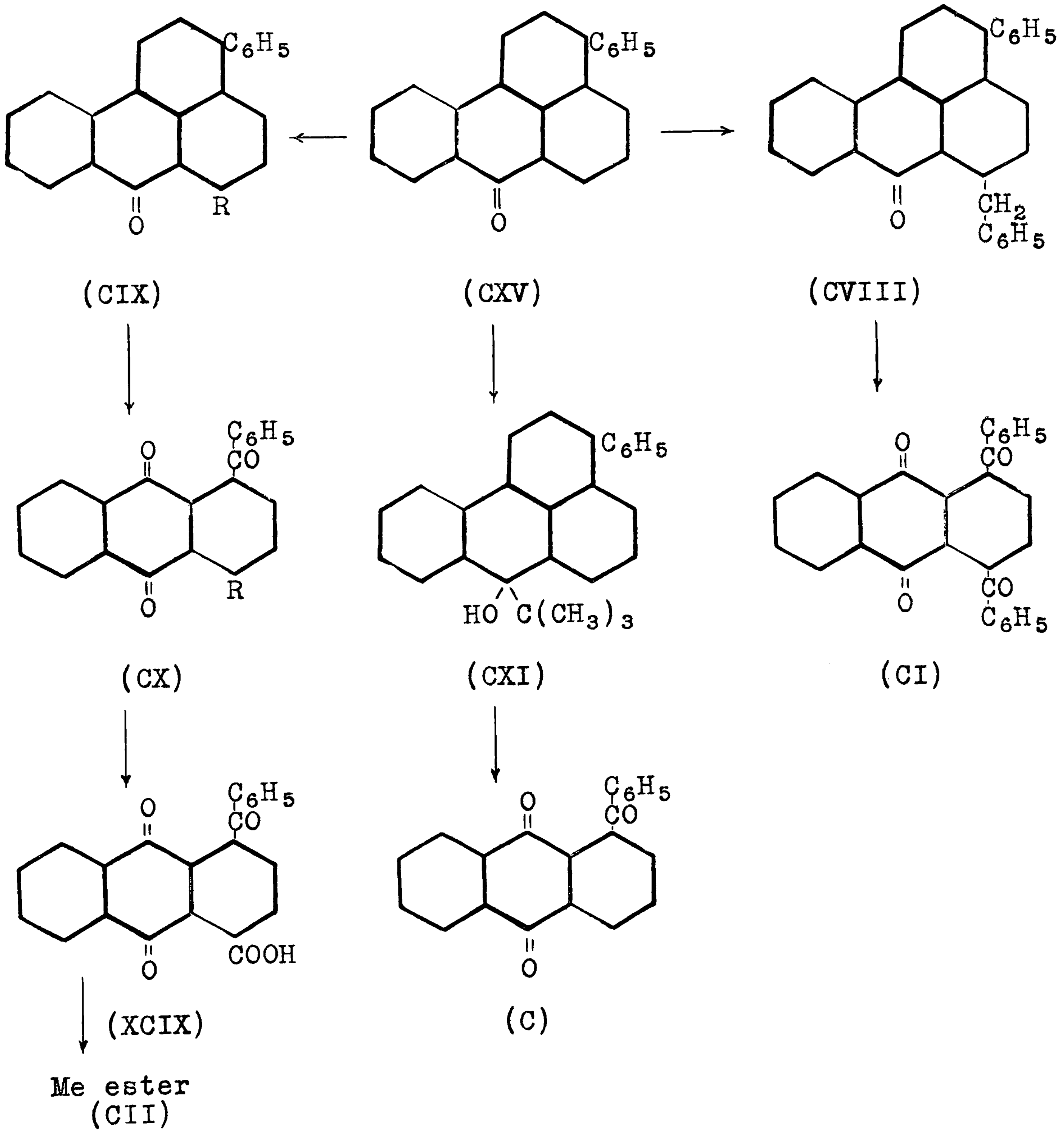
The carbinol was readily differentiated from the ketones obtained, by the use of the Grignard machine , in which it gave one mole of gas but showed no addition, whereas the ketones did just the opposite. The carbinol also formed the ethyl ether (CVI) very readily.

No crystalline solid could be obtained from the product of the reaction between benzanthrone and isopropylmagnesium bromide.

Attention was next turned to the Bz-1-phenylbenzanthrone, with the hope of obtaining reaction products having physical properties more favorable for isolation. Bz-1-phenylbenzanthrone (CXV) and benzylmagnesium bromide gave the ketone 4-benzyl-(Bz-1-phenyl)benzanthrone (CVIII). Its structure was proved by oxidizing it to 1,4-dibenzoylanthraquinone (CI). Ethyl-, n-butyl-, n-hexyl- and β-styrylmagnesium bromides likewise gave Bz-1-phenylbenzanthrones having the substituent groups in position-4 (CIX). The first three of these were readily oxidized to substituted α-benzoylanthraquinones (CX), which in turn were oxidized with somewhat greater difficulty to the known acid (XCIX). In every case the methyl ester was prepared from the silver salt of the acid and methyl iodide, and compared with a known sample of the ester (CII). Mixed melting points showed no depression.

In the case of 4-β-styryl-(Bz-1-phenyl)benzanthrone, the oxidation proceeded directly to the acid (XCIX). These results are summarized in the following Flow-sheet.

FLOW-SHEET IV



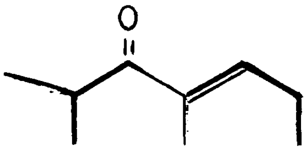
Phenyl-, cyclohexyl-, and β-phenylethylmagnesium halides, gave ketones with Bz-1-phenylbenzanthrone, to which by analogy formula (CIX) was assigned.

Several attempts were made to oxidize the diphenylbenzanthrone (CIX, $R=C_6H_5$). It was attacked with great difficulty by chromic acid, but gave only amorphous dark-colored products. Oxidation with dilute nitric acid in a sealed tube led to a similar result, while alkaline permanganate was without action, even after refluxing for seventeen hours.

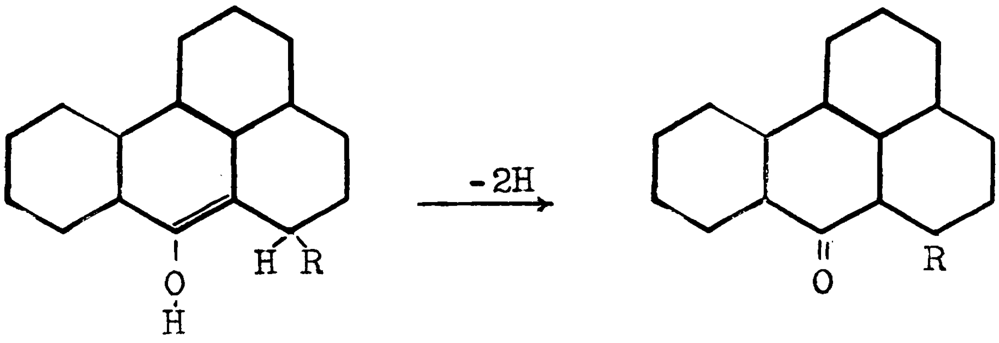
t-Butylmagnesium chloride as in the case of benzanthrone itself gave a carbinol (CXI) which was oxidized with ease to α-benzoylanthraquinone (C)(Flow-sheet IV).

Hoping to obtain additional evidence about the bond structures in benzanthrone, the substituted homologues described above were treated with various Grignard reagents. In the Grignard machine each showed no active hydrogen and one addition, but in no single instance were the products crystalline. On evaporation of the solvent a varnish always resulted; this gradually became black on standing. It is thus impossible to say whether 1,2- or 1,4-addition has occurred.

The unusual feature of these results is the fact that 1,4-addition has taken place, ketones being obtained instead of carbinols. The bond structure necessary in benzanthrone in order that the substituent group could enter position-4,is.



Although this may possibly represent only one form of a tautomeric mixture, it must be present to the extent of at least 60 percent (heptylmagnesium bromide on benzanthrone). The first magnesium-free substance formed in the reaction is probably of the type represented in (A). (Cf. p.22)

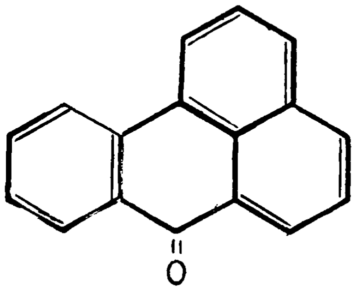


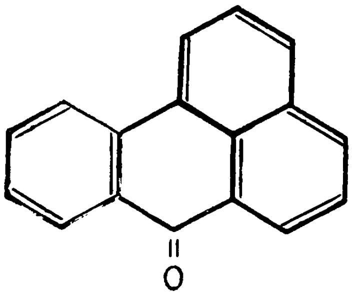
(A)　　　　(B)

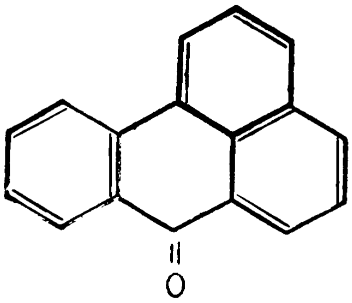
By the loss of two hydrogen atoms the ketone (B) is produced. The latter is the only product that can be isolated. While the removal of the hydrogen atoms may be partly accomplished by the oxygen of the air when the reaction mixture is worked up, it is more probable that an intramolecular oxidation and reduction occurs, giving rise to the ketone (B) and a reduced substance which is a constituent of the uncrystallizable oily residue. This latter interpretation was supported by the observation that the addition of quinone to these tarry residues was followed by a reaction (frequently quite vigorous) and the separation of a further quantity of the ketone (B).

In every instance there was a considerable amount of tarry by-product from which no further solid could be isolated. As these tars were excellent solvents, it is certain that the yield reported is lower than the actual yield. Some 1,2-addition product may also have been formed and escaped detection. It is to be noted that in no case was any product isolated which required the assumption of 1,6-addition of the Grignard reagent for its formation.

From a study of the absorption spectra and non-addition of maleic anhydride, Clar concluded that benzanthrone has one of the two structures shown in (A) or (B).

