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The Synthesis of 3-Ethyl-9-Acetylphenanthrene

Elizabeth R. Bender

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In 1929, there was recognized a relatively small number of naturally occurring phenanthrene compounds as compared with those known today. These compounds include several groups of \textbf{THE SYNTHESIS OF 3-ETHYL-9-ACETYLPHENANTHRENE} that are as strikingly similar in structure as they are different in their actions on the animal organism. For instance, the structure of the sterols and bile acids contain the perhydrocyclopentenophenanthrene ring system. Upon later research, it was found that the sex hormones and cardiac glycosides (heart poisons secreted by toads) have a structure very similar to this system. They are all derivatives of cyclopentenophenanthrene.

The problem with which a great number of people are confronted with today is one of the most baffling diseases which has ever been known to medical science. Cancer did not attract too much attention until the early part of the twentieth century when it became more apparent that men working with the distillation of coal tar often developed skin cancer. The fact that there were some chemicals from this coal tar which produced hard tumors in mice and Ichikawa in Tokyo, California, produced cancers in rabbits by long application of a coal tar.

\textbf{A Thesis Submitted to Marquette University in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science}

MILWAUKEE, WISCONSIN

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In 1929, there was recognized a relatively small number of naturally occurring phenanthrene compounds as compared with those known today. These compounds include several groups of substances which are as strikingly similar in structure as they are different in their actions on the animal organism. For instance, the structure of the sterols and bile acids contain the perhydrocyclopentenophenanthrene ring system. Upon later research, it was found that the sex hormones and cardiac glycosides (heart poisons secreted by toads) have a structure very similar to this system. They are all derivatives of cyclopentenophenanthrene.

The problem with which a great number of people are confronted with today is cancer. This is one of the most baffling diseases which has ever been known to medical science. Cancer did not attract too much attention until the early part of the twentieth century when it became more apparent that men working with the distillation of coal tar often developed skin cancer. The fact that there were some chemical agents present in this coal tar which produced these cancers was confirmed by Yamagiwa and Ichikawa in Tokyo (17). They succeeded in producing cancers in rabbits by long application of a coal tar.

These compounds which produce cancer were given the name of carcinogenic. Further investigation showed that

these substances having carcinogenic activity were found in
the high-boiling, neutral and nitrogen-free fractions of the
c oal tars. At the Research Institute of the Cancer Hospital
in London, Kennaway (17) and his associates started an
intensive study of the various carcinogenic compounds. It
seemed probable that the carcinogenic constituents of the
higher-boiling tar distillates were tested on mice with
negative results. The mouse was used as a testing animal
because the disease develops more rapidly in mice than in
the larger animals. Hieger observed that the tars and oils
known to produce cancer in these animals give characteristic
fluorescence spectra with bands at 4000, 4180 and 4400A.
A number of hydrocarbons of known structure was submitted
to optical examination in the hope of identifying the
characteristic spectrum. Special attention was paid to the
derivatives of anthracene, since fluorescence is one of the
particularly striking properties of this group of substances.
It was found that anthracene had neither the spectrum nor
the activity of the carcinogenic compounds, but 1,2-benz-
anthracene gave bands similar to the carcinogenic tars.

After the discovery of various carcinogenic compounds
their identification was attempted both by synthesis of
the compound and the degradation of the compound. Synthetic
methods developed for the purpose of identifying aromatic
degradation products have been of great advantage in attacking

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(17) Fieser, L. F. The Chemistry of Natural Products Related
to Phenanthrene, New York, Reinhold Publishing Corp.,
(1937, 82.)
this problem. This synthetic work establishes a direct connection to the chemistry of the cancer-producing hydrocarbons, for nearly all of these remarkable substances contain the phenanthrene nucleus. Several of the most potent carcinogenic compounds are obtained as a degradation product of a bile acid. An example of this is methyl-cholanthrene which was obtained as a degradation product of desoxycholic acid, one of the bile acids.

With respect to carcinogenic potency, methyl-cholanthrene is not surpassed by any compound yet tested although it is almost equaled by cholanthr ene itself. The production of a carcinoma is favored by introduction of substituents into the 5-position of the 1,2-benzanthracene molecule. 2-methyl-3,4-benzophenanthrene is carcinogenic to a high degree as are certain hexacyclic hydrocarbons derived from the pentacyclic hydrocarbon 3,4-benzopyrene (12).