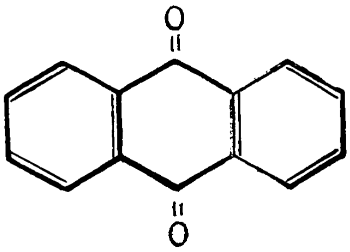

(A)


(B)


(C)

The formation of 4-substituted benzanthrones by the action of the Grignard reagent would be impossible with (B), and therefore favors (A). However, the non-addition of maleic anhydride does not exclude structure (C), which contains the normal naphthalene nucleus, for the diene synthesis is of diagnostic value only when positive (72).

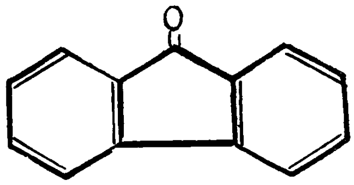
The fact that 1,4-addition of the Grignard reagent occurs with benzanthrone sharply differentiates this ketone from the great majority of polynuclear ketones described in the literature. As anthraquinone gives only 1,2-addition products with the Grignard reagent (p. 26), is probably has the bond system shown in (D), in which 1,4-addition is impossible.



(D)

The reactions have been investigated by many workers and it is probable that if any 1,4-addition product were formed it would have been detected in some instances. The structure (D) is also in agreement with conclusions reached by Anderson (73) from a study of ultra-violet absorption spectra.

Since fluorenone gives only carbinols (1,2-addition products) with the Grignard reagent, the structure (E) is indicated.



(E)

As this is a dibenzocyclopentadienone, it might be expected to add maleic anhydride. The fact that it does not (74), cannot be considered to rule out (E) for the reason mentioned above (p. 50).

The Bz-1-phenylbenzanthrone used in this work was prepared by two methods. In the first, the reactions were carried out in such a manner as to make possible the isolation of intermediate products.

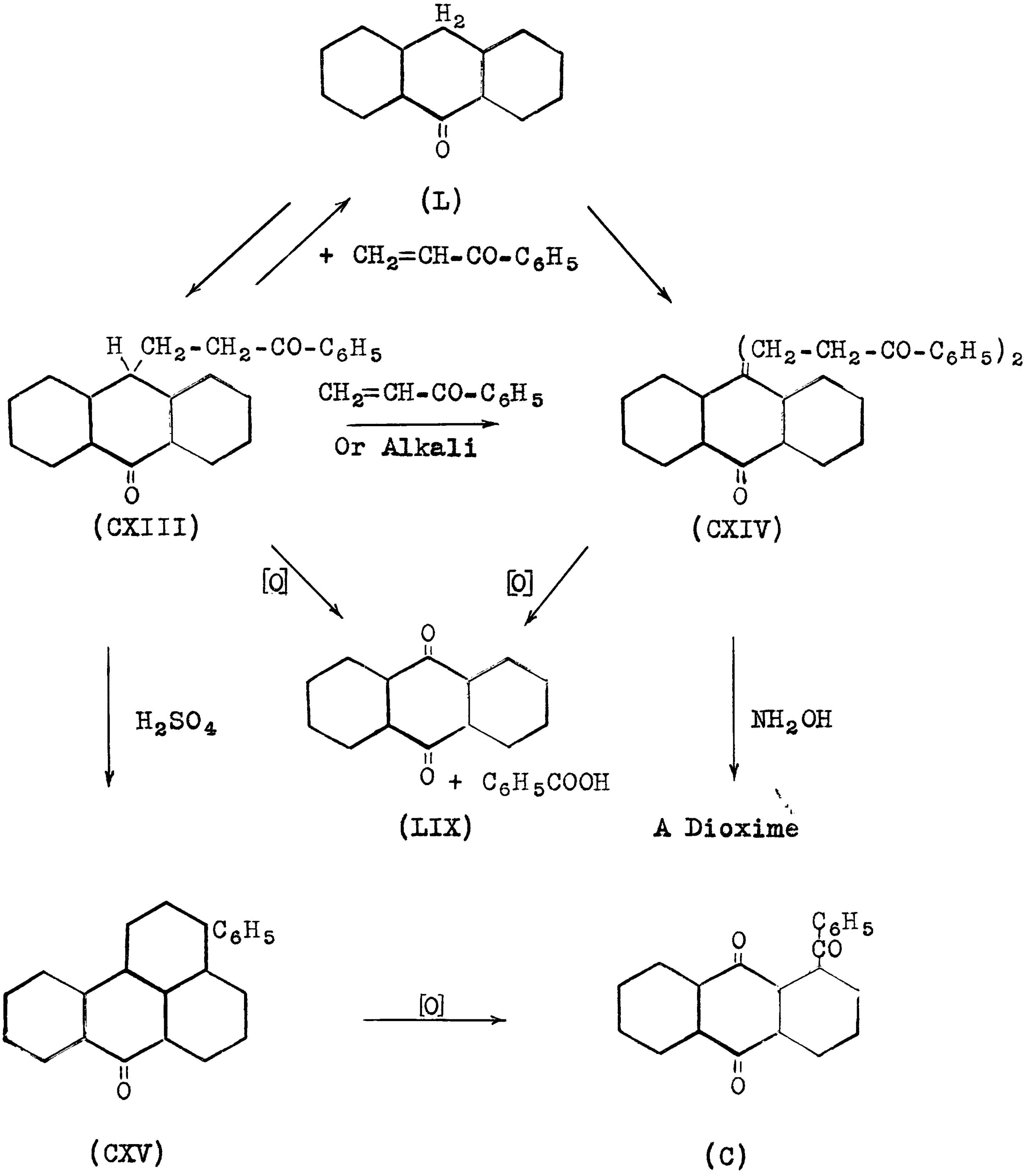
When anthrone (L) and β-chloropropiophenone were heated together in the presence of 72 percent sulfuric acid, hydrogen chloride was rapidly evolved and in a short time the liquid solidified. As is usual in such reactions the intermediate was undoubtedly phenyl vinyl ketone (CXII) (75), formed by loss of hydrogen chloride from the chloro compound, and the reaction was essentially a Michael addition of anthrone (L) to the unsaturated ketone (76). Two products were formed simultaneously, the bimolecular addition product (CXIII) and the trimolecular product (CXIV).

While it was possible to obtain the trimolecular product practically free from the other by using two equivalents of β-chloropropiophenone to one of anthrone, the reverse was not the case. Even when excess anthrone was present some of the trimolecular substance was always obtained, though by careful manipulation, the amount formed could be kept to a reasonable minimum. As would be expected, the primary addition product (CXIII) when warmed with more β-chloropropiophenone and sulfuric acid passed readily to the trimolecular product (CXIV). These reactions are shown in Flow-sheet V.

Several preliminary attempts were made to carry out the addition reaction in alkaline solution, in the presence of potassium acetate and an alkaline condensing agent such as sodium methylate, diethyl amine or piperidene. The results were very unsatisfactory, for although small amounts of the trimolecular product were isolated, the greater part of the anthrone was rapidly converted to dianthrone. The latter compound was formed even though the air in the flask was replaced by illuminating gas at the start of the experiment.

The structures of both products were shown by the formation of anthraquinone (LIX) and benzoic acid on oxidation by chromic acid, indicating that all side chains were on the meso carbon atoms.

FLOW-SHEET V

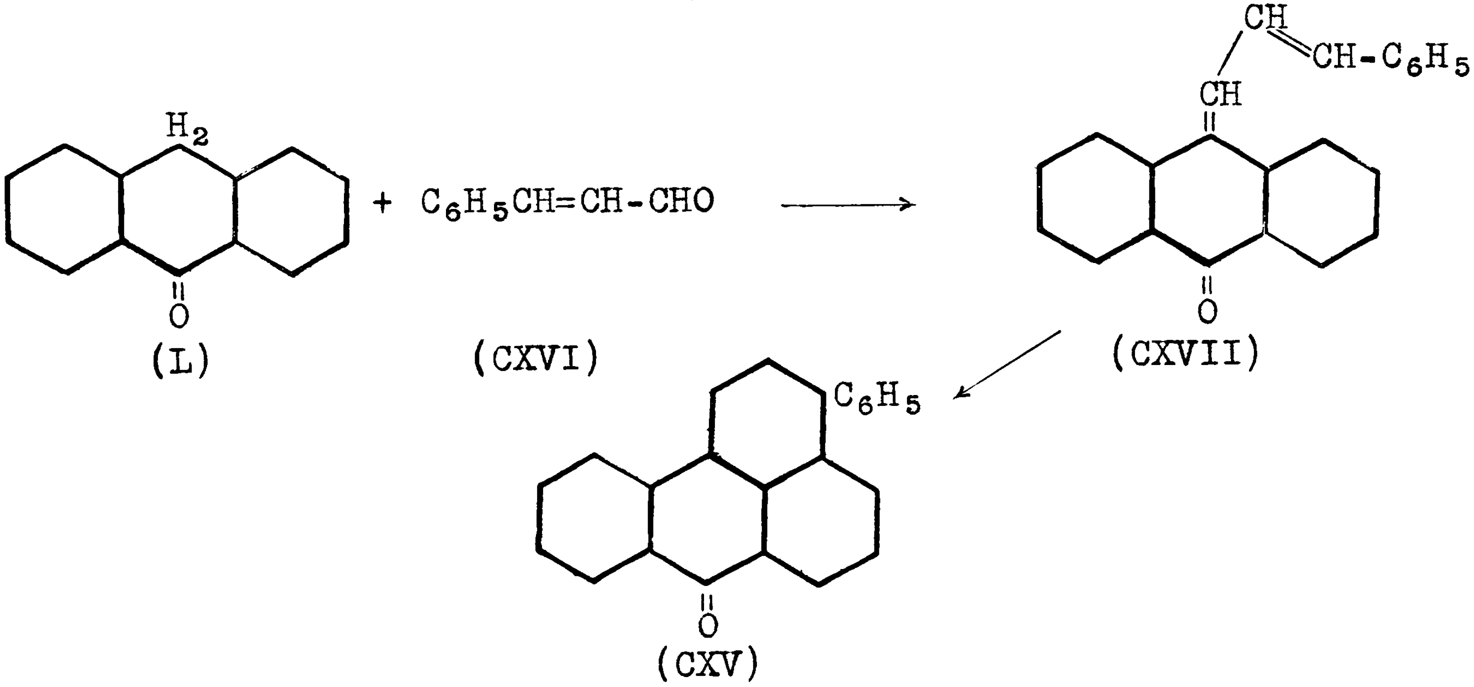

H2
(L)
+ CH2=CH-CO-C6H5
H CH2-CH2-CO-C6H5
CH2=CH-CO-C6H5
Or Alkali
(CH2-CH2-CO-C6H5)2
(CXIII)
(CXIV)
[O]
[O]
H2SO4
NH2OH
O + C6H5COOH
(LIX)
A Dioxime
C6H5
[O]
C6H5
CO
(CXV)
(C)

The trimolecular product (CXIV) formed a dioxime quite readily. As it is known that anthrones do not form such derivatives by the usual methods, the two carbonyl groups in the side chains have presumably reacted. When the bimolecular product was allowed to react with hydroxylamine under the same conditions it gave an oil from which the only product isolable was the same dioxime. In explanation of this result, it was found that the compound (CXIII) gave the trimolecular product under the influence of dilute alkali, even at room temperature.

Attempts to obtain a brominated derivative of (CXIII) were unsuccessful. In the presence of bromine the substance was rapidly converted into anthraquinone . This unexpected result was probably due to traces of hydrogen bromide which caused a reversal of the addition reaction to give anthrone. The latter was then oxidized by the bromine. A similar instance was discovered by Wells (77) using the addition product from anthrone and benzalacetophenone.

When the bimolecular compound (CXIII) was heated with 72-80 percent sulfuric acid, ring closure was effected with the formation of Bz-1-phenylbenzanthrone (CXV). The position of the phenyl group was shown by its being oxidized to α-benzoylanthraquinone (C) (Flow-sheet V). The preparation of the compound (CXV) from anthrone and some compound which on heating gives vinyl phenyl ketone is the basis of numerous patents (4, a,b,c,d,), though in most cases no intermediates are mentioned. In one instance (4, c) a condensation product, m.p. 186°, is described, which from the data given is obviously the trimolecular product (CXIV).

For the preparation of Bz-1-phenylbenzanthrone, better results were obtained using a second method starting with anthrone (L) and cinnamic aldehyde (CXVI).

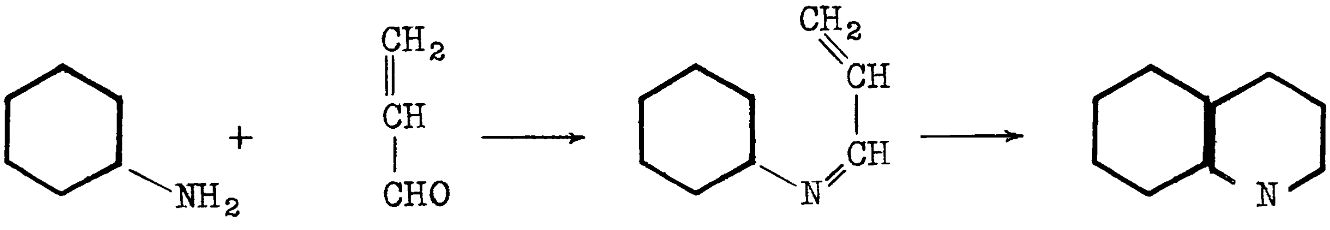


The intermediate cinnamalanthrone (CXVII) was not isolated.

This method is also described in several patents (4, f,g,i,j,k), both with and without the isolation of the intermediate (CXVII), but no details have ever been published.

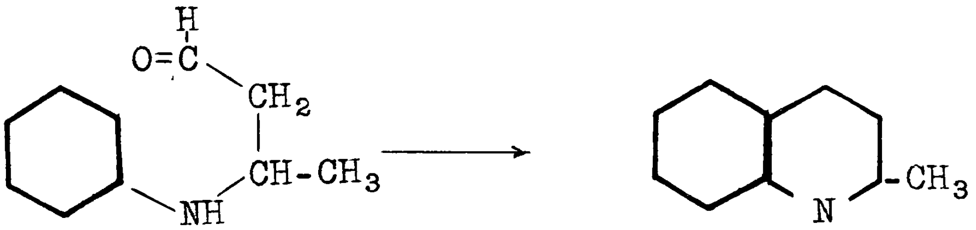
The formation of benzanthrones from anthrones is analogous to Skraup's quinoline synthesis, the two reactions taking place under identical conditions.

The synthesis of quinoline (CXIX) which was discovered by Skraup (78) in 1880, was generally believed to take place by ring closure of the anil (CXVIII) first formed, and dehydrogenation to give the heterocyclic compound.



(CXVIII) (CXIX)

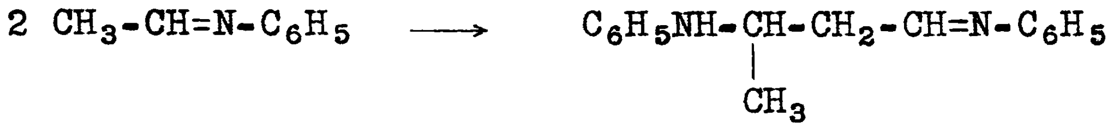
In 1886, C. Beyer (79) showed that such a mechanism was inapplicable when crotonaldehyde was used in place of glycerol, because quinaldine (α-methylquinoline) (CXXI) resulted, whereas lepidine would be expected if Skraup's mechanism were correct. Similarly cinnamic aldehyde gave α-phenylquinoline. He therefore suggested that the first step was the 1,4-addition of the amine to the aldehyde to give the substance (CXX), the latter then lost water and two hydrogen atoms to form (CXXI).



(CXX) (CXXI)

Thus the original mechanism is only possible with acrolein.

Miller (80), who carefully investigated the reaction between acetaldehyde and aniline, postulated the formation of ethylidene-aniline (CXXII). This was believed to polymerize to form (CXXIII).

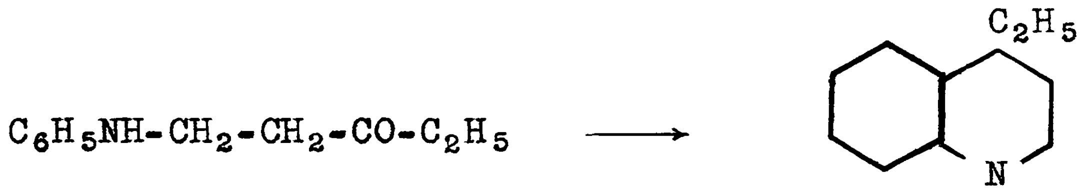


$$2\ CH_3\text{-}CH{=}N\text{-}C_6H_5 \longrightarrow C_6H_5NH\text{-}\underset{\displaystyle CH_3}{\underset{|}{CH}}\text{-}CH_2\text{-}CH{=}N\text{-}C_6H_5$$

(CXXII) (CXXIII)

The substance (CXXIII) was actually isolated, and on treatment with concentrated hydrochloric acid gave quinaldine (CXXI), by loss of aniline.

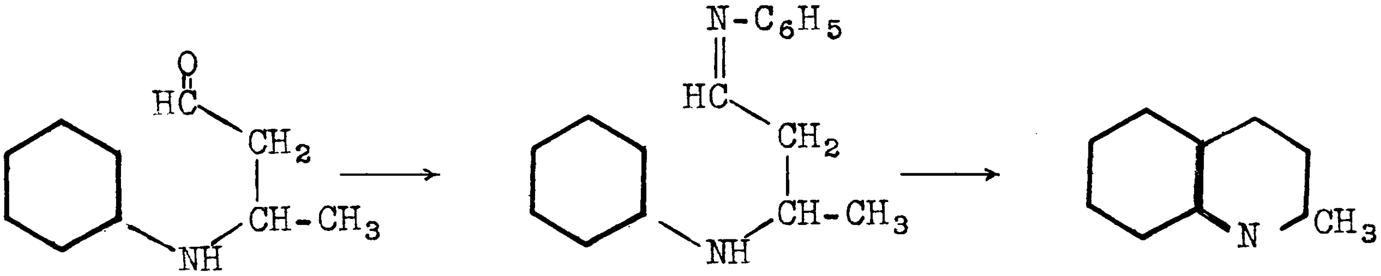
Blaise and Maire (81) discovered that the substance (CXXIV) could be made to undergo ring closure, with formation of 4-ethylquinoline (CXXV).



(CXXIV) (CXXV)

By analogy, they wrote the Skraup synthesis essentially after the manner of Beyer. They reconciled their views with Miller's work by pointing out that crotonaldehyde was probably the intermediate, that aniline added to the unsaturated aldehyde in the 1,4-positions to give (CXX), and the free aldehyde group then reacted with more aniline to give Miller's intermediate (CXXIII).

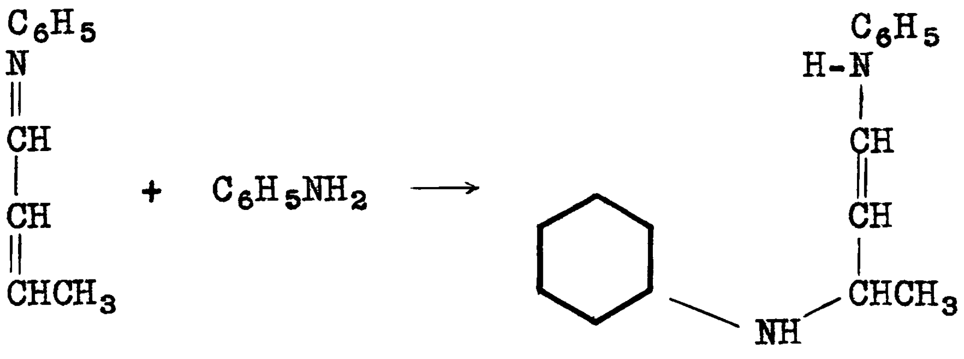
$$2\ CH_3\text{-}CHO \longrightarrow CH_3\text{-}CH{=}CH\text{-}CHO + H_2O$$



(CXX) (CXXIII) (CXXI)

Both Beyer and Blaise thus postulated addition of aniline to the α,β-unsaturated aldehyde as the first step in the reaction. In view of the great activity of the aldehyde carbonyl group and of the amine hydrogen, such a reaction seems unlikely. Schiff (82) has shown that acrolein and aniline react even in the cold, with elimination of a molecule of water.