The object of this thesis is the preparation of 3-ethyl triphenylene. To the knowledge of the author of this thesis, this compound has never been prepared. 2-methyl-triphenylene has been prepared similar to the method used (6) in this thesis. The following is a sketch of what is to be attempted.

3-Acetylphenanthrene is to be reduced to the 3-ethylphenanthrene by means of a Clemmensen reduction. This 3-ethylphenanthrene will then be subjected to a Friedel-

Crafts reaction with acetyl chloride to form the 3-ethyl-9-acetylphenanthrene. In order to form a closed ring, the acetyl group in the 9-position will be brominated, followed by a condensation with sodium-malonic ester after which the carbonyl groups will be reduced and the hydrocarbon will be dehydrogenated with selenium.

I wish to thank my major professor, Dr. G. C. Toraballa, for the suggestions and advice which has been given to the author during the investigation of this thesis.

Bender, Elizabeth R
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Phenanthrene was discovered in 1872 by Fittig and Löffler. It was thought to be a product of the coal tar distillation process. However, upon the degradation of phenanthrene by oxidation, it was shown that the final product was diphenyl methane. We know this today.

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INTRODUCTION

Phenanthrene was discovered in 1872 by Fittig and Ostermayer as an isomer of anthracene. Independently of Fittig and Ostermayer, Graebe also obtained the hydrocarbon by working with a product from technical anthracene (17). When phenanthrene was first obtained, it was given the structure of anthracene while anthracene was given the structure of phenanthrene. However, upon the degradation of phenanthrene by oxidation, it was shown that the final product was diphenyl.

\[
\text{Phenanthrene} \quad \xrightarrow{\text{Oxid.}} \quad \text{Diphenic acid} \quad \xrightarrow{} \quad \text{Diphenyl}
\]

When anthracene was oxidized, diphenyl could not be obtained. With this proof, the structure of the compounds were interchanged giving the phenanthrene and anthracene nuclei as we know them today.

Phenanthrene is found as a constituent of coal tar, and specifically, in the anthracene oil fraction. The separation of these two compounds is a rather long and tedious process.

and after an attempt of purification, if more than two percent oxidized than the naphthalene and also the ability to form anthracene is present, the melting point of the phenanthrene a 9,10-addition compound with elemental bromine. will be raised (17). Pure phenanthrene melts at approximately it is to be expected that the central nucleus of the 101°C, whereas the anthracene melts at 217°C.

A separation of these two compounds cannot be achieved by the use of solvents alone, therefore chemical action has mixtures of the mono- and di-derivatives produced. This attack in substitution reactions. There are often isomeric to be used. One method is the heating of phenanthrene in an leaves a rather wide field as there are no less than five alcoholic solution with nitric acid in order to oxidize the mono-substitution and twenty-six di-substitution products anthracene present. The anthraquinone and the dinitro-anthra- possible. Consequently, there are often very complicated quinone which forms, precipitates and the phenanthrene is obtained from the filtrate. The hydrocarbon is then distilled is very difficult as they tend to form a supersaturated and further crystallized. Another method is the use of solution and also there is a great tendency to form mixed crystals. The phenomenon of polymorphism is also quite not completely remove all of the anthracene (16).

As to the reactivity of phenanthrene it is more reactive than naphthalene and less reactive than anthracene (13). This is particularly true in the nitration and sulfonation Upon oxidation, anthracene is more easily converted to the of the hydrocarbon and in the Friedel-Crafts reaction.
quinoine than phenanthrene. Phenanthrene appears to have the same strong double bonds as naphthalene and, as it is illus- trated, the respective structures of the two are very similar.

![Naphthalene](image1.png) ![Phenanthrene](image2.png)

Naphthalene's less activity as compared to phenanthrene is noted by the ability of the phenanthrene to be more easily

oxidized than the naphthalene and also the ability to form
a 9,10-addition compound with elemental bromine.

It is to be expected that the central nucleus of the
tricyclic hydrocarbon would be the most exclusive point of
attack in substitution reactions. There are often isomeric
mixtures of the mono- and di-derivatives produced. This
leaves a rather wide field as there are no less than five
mono-substitution and twenty-six di-substitution products
possible. Consequently, there are often very complicated
mixtures form in a reaction. The separation of these mixtures
is very difficult as they tend to form a supersaturated
solution and also there is a great tendency to form mixed
crystals. The phenomenon of polymorphism is also quite
common (17). Usually if a pure product of 20-25% yield is
obtained, it is regarded as a highly satisfactory result.
This is particularly true in the nitration and sulfonation
of the hydrocarbon and in the Friedel-Crafts reaction.