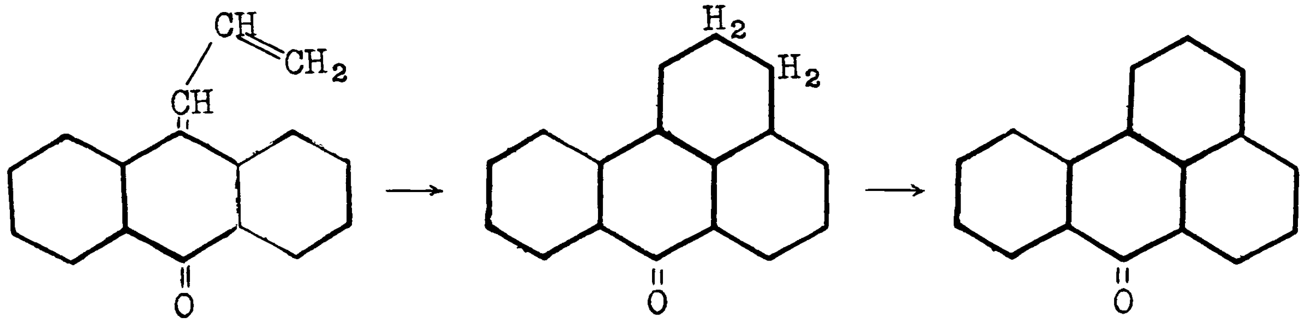
More recently, Konig (83) has proposed a mechanism which is in better agreement with the known experimental evidence. He pointed out that 1,4-addition of aniline to the anil (CXXVI) would give the same intermediate (CXXIII).



(CXXVI) (CXXIII)

Thus the most modern mechanism is a combination of the two earlier ones, anil formation and 1,4-addition. Ring closure is accompanied by loss of aniline as in the earlier mechanism.

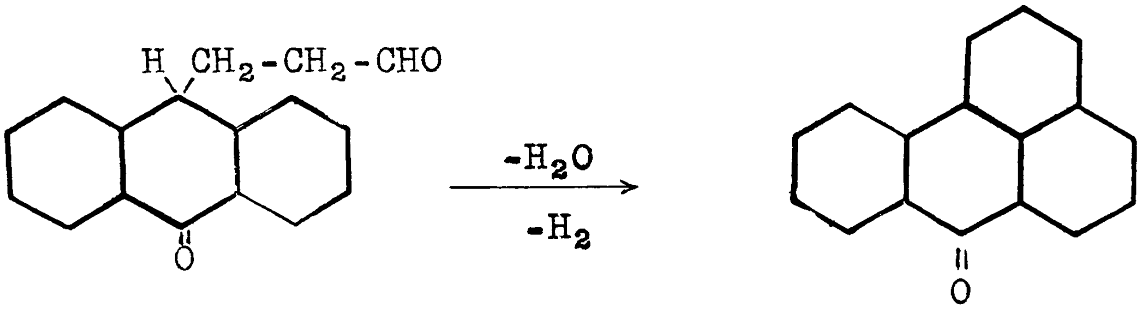
The series of reactions proposed by Bally and Scholl (84) for the formation of benzanthrone is an exact parallel to the first of these. They considered that aldol condensation took place with any anthrone present to give (CXXVII), which in turn gave benzanthrone by ring closure and the loss of two hydrogen atoms.



(CXXVII)

The latter reduced more anthraquinone to anthrone. The modern commercial method of preparation involves a preliminary reduction of all the anthraquinone to anthrone.

Meerwein (76) however, considered that the first step was a Michael addition to the α,β-unsaturated aldehyde, the intermediate (CXXVIII) being formed, since he had found that anthrone was capable of adding to many conjugated systems.

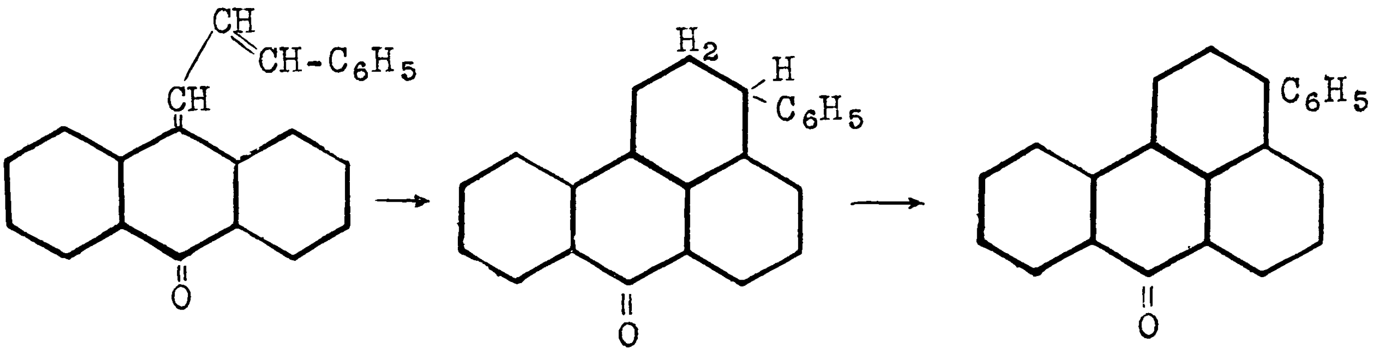


(CXXVIII)

Subsequent ring closure and dehydrogenation occurred.

Meerwein was not successful in his attempts to condense anthrone and unsaturated aldehydes. However the formation of Bz-1-phenylbenzanthrone from cinnamic aldehyde and anthrone undoubtedly proceeds through aldol condensation, because the condensation product has been isolated and shown to undergo ring closure under the same conditions. Further the location of the phenyl group in position-Bz-1 is only possible with this mechanism, a 1,4-addition to the aldehyde would give the known Bz-3-phenyl derivative which has been made in another way.

The details of the actual ring closure are vague; a dihydrobenzanthrone (CXXIX) may be first formed. The last step, dehydrogenation, is undoubtedly brought about by some component of the mixture, since the yield of Bz-1-phenylbenzanthrone is not over 50-60 percent.



(CXVII) (CXXIX) (CXV)

Hence the original mechanism of Bally and Scholl receives support.

On the other hand, with α,β-unsaturated ketones, esters etc., of which a great variety has been specified in the patent literature, addition to the conjugated system takes place first. This is illustrated by the isolation of the primary addition product (CXIII) in the case of vinyl phenyl ketone. The open chain ketone then undergoes ring closure, dehydration and dehydrogenation to give (CXV) (Flow-sheet V). This example is closely analogous to the formation of 4-ethylquinoline (CXXV) from the compound (CXXIV) (Cf. p.57).
Thus it seems extremely probable that there are two independent mechanisms for benzanthrone formation.

Experimental

I. Preparation of the Starting Materials.

Some of the BENZANTHRONE used in this work was prepared according to the directions in Organic Syntheses (85), but the greater part was kindly donated by the National Aniline and Chemical Company.

The crude material from both sources was purified by dissolving 75 g. of the solid in 500 cc. of tetrachloroethane and refluxing for 15 minutes with 2 g. of decolorizing carbon (*). The hot solution was filtered with suction and the cake of insoluble material washed with 50 cc. of hot tetrachloroethane. The combined filtrate was steam-distilled to remove the solvent, a process requiring but little time. The benzanthrone remained in suspension and was filtered and dried. The solid was finally recrystallized from chlorobenzene (3 cc. per gram); after cooling, the crystals were filtered and thoroughly washed with methyl alcohol. The yellow product so obtained melted at 170°. The recovery was 50-53 grams.

ANTHRONE was prepared according to the directions given in Organic Syntheses (86).

(*) "Charcoal, purified by acid" obtained from The General Chemical Company of New York, was used.

β-CHLOROPROPIOPHENONE was obtained from β-chloropropionic acid following the method of Hale and Britton (87).

Bz-1-PHENYLBENZANTHRONE. A mixture of 50 g. each of anthrone and cinnamic aldehyde, and 25 g. of α-chloronaphthalene in a 250 cc. wide-mouth Erlenmeyer flask, was heated in an oil-bath to 250° during a twenty minute period. At 185°, water began to be evolved. The flask was heated at 250-60° for one and two-thirds hours. The dark oil was at once transferred to a flask fitted for steam-distillation, rinsing with a little butanol. The α-chloronaphthalene was recovered from the oily layer of the distillate. The residue was chilled, and after decanting the water, was heated to boiling with 100 cc. of butanol which dissolved it completely. As soon as the mixture was sufficiently cool, 25 cc. of acetone was added. After standing several hours, the crystalline mass was filtered and washed five or six times with 25 cc. portions of acetone to remove all of the dark oil, leaving the substance with a bright yellow color. The yield was 30-38 g. of m.p. 178-80°, which was pure enough for most purposes. If necessary the product was recrystallized from chlorobenzene (5 cc. per gram) or from p-cymene (3 cc. per gram).

The butanol-acetone filtrate on standing deposited a yellow solid consisting largely of dianthrone.

Recrystallization from p-cymene (4 cc. per gram) yielded 10 g. of dianthrone m.p. 240-250°dec. The yield of Bz-1-phenylbenzanthrone based on the anthrone which was not recovered as dianthrone was 50-60 percent.

In preparing the Grignard reagents, the procedures recommended by Gilman (89) were followed as far as possible. In every case three equivalents of the reagent were used. The method employed will be illustrated by describing a typical run in detail.

II. The Grignard Reagent on Benzanthrone

(A) 4-Phenylbenzanthrone (V)

To a solution of the Grignard reagent prepared in the usual manner from 6 g. (0.25 mole) of magnesium turnings and 39 g. (0.25 mole) of bromobenzene in 125 cc. of ether, 20 g.(0.086 mole) of finely powdered benzanthrone was added in the course of 1-2 minutes. The mixture was refluxed gently for one hour with stirring. The ether was removed by suction while gently heating, leaving a thick oil. To this, 100 cc. of dry benzene was added, and the solution was refluxed for another hour. The magnesium complex was decomposed by the addition of a mixture of 30 cc. of acetic acid and 75 cc. of water. After the removal of substances volatile with steam, the thick residual oil solidified on cooling, to a brittle, brown solid. This was finely powdered, dried in the air, and stirred with 25 cc. of ether, which dissolved the greater part of it. The fine, yellow powder remaining undissolved, was filtered and washed with a further 10 cc. portion of ether. It was then stirred with 12 cc. of acetone to remove soluble impurities, leaving 7 g. of a bright yellow solid, m.p. 182-5°. In some runs the acetone wash was not necessary, to obtain a product melting above 180°.