The nitration of phenanthrene in glacial acetic acid
solution with diacetyl ortho nitric acid yields the 9-nitro­
phenanthrene as the chief product. Small amounts of the 2-
and 4-derivatives are obtained along with an extremely
small amount of the 3-isomer. (33)

The sulfonation of the hydrocarbon has been the subject
of careful studies by four main investigators, Werner,
Sandqvist, Fieser and Ioffe'.

Werner prepared three phenanthrene sulfonic acids by the action of concentrated or fuming sulfuric acid on the hydrocarbon. The three acids which he isolated and characterized were the 2-, 3-, and 9-phenanthrene sulfon acids. He also developed a method of separating the 2-acid as a barium salt. Fieser, interested by Werner's work, continued the study and was able to improve the methods of separation and identification of the isomers through the p-toluidine salt (18). The yields which Werner obtained were poor, and through various modification, Fieser increased the yields.

With the identification through the p-toluidine salts, the phenanthrene sulfonic acids all formed crystalline salts with fairly well separated melting points. The 2- and 3-sulfonic acids were obtained more easily and more abundantly than the 9-sulfonic acid. Fieser was also able to separate and identify the 1-sulfonic acid. This he came upon quite accidentally while trying to separate a phenanthrol mixture by fusion with alkali.

Ioffe' based his work on the fact that the 2- and 3-acids would be favored at high temperatures. Using time-temperature curves, he concluded that the 9-acid is formed first, even at a high temperature, and then there is a rearrangement to the 3-position (17). There was also some indication that the 3-acid later rearranges into the 2-acid.

Sandqvist and Fieser found that the formation of disulfonic acids occurred even when phenanthrene is not sulfonated completely at room temperature. When either the 2- or 3-acids is submitted to sulfonation, the second substituent enters the unsubstituted terminal nucleus chiefly at C₆ and C₇, and to a much lesser extent at C₈.

The preparation of 2- and 3-aminophenanthrene can be obtained from the corresponding phenanthrene-sulfonic acids and nitrophenanthrenes. However, this involves the tedious separation of the isomeric sulfonic acids and nitrophenanthrenes. The halogen derivatives of phenanthrene can be obtained by the diazotization of the various aminophenanthrenes.

In the Friedel-Crafts reaction for the acylation of the hydrocarbon, Willgerodt and Albert used carbon disulfide as a solvent and claimed the isolation of the 9-acetylphenanthrene. Later, Mosettig and Van deKamp tried the same reaction, but obtained only resinous products (28). With the use of nitrobenzene, they found that the reaction proceeded smoothly and simply. They obtained a 64% yield of the 3-acetylphenanthrene and 15% of the 2-acetylphenanthrene.

Benzoyl chloride and o-toluoyl chloride reacted in the same manner to give 20% of the 3-isomer, 3% of the 2-isomer and 6% of the 1-isomer (3). Bachmann used the Perrier modification in the preparation of the benzoyl compounds.

---

the 1-derivative, he used carbon disulfide as a solvent and for the 2- and 3-derivatives, he used nitrobenzene as a solvent (9). With the o-toluoyl chloride, nitrobenzene was used as a solvent after carbon disulfide failed to bring about the desired results. From the 9-o-toluoyl phenanthrene, 1,2,3,4-dibenzanthracene can be obtained. This compound is thought to have rather high carcinogenic activity.

It has been found that the acetylation of 9,10-dihydrophenanthrene reacts far more smoothly than phenanthrene itself. A 90% yield of 2-acetyl-9,10-dihydrophenanthrene was obtained by Mosettig and Burger (27).

In general, with the Friedel-Crafts reaction, the 3-position is favored.

The various phenanthryl ketones can be reduced to their respective hydrocarbons by means of a Clemmensen reduction. Although in some cases the yield from this Clemmensen is low, it is one of the best and simplest types of reduction. These alkylated phenanthrenes can also be prepared by the synthesis and cyclization of a Y-arylbutyric acid, followed by the aromatization of the six-membered ring. In the case of phenanthrene, a naphthylbutyric acid is required.