The ethereal filtrate was allowed to evaporate to a thin syrup, and 1 g. of quinone was added. Heat was evolved, and in a few minutes the solution set to a mass of crystals. After standing over night, the solid was filtered and washed with methyl alcohol followed by acetone. In this way an additional 4 g. of product was obtained, m.p. 178-80°. The total yield was 11 g. (41 percent).

The crude material was purified for analysis by recrystallization from glacial acetic acid, from which it separated in bronze-colored prisms, m.p. 185-6°. It is only very slightly soluble in the common organic solvents in the cold. It dissolves in concentrated sulfuric acid to give a bright orange-red solution, from which it is precipitated unchanged by the addition of water.

1) Oxidation of 4-Phenylbenzanthrone(V)

In a 1-litre 3-neck round-bottom flask, fitted with a reflux condenser and a mechanical stirrer, was placed 6 g. of potassium permanganate and 3 g. of sodium hydroxide in 500 cc. of water. To this was added 3 g. of 4-phenylbenzanthrone, and the mixture boiled gently for 20 hours with continuous stirring. The solid was filtered and colorless filtrate acidified with concentrated hydrochloric acid. The precipitated acid (XCII) was filtered after standing over night, and washed with water. The yield was small (less than 0.1 g.), but the acid had the same melting point as a pure sample, 288-290°dec.

From the original solid, containing manganese dioxide, 2.1 g. of unattacked starting material was recovered.

2) Methyl ester of 4-Phenylanthraquinone-1-carboxylic acid(XCIV)

The acid obtained as above was dissolved in dilute ammonium hydroxide, and the solution warmed on the steam-bath until the odor of ammonia was barely perceptible. The addition of a few drops of silver nitrate solution caused the precipitation of a bright yellow silver salt, which was coagulated by warming, washed with water, and dried in a vacuum desiccator. The silver salt was refluxed on the steam-bath with 4 cc. of methyl iodide, for 5 hours, the silver iodide filtered, and the solution evaporated to dryness on the steam-bath. The yellow residue was dissolved in acetone, decanted from a trace of insoluble matter, and the clear liquid evaporated to a volume of about 2 cc. After the addition of 2-3 drops of water, the solution was allowed to cool. Rosettes of bright yellow needles separated, m.p.192-4°. A mixed melting point with the pure ester obtained by synthesis showed no depression.

3) Chromic Acid Oxidation of 4-Phenylbenzanthrone

To a boiling solution of 5 g. of 4-phenylbenzanthrone in 50 cc. of glacial acetic acid, was added in the course of 30-40 minutes a solution containing 25 g. of chromic acid. The latter was prepared by heating 25 g. of chromic acid in 50 cc. of glacial acetic acid. Portions of the hot liquid were decanted into the reaction mixture. After the addition of about two-thirds of the liquid, water was added in small amounts (10-15 cc. in all) to complete the solution of the remaining chromic acid, which was added to the boiling mixture as before. After refluxing for a total of 3 hours, the solution was diluted with 3-4 volumes of water and allowed to cool. The precipitated solid was filtered, the chromium changed to the sulfate by the addition of 37 g. of concentrated sulfuric acid, and the solution evaporated to a syrupy consistency to remove acetic acid. Dilution with water caused the separation of a further quantity of solid. The combined precipitates were warmed with dilute ammonium hydroxide (containing a little ammonium chloride to coagulate insoluble material) and filtered. The acid was obtained by adding hydrochloric acid to the filtrate, and after warming for a few minutes was filtered and washed with water. In this way, about 1 g. of a light brown amorphous product was obtained.

As this substance was very insoluble in the usual organic solvents, it was purified by the precipitation of its slightly soluble sodium salt. To the paste made from the crude acid in 10 cc. of water, 2 cc. of a 20 percent solution of sodium hydroxide was added. The clear solution formed quickly turned cloudy, owing to the separation of the sodium salt. After standing a few minutes, this was filtered, washed quickly with a small amount of water, and dissolved by allowing water to drip slowly through the filter. The acid was obtained by acidifying as above. One or two repetitions of this, gave a nearly white product, m.p. 286-8°with evolution of gas. This acid does not appear to be an anthraquinone derivative, since it is not reduced to a colored vat by an alkaline solution of sodium hydrosulfite, nor by boiling with zinc dust and dilute sodium hydroxide.

4) Methyl Ester

The acid (0.35 g.) was refluxed gently for one and one-half hours in 15 cc. of methyl alcohol containing 25 percent of hydrogen chloride by weight. On cooling, the ester separated in nearly colorless needles. It was purified by dissolving it in 2-3 cc. of chloroform and adding methyl alcohol dropwise until crystals commenced to form. After crystallization was complete, the solid was filtered and washed with methyl alcohol. After two recrystallizations the ester was white, and melted at 217-8°.

5) Cinnamylidene Acetic Acid (89)

A mixture of 40 g. of malonic acid, 60 g. of cinnamic aldehyde and 100 g. of pyridine was heated on the steam-bath for three and three-quarter hours, followed by gently refluxing over a wire gauze for two and one-quarter hours. On pouring into a litre of ice-cold 15 percent sulfuric acid an oil separated which quickly solidified to a pasty solid. The latter was filtered and washed with dilute sulfuric acid, and once with acetic acid followed by water. It was dissolved in dilute sodium hydroxide and the cloudy solution cleared up by shaking twice with ether. Acidification of the liquid precipitated the crude acid. It was once recrystallized from methyl alcohol. The yield was 20 g.,m.p. 150°. It was further purified by recrystallizing from chloroform with the addition of methyl alcohol. Eleven grams (17 percent) of acid m.p.162° was thus obtained.

6) Methyl Ester (XCVI) (89)

The acid (8 g.) was refluxed for 8 hours with 80cc. of methyl alcohol containing 3 percent of dry hydrogen chloride. About one-half of the solvent was removed by distillation, and the warm solution poured into 300 cc. of an ice-cold 3 percent solution of sodium carbonate. A light buff solid separated, m.p. 67°. The yield was 8.7 g., practically quantitative.

7) Synthesis of 4-Phenylanthraquinone-1-carboxylic Acid Methyl Ester (XCIV)

Methyl cinnamylidene acetate (2.3 g.) and α-naphthoquinone (2.1 g.) were mixed in a Pyrex test-tube which was then immersed for 20 minutes in an oil-bath at 180-90°. The dark viscous mass was rinsed out of the tube with 15-20 cc. of hot acetone. On standing, the solution set to a mass of crystals which was filtered and washed with methyl alcohol. The yield was 0.5-0.6 g. (10-14 percent). The crude product was recrystallized twice from acetone, yielding rosettes of bright yellow needles, m.p. 197-8°.

8) The Tetrahydro-compound (XCVII)

The original filtrate on standing deposited the tetrahydro-compound, mixed with some of the anthraquinone derivative just described. The latter, being much more soluble in acetone, was readily separated. The yield of the tetrahydro-compound was 0.3 g. (7 percent). The substance crystallized from glacial acetic acid in light bronze hexagonal plates , m.p. 164-5°.

7) Hydrolysis

The ester (XCIV) was readily hydrolyzed by boiling for 15 minutes with 50 percent (by volume) methyl alcohol containing 1 percent of sodium hydroxide. The solution was filtered and acidified with hydrochloric acid. The precipitate was coagulated by warming a few minutes on the steam-bath, filtered and washed with water. The acid (XCII), so obtained, was a cream-colored solid, m.p. 288-90° dec. It is only slightly soluble in most organic solvents. With alkaline hydrosulfite solution, it gives a red vat which is decolorized on shaking with air. It dissolves in concentrated sulfuric acid to form a yellow solution.

8) Decarboxylation

The acid (XCII) (0.3 g.) was heated with 2 cc. of quinoline and a pinch of copper powder at 140-160° for 15 minutes, when the evolution of carbon dioxide ceased. The mixture was rinsed out with water into dilute hydrochloric acid, and the precipitated solid filtered and washed free from quinoline with dilute acid. The precipitate was completely insoluble in sodium hydroxide. When recrystallized from glacial acetic acid, it formed sheaves of yellow needles m.p. 176-8°, and agreed in its properties with the α-phenylanthraquinone described by Diels and Alder (90).

B. 4-Benzylbenzanthrone (XCVIII)

To the Grignard solution prepared from 15.7 g. of benzylchloride and 3 g. of magnesium turnings in 100 cc. of ether 10 g. of benzanthrone was added, and the reaction carried out as described above(p. 64). The product obtained after steam-distillation was a thick oil, which was dried at 100° for 2-3 hours, and dissolved by warming in 40 cc. of acetone. The solid which separated on standing was filtered and washed with a mixture of equal parts of acetone and methyl alcohol. The pure substance formed yellow needles, m.p. 135°.

1) Oxidation of 4-Benzylbenzanthrone

One gram of the substance dissolved in 10 cc. of glacial acetic acid was oxidized by means of 5 g. of chromic acid in the same amount of the solvent; to complete the solution of the oxidizing agent, 2-3 cc. of water was added. The oxidation proceeded smoothly, and after 40 minutes of refluxing the mixture was poured into 5 volumes of water. The acid(XCIX) which separated was filtered and washed with water. By evaporation of the filtrate after the addition of 7.5 g. of concentrated sulfuric acid, a further quantity was obtained. The total yield was 0.83 g. (75 percent). As this acid formed a slightly soluble sodium salt, it was purified in the same manner as the acid obtained by chromic acid oxidation of 4-phenylbenzanthrone. After two or three reprecipitations, it was obtained as a white amorphous solid, m.p.275-8°. Though only slightly soluble in most organic solvents, when warmed with acetone it became crystalline (needles). In concentrated sulfuric acid it formed a yellow solution which turned intensely green on the addition of copper powder. Dilution of the green solution caused the appearance of a flocculent violet-blue precipitate. On reduction, the acid formed a deep red vat.