By using decalin as a solvent, phenanthrene 2-, 3-, and 9-aldehydes could be prepared with an average yield of 90% of the theoretical. In this reaction, the oxidation of the

The 2-, 3- and 9-ω-bromoacetyl derivative of phenanthrene are easily obtained by the bromination of the methyl ketones with elemental bromine.

Using a 2% sodium hypochlorite solution on the ω-bromoacetyl compounds, the respective carboxylic acids can be obtained. The corresponding ω-amino alcohols and ω-amino ketones can be obtained also from the ω-bromoacetyl phenanthrene compounds by the direct reaction with an amine (31).

Phenan-threne 9-carboxylic acid can be prepared from 9-bromophenanthrene either by means of 1) a Grignard reagent, used to prepare many derivatives which have been difficult by carbonation, or by condensation with ethyl chlorocarbonate to obtain the phenanthrene. Also, these aldehydes can be reduced to the corresponding alcohols by using the Rosenmund method of obtaining the aldehydes (38). The following is the general method used.

The 1-phenanthroic acid has been prepared, but with difficulty and in poor yields by the alkali fusion of 1-benzoyl phenanthrene.

The 2-, 3-, and 9-aldehydes have been prepared by Mosettig and Van deKamp from the corresponding acid chlorides using the Rosenmund method. This catalytic reduction of the acid chloride was the simplest and the most convenient to use.

By using decalin as a solvent, phenanthrene 2-, 3-, and 9-aldehydes could be prepared with an average yield of 90% of the theoretical. In this reaction, the oxidation of the

---

phenanthrene nucleus is not possible (29).

Bachmann, in 1935, prepared 1-phenanthraldehyde by a process similar to the Sonn and Müller process. However, starting with the anilide obtained by the Beckman arrangement (4) of the oxime of 1-benzoylphenanthrene, the overall yield from the ketone was 60% of the theoretical amount. Reaction of the above mentioned anilide with phosphorous pentachloride, followed by a reduction of the product by stannous chloride and hydrochloric acid in absolute ether yielded the 1-phenanthraldehyde (2). This aldehyde can be used to prepare many derivatives which have been difficult to obtain at the 1-position. Also, these aldehydes can be reduced to the corresponding alcohols.

Shoppee likewise used this Sonn and Müller method of obtaining the aldehydes (38). The following is the general method used.

\[
\begin{align*}
&\text{RC-Cl} \rightarrow \text{RC-NHC}_6\text{H}_5 \xrightarrow{\text{PCl}_3} \text{RC-NC}_6\text{H}_5 \xrightarrow{\text{SnCl}_2} \text{RC-NC}_6\text{H}_5 \xrightarrow{\text{Hydrolysis}} \text{RCH}
\end{align*}
\]

Probably the most satisfactory method for the preparation of the 9-phenanthrol consists in the reduction of 10,10-di-cloro-9-phenanthrol (19).

There are five possible phenanthrols and all of these are known. However, the only ones which are readily available are the 2- and 3-phenanthrols. These two are readily prepared from the sulfonates by an alkali fusion (18). At the time Fieser was doing this work, Shoesmith and Guthrie synthesized the 1-phenanthrol by heating the α-naphthol paraconic acid with loss of carbon dioxide and water and the formation of a new ring. (37)

\[
\text{H} \quad \text{C}=\text{O} \quad \text{H} \quad \text{C}-\text{C}=\text{O} \quad \text{H} \quad \text{C}-\text{OH} \quad \text{H} \quad \text{C}-\text{C}=\text{O} \quad \text{H} \quad \text{C}=\text{O}
\]

\[
\begin{align*}
\alpha-\text{Naphthaldehyde} & \quad \text{Succinic Acid} & \quad \alpha-\text{Naphthol Paraconic Acid} & \quad 1-\text{Phenanthrol} \\
\end{align*}
\]

A more practical way of obtaining the 1-phenanthrol is by brominating 1-keto-1,2,3,4-tetrahydrophenanthrene and eliminating hydrogen bromide by the action of diethyl aniline. Møssettig and Burger obtained this as a by-product in the preparation of amino alcohols from the 1,2,3,4-tetrahydrophenanthrene (27).

Probably the most satisfactory method for the preparation of the 9-phenanthrol consists in the reduction of 10,10-dichloro-9-phenanthrone (19).

4-Phenanthrol has been obtained in a small yield from

the condensation product of α-naphthaldehyde and succinic acid (17).