2) The Silver Salt

The pure acid was dissolved in the minimum amount of dilute ammonium hydroxide, and the filtered solution warmed on the steam-bath until the odor of ammonia was very faint. The addition of silver nitrate caused the separation of a yellow, curdy precipitate which after being warmed, formed opaque nodules. This was washed with water and dried in a vacuum desiccator.

Anal. Calcd. for $C_{22}H_{11}O_5Ag$. Ag, 23.3%. Found. Ag, 23.1%,23.5%

3) The Methyl Ester (CII)

The acid was dissolved in dilute potassium hydroxide, and dimethyl sulfate and 20 percent potassium hydroxide were added alternately in small portions with frequent shaking. The ester separated slowly as a fine powder which was filtered after 3-4 hours, and washed first with dilute alkali, and then with water. It was purified by dissolving it in chloroform, in which it is very soluble, and adding methyl alcohol until crystallization commenced. The ester separated in light yellow plated, m.p. 184-5°.

Refluxing the acid with methyl alcohol containing 25 percent of hydrogen chloride for 1-2 hours, failed to give any of the ester.

4) Decarboxylation

This was carried out as described above (p. 71), using quinoline and copper powder. The product after recrystallizing from acetone, formed light brown crystals, m.p. 222-5°. A mixed melting point with an authentic sample prepared from anthraquinone-α-carboxylic acid in the usual way (*) showed no depression.

5) Conversion to 1,4-Dibenzoylanthraquinone(CI)

The acid chloride of (XCIX) was prepared by heating

(*) For the preparation of this sample, I am indebted to Miss M. Gilbert.

three grams of the acid with 26 g. of thionyl chloride on the steam-bath for one and three-quarter hours. It separated as a mass of fine needles. After cooling, the dark mixture was filtered, and the solid washed several times with dry benzene followed by anhydrous ether. The light grey residual solid was dried in a vacuum desiccator. The yield was 2.6 g.

A mixture of 2 g. of the acid chloride, 35 cc. of dry benzene, and 0.2 g. of sublimed anhydrous ferric chloride was refluxed for 3 hours. The solution became dark green. After the removal of the solvent by distillation with steam, the residual dark-colored solid was pulverized, warmed with dilute ammonium hydroxide, filtered and washed with water. It was then refluxed for one hour with a solution of 2 g. of potassium hydroxide in 25 cc. of methyl alcohol, which dissolved the greater part. The insoluble residue was dark grey, and melted at 223-5°. Recrystallized from acetic acid , it separated in almost colorless needles, which before filtering adsorbed enough colored material to become grey. The solution in concentrated sulfuric acid gave an intense green color with copper powder, the green giving place to violet on dilution with water. With alkaline hydrosulfite, the compound formed a red vat. These properties agree with those given by Scholl and Meyer (71) for 1,4-dibenzoylanthraquinone (CI).

C. 4-Cyclohexylbenzanthrone (CIII)

To the Grignard reagent prepared from 6 g. of magnesium turnings and 29.5 g. of cyclohexyl chloride in 200 cc. of ether, 15 g. of benzanthrone was added. After treating as above, the product was obtained as a brittle solid which was powdered and dried. On dissolving the product in 40 cc. of ether, a brown, crystalline solid (m.p. 240°) separated. The latter was recrystallized from acetone, the substance separating in this case melting much lower (about 135°). Two grams of quinone added to the ethereal filtrate caused the separation of a further quantity of the lower-melting compound, 4-cyclohexylbenzanthrone. The substance crystallized from alcohol in yellow needles, m.p. 138-9°.

D. 4-n-Heptylbenzanthrone (CIV)

To the solution of the Grignard reagent prepared from 3 g. of magnesium turnings and 22.3 g. of n-heptyl bromide in 75 cc. of ether, was added 10 g. of benzanthrone. The mixture was treated as usual, yielding a thick oily product which was dried at 110° for one and one-half hours. It was then dissolved in 25 cc. of ether and 2 g. of quinone added. In a short time the liquid set to a paste of fine crystals which were rinsed out onto the filter, and washed, with a mixture of 3 parts of benzene and 7 parts of Skelly Solve B. Finally the solid was washed several times with methyl alcohol to remove quinhydrone.

Attempts to obtain the substance in crystalline form without the use of quinone were unsuccessful. After purification the compound was obtained in light-yellow needles, m.p. 77-8°.

E. The Carbinol (CV); 10-t-butyl-benzanthrenol-10.

To the Grignard reagent prepared from 3.6 g. of magnesium powder and 12.3 g. of t-butyl chloride in 110 cc. of ether, 8 g. of benzanthrone was added. The solution was refluxed for three hours. After the removal of the ether and its replacement by benzene, heating was continued for one-half hour. The complex was decomposed by the addition of 50 cc. of 30 percent acetic acid. After the removal of the solvent by steam-distillation, the residual thick oil that solidified on cooling, was powdered and dried. On stirring with 25 cc. of ether, everything dissolved except 2 g. of unchanged benzanthrone. The latter was filtered and the ethereal solution allowed to evaporate slowly. The crystalline solid which separated was rinsed from the flask and washed with a mixture of 3 parts of benzene and 7 parts of Skelly Solve B, in which it was insoluble. Quinone was without noticeable effect on the tarry filtrate.

The product was shown to be a carbinol by treatment with methylmagnesium iodide in the Grignard machine , one mole of gas being evolved, but no addition taking place. It is more soluble in organic solvents than are the ketones obtained in the other cases described, and is lighter in color.

After purification the carbinol formed nearly colorless square plates, m.p. 138-9°.

1) The Ethyl Ether (CVI)

A solution of 0.3 g. of the carbinol in 6 cc. of absolute ethyl alcohol acidified with 6 drops of concentrated hydrochloric acid, was refluxed for 20 minutes. On cooling, the white needles which separated were filtered and washed with 95 percent alcohol,m.p. 160.5-162°.

2) Oxidation

To a boiling solution of 0.2 g. of the carbinol in 3 cc. of glacial acetic acid, a solution containing 1 g. of chromic acid in 5 cc. of acetic acid and 1 cc. of water was added in the course of 10 minutes. The solution was refluxed a further 20 minutes, and evaporated nearly to dryness on the steam-bath, after the addition of 1 cc. of concentrated sulfuric acid. Dilution with 50 cc. of water precipitated a nearly-white acid, m.p. 286-8° dec.

The acid was refluxed with 5 cc. of methyl alcohol containing 8 percent of anhydrous hydrogen chloride for 75 minutes. Nearly colorless needles separated on cooling, which after one recrystallization from methyl alcohol melted at 184-5°. A mixed melting point with a known sample of anthraquinone-α-carboxylic acid methyl ester (m.p.188-90°) was 184-6°.

Further details on the substances described above are given in the following Tables.

TABLE IX

Substance	Formula	Calcd. C	Calcd. H	Found C	Found H
V	$C_{23}H_{14}O$	90.2	4.6	90.4	5.0
XCII	$C_{21}H_{12}O_4$	76.8	3.7	76.6	4.0
XCIV	$C_{22}H_{14}O_4$	77.2	4.1	77.0	4.2
CrO_3 Acid	$C_{21}H_{12}O_4$	76.8	3,7	76.7	3.3
" Ester	$C_{22}H_{14}O_4$	77.2	4.1	77.4	4.0
XCVII	$C_{22}H_{18}O_4$	76.3	5.1	76.4	5.2
XCVIII	$C_{24}H_{16}O$	90.0	5.0	90.2	4.8
XCIX	$C_{22}H_{12}O_5$	74.2	3.4	74.3	3.6
CII	$C_{23}H_{14}O_5$	74.6	3.8	74.5	4.2
CIII	$C_{23}H_{20}O$	88.4	6.4	88.1	6.3
CIV	$C_{24}H_{24}O$	87.8	7.3	87.8	7.7
CV	$C_{21}H_{20}O$	87.5	6.9	87.8	7.2
CVI	$C_{23}H_{24}O$	87.6	7.3	87.4	7.7

TABLE X

Substance	R, in RMgX	Yield Grams	Yield %	Solvent for Purification	M.p. °C	Crystal Form
V	Phenyl	11.	41.	Acetic acid	186	Prisms
XCVIII	Benzyl	3	21	Acetic acid	135	Needles
CIII	Cyclohexyl	3	15	Alcohol	138-9	Needles
CIV	n-Heptyl	9	61	Alcohol	77-8	Needles
CV	t-Butyl	1.4	20	Alcohol	140	Plates

Cyclohexyl- and n-heptylbenzanthrone gave orange-colored solutions in concentrated sulfuric acid; the other compounds of Table X gave deep red solutions.

III. The Grignard Reagent on Bz-1-Phenylbenzanthrone

A. 4-Benzyl-(Bz-1-phenyl)benzanthrone

To the Grignard reagent prepared from 3 g. of magnesium turnings, 17.7 g. of benzyl chloride and 100 cc. of ether, was added 10 g. of Bz-1-phenylbenzanthrone, and the solution was treated in the usual way (Cf. p. 64). The product was dissolved in ether and the solution allowed to stand over night in an unstoppered Erlenmeyer flask, whereupon crystals formed. The solid was removed, boiled with a small quantity of glacial acetic acid to remove gummy impurities, and filtered. The pure substance crystallized from acetic acid in hexagonal plates, m.p. 179-80°.

1) Oxidation

One-half gram of the once-recrystallized product was oxidized by means of 2.5 g. of chromic acid in the course of 30 minutes, as described under 4-benzylbenzanthrone. On diluting the reaction mixture, 0.4 g. of nearly white solid was precipitated, which after two recrystallizations from glacial acetic acid was obtained in cream-colored needles, melting at 225-7°. A mixed melting point with the 1,4-dibenzoylanthraquinone described on p. 75 showed no depression.

B. 4-Ethyl-(Bz-1-phenyl)benzanthrone (CIX; $R=C_2H_5$)

To the solution of the Grignard reagent prepared from 2.4 g. of magnesium turnings, 10.9 g. of ethyl bromide, and 60 cc. of ether was added 10 g. of Bz-1-phenylbenzanthrone. The solid obtained after the usual treatment was stirred with 25 cc. of ether, whereupon crystals rapidly formed. These were filtered and washed with ether. The pure substance separates from ethyl alcohol in plates, m.p. 120-2°.