Some rather unusual substitution reaction of the phenanthrols have been reported by Mossettig and Burger (25). When 3-phenanthrol was treated with one mole of acetyl chloride in a Friedel-Crafts reaction, 3-acetoxyphenanthrene was obtained. However, if two moles of acetyl chloride were used, then 3-acetoxy-4-acetylphenanthrene was obtained in 30% yield (26). With the methyl ether in nitrobenzene solution in the presence of aluminum chloride, the 9-derivative is obtained. The product of the Kolbe reaction of sodium-3-phenanthrolate is 2-carboxy-3-phenanthrol. In all of these cases substitution would be expected to occur at the 4-position. In this work Mossettig and Burger found that the normal hydroxy acid, 4-carboxy-3-phenanthrol, is rather unstable, as the carboxyl group is easily displaced on heating.

Not only with the phenanthrols does the 4-position seem to be avoided, but also with other phenanthrene compounds. This could be due to the spatial requirements of the molecule or perhaps to some form of steric hindrance.

Many early reports concerning various hydro derivatives


Of phenanthrene might appear incomplete or inaccurate in the light of careful studies of the high pressure hydrogenation of phenanthrene carried out by Schroeter (35)(36). Three stages of hydrogenation were defined in this work and the structure of the highly purified hydrocarbons were all established by synthesis. Hydrogen atoms first enter the reactive central nucleus, giving 9,10-dihydrophenanthrene. The next pair of hydrogen atoms probably saturates one of the double bonds of a terminal ring such as that at C₁ and C₂, giving a tetrahydro compound which has two dihyrobenzenoid rings and which consequently is unstable. By a migration of one double linkage into the central nucleus, this isomerizes to a more stable structure.

![Chemical diagram](image)

Schroeter, G. Ber. 57, 2025, (1924).
it alone contains an intact naphthalene grouping. While the hydrocarbon can be isolated from the hydrogenation mixture in a pure form through the picrate, it is more conveniently prepared by synthesis. The 4-keto-1,2,3,4-tetrahydrophenanthrene has been very useful in preparing benzophenanthrene, by condensing the ketone with sodio-malonic ester (7).

9-10-dihydrophenanthrene was not obtained by Schroeter in quantity, for it was necessary to separate the substance from a mixture consisting largely of the other two hydrocarbons. The chief difficulty with this manner of preparing the mixture was sulfonated. The dihydro compound formed a readily soluble disulfonate which can be obtained after removal of the groups. This method can be used in the determination of less soluble monosulfonate of 1,2,3,4,5,6,7,8-octahydrophenanthrene. In one instance there has been observed a by-product which evidently results from the hydrogenation of many similar compounds.

After removing the tetrahydro derivative as the picrate, the quinone is that the quinone is quite easily oxidized to the soluble disulfonate which can be obtained after removal of the groups. This method can be used in the determination of less soluble monosulfonate of 1,2,3,4,5,6,7,8-octahydrophenanthrene. More recently it has been discovered that pure 9,10-dihydrophenanthrene can be prepared in any desired amount by a process of selective hydrogenation, using copper-chromium-barium oxide catalyst. Also the unsymmetrical isomer of the octahydrophenanthrene, 1,2,3,4,9,10,11,12-octahydrophenanthrene, is readily available in quantity by synthesis.

Adkins and Connor (1) used chromium-copper oxides for the hydrogenation of many similar compounds.

As to oxidation, phenanthrenequinone can be prepared easily and in fair yield by the oxidation of the hydrocarbon in glacial acetic acid solution with chromic anhydride. As stated before, this is one method used in separating the anthracene from phenanthrene. When the phenanthraquinone is purified by using a sodium bisulfite solution, the anthraquinone separates and, after filtration, the filtrate is acidified bringing back the phenanthraquinone.

The chief difficulty with this manner of preparing the quinone is that the quinone is quite easily oxidized to the diphenic acid by cleavage of the linkage between the carbonyl groups. This method can be used in the determination of substituted phenanthraquinones. In one instance there has been observed a by-product which evidently results from the cleavage of the linkage between one ketone group and a benzene ring, followed by further oxidation and lactonization (17).

This list of derivatives is not meant to be complete by any means. It is merely intended to show what can be done to the phenanthrene nucleus and several of the reactions which the derivatives of phenanthrene can be subjected.