1) Oxidation

One-half gram of the substance was oxidized as described under 4-benzyl-(Bz-1-phenyl)benzanthrone. On dilution of the reaction mixture a cream-colored precipitate of 1-benzoyl-4-ethylanthraquinone (CX; $R=C_2H_5$) was obtained. After purification this substance formed very light yellow needles melting at 198°.

2) Oxidation of the Ketone (CX; $R=C_2H_5$)

To a boiling solution of 0.15 g. of the compound in 5 cc. of acetic acid was added a solution of 0.75 g. of chromic acid in 3 cc. of acetic acid and 2 cc. of water. The mixture was refluxed for 2 hours, then diluted and allowed to stand several hours. The precipitate was filtered, washed with water and dissolved in dilute ammonium hydroxide.

The silver salt of the acid was prepared in the usual way, dried thoroughly, and refluxed with 4 cc. of methyl iodide for 2 hours. The liquid was evaporated and the residue warmed with 2 cc. of chloroform. The solution so obtained was decanted from the insoluble solid, evaporated nearly to dryness, and diluted with a small amount of methyl alcohol. Yellow crystals separated, m.p. 181°. Mixed with the pure ester (CII) (m.p. 184-5°), it melted at 183-5°.

C. 4-n-Butyl-(Bz-1-phenyl)benzanthrone (CIX, $R=C_4H_9$)

To the Grignard reagent prepared from 1.3 g. of magnesium turnings, 7.6 g. of n-butyl bromide and 40 cc. of ether was added 5 g. of Bz-1-phenylbenzanthrone. After the usual treatment, a gum was obtained which was dissolved in 20 cc. of ether. One gram of quinone was added and the solution allowed to stand over night. The pasty mass of crystals was filtered and washed with a mixture of 3 volumes of methyl alcohol and 2 of acetone, which removed the dark oil without dissolving the yellow solid. On standing, the filtrate deposited two successive crops of crystals. The pure substance formed yellow needles, m.p. 81-2.5°.

1) Oxidation

One gram of the compound was oxidized as in the previous case, yielding 0.6 g. of 1-benzoyl-4-n-butylanthraquinone (CX, $R=n\text{-}C_4H_9$).

This substance is very similar in its properties to the other members of the series. After purification it melted at 123-4.5°.

2) Oxidation of the Ketone (CX, R=n-C_4H_9)

The oxidation was carried out by heating together 0.3 g. of the substance and 10 cc. of dilute (50:50) acetic acid containing 1.5 g. of chromic acid, on the steam-bath for several hours. After the addition of 2 g. of concentrated sulfuric acid, the solution was evaporated nearly to dryness. Subsequent dilution precipitated the acid(XCIX) which was identified by preparing the silver salt and converting this to the ester (CII) by means of methyl iodide as described above. A mixed melting point with the pure ester showed no depression.

D. 4-n-Hexyl-(Bz-1-phenyl)benzanthrone (CIX, R=n-C_6H_{13})

To the solution prepared from 1.2 g. of magnesium turnings, 8.2 g. of n-hexyl bromide, and 40 cc. of ether, 5 g. of Bz-1-phenylbenzanthrone was added. The product obtained after the usual procedure was dried in an open beaker by warming for several hours and dissolved in 25 cc. of ether. The addition of 1 g. of quinone caused the separation of a bulky crystalline precipitate. This was stirred with a mixture of two parts of acetone and three of methyl alcohol, filtered and washed with the same combination of solvents. The filtrate on standing deposited a second crop of crystals. The substance was recrystallized from the acetone-alcohol mixture, and was obtained in yellow needles, m.p. 88°.

1) Oxidation

One gram of the substance was oxidized in acetic acid solution by means of 3 g. of chromic acid, the mixture being refluxed one-half hour in all. The greater part of the solvent was evaporated on the steam-bath, and residual syrup diluted with water. The solid (CX, $R=C_6H_{13}$) when dry weighed 0.75 g. A pure sample melted at 128°.

2) Oxidation of the Ketone (CX,$R=C_6H_{13}$)

The ketone was oxidized in dilute acetic acid as described under the corresponding butyl compound (CX, $R=n\text{-}C_4H_9$), and the resulting acid (CXIX) identified in the same way by a mixed melting point of its methyl ester (CII)

E. 4-Phenyl-(Bz-1-phenyl)benzanthrone (CIX, $R=C_6H_5$)

The Grignard reagent was prepared from 3 g. of magnesium turnings, 18.5 g. of bromobenzene and 65 cc. of ether. To this was added 10 g. of Bz-1-phenylbenzanthrone, and the reaction was carried out as described in the previous cases.

The solid remaining after steam-distillation was stirred with ether. A crystalline product remained undissolved. Treatment of the filtrate with 1 g. of quinone resulted in the separation of a further quantity of solid. As the product was contaminated with some unchanged starting material, it was dissolved in hot acetic acid and allowed to crystallize. When the mixture had cooled to 50°, the diphenylbenzanthrone was filtered and washed with acetic acid. About one and one-half grams of starting material was obtained on allowing the filtrate to stand.

The diphenylbenzanthrone is the least soluble of the products obtained in these reactions. It crystallizes from glacial acetic acid (40 cc. per gram) in plates, m.p. 223-4°. It is very resistant to oxidation. On boiling with chromic acid in acetic acid solution. it gave only dark, amorphous products. A similar result was obtained on heating in a sealed tube with dilute nitric acid (Sp. Gr. 1.1) at 180° for five hours. It was not attacked by alkaline permanganate.

F. 4-Cyclohexyl-(Bz-1-phenyl)benzanthrone (CIX, $R=C_6H_{11}$)

The formation of the reagent appeared somewhat more sluggish in this case, so external heat was applied during the addition of a solution of 12 g. of cyclohexyl chloride in 60 cc. of ether to 1.8 g. of magnesium turnings. About 30 minutes were required for this addition, and heating and stirring were continued for 30 minutes more before adding 5 g. of Bz-1-phenylbenzanthrone. The crude product obtained after the usual treatment was dissolved in ether and 1.5 g. of quinone added. The dark, crystalline mass obtained on slow evaporation of the solvent was stirred with a mixture of 3 parts of benzene and 7 parts of Skelly-solve B, filtered and washed with the same mixture, and finally with acetone to romove quinhydrone. Yellow crystals remained, which after purification melted at 190-1°.

G. 4-β-Styryl-(Bz-1-phenyl)benzanthrone (CIX, R=β-styryl)

A solution of 18.3 g. of β-styryl bromide in 40 cc. of ether was added in the course of one-half hour to 2.4 g. of magnesium turnings. Refluxing and stirring were continued for 40 minutes more before the addition of 5 g. of Bz-1-phenylbenzanthrone. The product, after the usual treatment, was dried at 100°, dissolved in ether, and treated with 1.5 g. of quinone. On standing, crystals formed which were filtered, washed once with acetone, and then with a mixture of 2 parts of acetone to three of methyl alcohol. It was further purified by boiling with a small amount of the solvent mixture, cooling and filtering. A sample recrystallized from glacial acetic acid melted at 186-7°. This substance, unlike the other benzanthrones, reacted instantly with bromine, showing the presence of the unsaturated side-chain.

1) Oxidation

A small quantity of the 4-β-styryl-(Bz-1-phenyl)benzanthrone was refluxed for 40 minutes in acetic acid with 5 parts of chromic acid. The liquid was evaporated nearly to dryness on the steam-bath, diluted with water, and the precipitated acid filtered and washed with water. The methyl ester was prepared from the silver salt as described above. A mixed melting point with the pure ester (CII) showed no depression.

H. 4-β-Phenylethyl-(Bz-1-phenyl)benzanthrone (CIX, R=C_8H_9)

Five grams of Bz-1-phenylbenzanthrone was added to the Grignard reagent prepared from 12.3 g. of β-phenylethyl bromide, 1.6 g. of magnesium turnings and 40 cc. of ether. The crude product was dried, dissolved in 15 cc. of ether, and treated with 1 g. of quinone. Two successive crops of crystals were obtained. After purification, the substance formed yellow needles, m.p. 154-5°.

I. The Carbinol; 10-t-Butyl-(Bz-1-phenyl)benzanthrenol-10 (CXI)

To 7 g. of magnesium turnings was added a solution of 12.3 g. of t-butyl chloride in 100 cc. of ether, at the rate of about 90 drops per minute. Stirring and refluxing were continued for 15-20 minutes after all the halide solution had been added. The liquid was decanted from the excess magnesium into a dry flask. Five grams of Bz-1-phenylbenzanthrone was added and the reaction was carried out as usual. The dried, crude product was dissolved in ether, and the 2.5 g. of unreacted starting material which separated was filtered off. Evaporation of the filtrate yielded a dark greenish gum which was dissolved in a mixture of 3 parts of benzene and 7 parts of Skelly-solve B. On standing several days, nearly-colorless plates separated which were washed by decantation with the mixed solvents, and dissolved in 5 cc. of ether. On evaporation of the ether, the carbinol was deposited in crystalline form. The purified product melted at 159-60°.

1) Oxidation

The product (0.2 g.) was oxidized by the method used for the other carbinol (p. 78). The oxidation product, α-benzoylanthraquinone (C), was identified by a mixed melting point with a known sample.

IV. Anthrone and β-Chloropropiophenone

A mixture of 12 g.(0.062 mole) of anthrone and 10 g. (0.059 mole) of β-chloropropiophenone in 50 cc. of 70 percent sulfuric acid was heated in a boiling water-bath with constant stirring. The oily layer which quickly formed gave off hydrogen chloride very rapidly for 4-5 minutes and in a short time (5-10 minutes more) solidified. If the heating were continued for a longer time than that specified, ring closure occurred with the formation of Bz-1-phenylbenzanthrone. The reddish solid was rinsed, and ground up with water in a mortar. After being thoroughly washed, the product was boiled with 25 cc. of methyl alcohol, filtered hot, and washed with the same solvent to remove colored impurities. The solid, after being dried, was dissolved in the miniuum amount of boiling benzene and allowed to cool to 40°. The trimolecular product (CXIV) separated first and was filtered. The yield was 4 g. (15 percent based on β-chloropropiophenone). This was recrystallized from benzene (3 cc. per gram), from which it separated in colorless plates, m.p. 187-8°. It is slightly soluble in benzene, acetic acid, and chloroform, and insoluble in alcohol. It dissolves in concentrated sulfuric acid to form a yellow solution.