As mentioned above, it is very difficult to separate phenanthrene from anthracene. When phenanthrene is obtained from the anthracene oil fraction of coal tar, it is a dark brown oily crystalline substance. As to solubility, phenanthrene is more soluble in organic solvents than anthracene, and technical material containing over fifty percent phenanthrene is obtained by crystallization. By further crystallization of technical phenanthrene it is possible to remove the bulk of anthracene and other impurities and to obtain colorless preparations melting at temperatures from about 102°C to 115°C. Pure phenanthrene melts at approximately 101°C. The material purified only by physical methods contains appreciable quantities of anthracene, carbazole and fluorene. Of the three, anthracene is the most persistent and more drastic means have to be taken in order to remove this impurity.

E. Schmidt (34) introduced a convenient method which depends on the greater ease of oxidation of anthracene as compared with phenanthrene. The solubility of anthraquinone in a solvent like alcohol is such that it is easily separated from phenanthrene. The crude phenanthrene is heated in

(34) Schmidt, E. Ber., 7, 305, (1874).
DISCUSSIONS OF EXPERIMENTAL WORK

Purification of Phenanthrene

As mentioned above, it is very difficult to separate phenanthrene from anthracene. When phenanthrene is obtained from the anthracene oil fraction of coal tar, it is a dark brown oily crystalline substance. As to solubility, phenanthrene is more soluble in organic solvents than anthracene, and technical material containing over fifty percent phenanthrene is obtained by crystallization. By further crystallization of technical phenanthrene it is possible to remove the bulk of anthracene and other impurities and to obtain colorless preparations melting at temperatures from about 102° C to 115° C. Pure phenanthrene melts at approximately 101° C. The material purified only by physical methods contains appreciable quantities of anthracene, carbazole and fluorene. Of the three, anthracene is the most persistent and more drastic means have to be taken in order to remove this impurity.

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(34) Schmidt, E. Ber., 7, 205, (1874).

alcoholic solution with a quantity of nitric acid sufficient to oxidize the anthracene present. This converts the anthracene into anthraquinone, and dinitroanthraquinone, which precipitates and the phenanthrene is obtained from the filtrate. The hydrocarbon is then distilled and recrystallized. By this method, Schmidt obtained a melting point of 100°C and proved it to be phenanthrene by degradation into diphenyl.

Cohen and Cormier (16) also used concentrated nitric acid for the oxidation of anthracene into the anthraquinone. Under the conditions used practically all of the anthracene is oxidized while the phenanthrene is nitrated only to a very negligible extent. The flakes or plates obtained by these two gentlemen melted at 99-99.5°C. Their process consisted of refluxing the phenanthrene in ethyl alcohol with concentrated nitric acid. The material which precipitated upon cooling of the filtrate was distilled as a pale yellow oil. This distillation was not performed under reduced pressure because the side arm would be clogged with crystals.

In this distillation by Cohen and Cormier, when the yellow oil started to darken, the distillation had to be stopped or else an explosion would occur. In order to prevent these explosions, W. E. Bachmann, at a later date, used glacial acetic acid and an aqueous chromic anhydride solution in place of the nitric acid. After refluxing these with phenanthrene for a while, concentrated sulfuric acid was added...
acid was added. After dilution with water, and followed by filtration, washing and distillation, the product was then recrystallized from ethyl alcohol. A melting point of 98.7-99.5°c was obtained (3).

This oxidation method cannot be relied upon to remove the last traces of anthracene, but this can be accomplished by boiling a solution of the purified hydrocarbon in nitrobenzene with maleic anhydride (15).

On a small scale purification, the picrate is often useful. The picrate, which is yellow needles melting at 145°c can be reconverted into the hydrocarbon by distribution between aqueous ammonia or soda solution and ether. This is very impractical on a large scale and it is also too expensive a method to use for large scale work.

The phenanthrene used in this thesis was a granular tan-colored substance with a melting point of 96-99°c before recrystallization. After recrystallization, white plates melting between 98-100°c were obtained.

A trial recrystallization was first made with ethyl alcohol using five grams of phenanthrene and 100 milliliters of ethyl alcohol. The phenanthrene was very soluble in the hot alcohol, but difficultly soluble in the cold alcohol. This was shown quite readily when the alcohol solution was allowed to cool. A recovery of 3.5 grams of phenanthrene was recovered.