The original filtrate on standing deposited white crystals of the primary addition product (CXIII). The yield was 12 g. (63 percent). As this substance crystallized from benzene extremely slowly, and in very small, poorly-formed crystals, it was purified by recrystallization from glacial acetic acid from which it crystallized more rapidly. The melting point of the carefully purified product was not sharp, but always over a range, the analytical sample fusing at 141-4°.

When the bimolecular product was warmed with an additional mole of the β-chloropropiophenone in 70 percent sulfuric acid for 5-10 minutes, it gave the trimolecular compound (CXIV).

1) Dioxime of the Trimolecular Product (CXIV)

One-half gram of the substance (CXIV) was warmed on the steam-bath with 20 cc. of alcohol containing 0.7 g. of hydroxylamine hydrochloride and 1.2 cc. of 20 percent sodium hydroxide solution for 20 minutes. On cooling, colorless rods separated. These were recrystallized from ethyl alcohol, m.p. 244-5°.

Anal. Calcd. for $C_{32}H_{28}O_3N_2$ N, 5.7% Found N 5.8%, 5.4%.

A dioxime of the bimolecular product would have had 7.9% N

The bimolecular product similarly treated gave an oil. This was dissolved in chloroform and the solvent allowed to evaporate until crystals formed. The only solid obtained was the same dioxime as above, as shown by a mixed melting point.

2) Oxidation of the Bimolecular Product (CXIII)

To a boiling solution of 0.5 g. of the substance (CXIII) in 7 cc. of glacial acetic acid a solution of chromic acid in 50 percent acetic acid was added in small portions until excess was present as shown by the color of the mixture. The liquid was refluxed for 5 minutes more, and diluted with water. Anthraquinone separated in fine needles, (m.p. 275°), which gave a red vat on boiling with zinc dust in alkaline solution. The original filtrate was treated with 1-2 cc. of concentrated sulfuric acid, and shaken with a small quantity of ether. Evaporation of the ethereal solution left benzoic acid, identified by a mixed melting point.

3) Oxidation of the Trimolecular Product (CXIV)

This was carried out as described in the last paragraph, and gave the same products, anthraquinone and benzoic acid.

4) Effect of Alkali on (CXIII)

The bimolecular product (0.25 g.) was allowed to stand in 15 cc. of methyl alcohol containing 2 drops of 20 percent potassium hydroxide solution. The orange-red solution gradually became light yellow. The solid was filtered , and found to consist of the trimolecular product (0.12 g.).

5) Action of Bromine on (CXIII)

The bimolecular product (0.5 g.) was dissolved in a few cubic centimeters of chloroform, and one molecular equivalent of bromine dissolved in the same solvent was added. It was decolorized instantly. Evaporation of the solvent left a gum, which was warmed with alcohol. The light yellow crystalline solid that separated proved to be anthraquinone.

6) Bz-1-phenylbenzanthrone (CXV)

In a beaker suspended in boiling water, 10 g. of the bimolecular product (CXIII) was heated with 100 g. of 80 percent sulfuric acid for 25 minutes with constant stirring. The thick oil was chilled, washed by decantation, and ground in a mortar with water, which caused it to become much lighter in color. It was filtered and washed with water. The yellow solid so obtained, was boiled with 20-25 cc. of methyl alcohol and filtered hot to remove amorphous impurities. The remaining solid was heated with glacial acetic acid until solution was complete. On cooling, Bz-1-phenylbenzanthrone separated in rosettes of yellow needles, which after recrystallization from the same solvent melted at 182-3°. The yield was 4.2 g. (50 percent).

7) Oxidation of Bz-1-phenylbenzanthrone.

The purified substance (0.9 g.) was oxidized in glacial acetic acid solution by means of chromic acid in the usual way. After refluxing for 30 minutes, the solution was diluted with 5 volumes of water and allowed to stand. The α-benzoylanthraquinone (C) was filtered and washed with water. The yield was 0.8 g. A mixed melting point with an authentic specimen showed no depression.

Analytical data and other details are given in the following Tables.

TABLE XI

		Calcd.		Found	
Substance	Formula	C	H	C	H
CVIII	$C_{30}H_{20}O$	90.9	5.1	91.1	5.1
CIX					
$R=C_2H_5$	$C_{25}H_{18}O$	89.8	5.4	89.6	5.7
$R=n-C_4H_9$	$C_{27}H_{22}O$	89.5	6.1	89.4	6.0
$R=n-C_6H_{13}$	$C_{29}H_{26}O$	89.2	6.7	89.2	6.6
$R=C_6H_5$	$C_{29}H_{18}O$	91.1	4.7	91.4	4.8
$R=C_6H_{11}$	$C_{29}H_{24}O$	89.7	6.2	89.5	6.2
$R=C_8H_7$	$C_{31}H_{20}O$	91.2	4.8	90.9	4.9
$R=C_8H_9$	$C_{31}H_{22}O$	90.7	5.4	90.9	5.4
CXI	$C_{27}H_{24}O$	89.0	6.6	88.6	6.4
CX					
$R=C_2H_5$	$C_{23}H_{16}O_3$	81.2	4.7	81.2	5.0
$R=C_4H_9$	$C_{25}H_{20}O_3$	81.5	5.4	81.0	5.5
$R=C_6H_{13}$	$C_{27}H_{24}O_3$	81.8	6.1	81.8	6.4
CXIII	$C_{23}H_{18}O_2$	84.6	5.5	84.5	5.8
CXIV	$C_{32}H_{26}O_3$	83.8	5.7	84.1	5.8

C_4H_9=n-Butyl, C_6H_{13}=n-Hexyl, C_6H_{11}=Cyclohexyl

C_8H_7=β-Styryl, C_8H_9=β-Phenylethyl

TABLE XII

Substance	R, in RMgX	Yield Grams	Yield %	Solvent for Purification	M.p. ° C	Crystal Form
CVIII	Benzyl	2.5	19	Acetic acid	179-80	Plates
CIX						
R=C_2H_5	Ethyl	3.8	35	Alcohol	120-2	Plates
R=C_4H_9	n-Butyl	3.7	53	2:3 Mixture	81-2.5	Needles
R=C_6H_{13}	n-Hexyl	3.0	47	2:3 Mixture	88.	Needles
R=C_6H_5	Phenyl	5.6	45	Acetic acid	223-4	Plates
R=C_6H_{11}	Cyclohex.	1.4	22	Acetic acid	190-1	Plates
R=C_8H_7	β-Styryl	0.4	6	Acetic acid	186-7	Needles
R=C_8H_9	β-Phenyl-Et.	3.4	51	Acetic acid	154-5	Needles
CXI	t-Butyl	0.6	10	Acetic acid	159-60	Plates

2:3 Mixture = 2 parts of acetone + 3 of methyl alcohol.

The carbinol (CXI) gave an intense green color in concentrated sulfuric acid all the other benzanthrone derivatives listed in Table XII gave deep red solutions. The three substituted α-benzoylanthraquinones (CX) in Table XI all gave yellow solutions in the same solvent, which turned dark green on the addition of copper powder, the green giving place to violet on dilution with water.

The homologues of α-benzoylanthraquinone just mentioned were recrystallized from glacial acetic acid.

The results obtained with the Grignard machine are shown below.

TABLE XIII

Substance	Amount grams	Amount CH_3MgI cc.	Methane evolved cc.	Water added cc.	Methane evolved cc.	Temp. °C	Press. mm.	Active H	Addition
V	0.2040	2.00	—	1.0	32.6	24	760	—	1.0
XCVIII	0.2002	1.87	3.0	0.9	30.3	23	778	0.2	0.9
CIII	0.1718	1.10	2.0	1.1	11.3	22	764	0.2	1.1
CIV	0.2004	1.10	2.9	1.0	10.7	22.5	764	0.2	1.0
CV	0.2004	1.19	15.5	1.0	29.1	23	770	1.0	0.0
CVIII	0.1808	1.08	2.5	1.3	14.6	20	764	0.2	1.1
CIX									
$R=C_2H_5$	0.1986	1.88	3.0	1.0	31.6	20	764	0.2	0.9
$R=C_4H_9$	0.1965	1.00	1.0	1.1	12.5	21.5	770	0.1	0.9
$R=C_6H_{13}$	0.2017	0.94	1.2	1.0	12.0	24.5	756	0.1	0.9
$R=C_6H_5$	0.2020	1.05	2.2	1.0	10.3	22	764	0.2	1.1
$R=C_6H_{11}$	0.1950	0.94	3.2	1.0	11.6	24	765	0.3	1.0
$R=C_8H_7$	0.1000	0.95	0.4	1.1	17.5	23.5	756	0.1	1.0
$R=C_8H_9$	0.2060	0.93	2.4	1.5	10.9	23	765	0.2	1.0
CXI	0.1745	1.70	11.0	1.0	38.0	22	770	1.0	0.3

Grignard reagent - 0.00102 moles/cc.

Summary

1. 4-Substituted benzanthrones are obtained by the action of phenyl-, benzyl-, cyclohexyl- and n-heptylmagnesium halides on benzanthrone. Similarly, the Bz-1-phenyl homologues are obtained by the action of benzyl-, ethyl-, n-butyl-, n-hexyl-, phenyl-, cyclohexyl-, β-styryl-, and β-phenylethylmagnesium halides on Bz-1-phenylbenzanthrone. In both series t-butylmagnesium chloride gives a carbinol.

2. The formation of the ketones is due to 1,4-addition involving an unsaturated linkage in an aromatic ring.

3. No substance is found which requires the assumption of 1,6-addition of the Grignard reagent for its formation.

4. This reaction furnishes a new method for locating the positions of certain double bonds in polynuclear ring systems.

5. Anthrone reacts with vinyl phenyl ketone to give both bimolecular and trimolecular addition products. The primary product may undergo ring closure to form Bz-1-phenylbenzanthrone.

6. Two independent mechanisms appear to be possible for the formation of benzanthrones from anthrones. In the light of the evidence reviewed in this thesis, these are discussed and compared with the analogous mechanisms for the formation of quinoline by the Skraup synthesis.

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