Since this recrystallization was quite satisfactory in both the amount of material recovered and in its solubility with the alcohol, 100 grams of phenanthrene was purified in the same manner.

Reaction with acetyl chloride and phenanthrene with nitrobenzene as a solvent, and aluminum chloride as a catalyst. Probably the reason for the preference of nitrobenzene over the other solvents, such as carbon disulfide, is that the nitrobenzene combines with aluminum chloride to form a rather stable molecular compound (14). This complex has sufficient catalytic activity to promote the desired reaction, but if apparently does not instigate side reactions to the same extent as the more potent uncombined halide used in the reaction. There is also a possibility that the solvent influences the direction of the substitution, but this point has not been fully investigated to satisfaction.

The direct introduction of alkyl and acyl side chains into aromatic compounds may be accomplished by a variety of methods, most of which involve acid catalysts. The most important method for this purpose is that of Friedel and Crafts. Even though there are many and various purposes of the Friedel-Crafts reaction (22)(32), the process is not well understood and is affected by many factors other than the reactants themselves. Some of the factors which have to be

3-Acetylphenanthrene

After the purification, the first experiment is a Friedel-Crafts reaction with acetyl chloride and phenanthrene with nitrobenzene as a solvent, and aluminum chloride as a catalyst. Probably the reason for the preference of nitrobenzene over the other solvents, such as carbon disulfide, is that the nitrobenzene combines with aluminum chloride to form a rather stable molecular compound (14). This complex has sufficient catalytic activity to promote the desired reaction, but it apparently does not instigate side reactions to the same extent as the more potent uncombined halide used in the reaction. There is also a possibility that the solvent influences the direction of the substitution, but this point has not been fully investigated to satisfaction.

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The fact that acylation by the Friedel-Crafts reaction is superior to alkylation mainly is on the fact that acylating agents are in general more reactive than alkylation agents and partly on the fact that it is ordinarily not possible to use a true condensation product as product. Moreover, although usually required only small amounts of acetylating agents for at least a part of reaction., the reaction is not effective for each type of product. The reaction is not limited to condensation of monohaloarenes but also works on the hydrogenation of the reaction mixture.

---

considered in a Friedel-Crafts are temperature, time, pressure, degree of mixing and finally the manner of introduction of the reagents into the reaction mixture. The importance of the addition of reagents was clearly established in this experiment.

The fact that acylation, by the Friedel-Crafts reaction is superior to alkylation depends partly on the fact that acylating agents are in general more reactive than alkylating agents and partly on the fact that it is ordinarily not possible to introduce more than one acyl group on one compound. Moreover, alkylation usually required only small amounts of catalysts, whereas acylation calls for at least a mole of the catalyst for each mole of product. The reason is that the carbonyl compound which is formed combines with the catalyst forming a complex which is not destroyed until the hydrolysis of the reaction mixture.

\[
\begin{align*}
\text{Benzene} & \quad \text{C} & \quad \text{C} \\
\text{+} & \quad \text{Cl} & \quad \text{Cl} \\
\text{AlCl}_3 & \quad \text{AlCl}_3 \\
\rightarrow & \quad \text{AlCl}_3 \\
\text{AlCl}_3 & \quad \text{AlCl}_3 \\
\text{Benzene} & \quad \text{Benzoyl Chloride} \\
\end{align*}
\]

Benzene Benzoyl Chloride Aluminum Chloride Complex of Benzophenone

The Friedel-Crafts method of acylation in the narrowest sense involves the use of acid halides and anhydrides, which react with aromatic compounds in the presence of anhydrous aluminum chloride to produce ketones (21).

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In this thesis, the acylating agent used was acetyl chloride. The Friedel-Crafts reaction has been used on the phenanthrene nucleus for many different purposes (20).

The acylation of phenanthrene was first attempted by Willgerodt and Albert using carbon disulfide as the solvent. They claimed that 9-acetylphenanthrene, melting at 123°C was obtained by this method. However, when Mosettig and Van deKamp tried this same reaction, it resulted in little more than resinous products. The results were no better when the reaction was moderated by using acetic anhydride in place of acetyl chloride, by operating at a lower temperature, -15°C, or by employing the milder condensing agent of stannic chloride. The solvent was changed from carbon disulfide to nitrobenzene and the reaction proceeded quite smoothly, but still Willgerodt and Albert's 9-acetyl compound was not obtained. With nitrobenzene as a solvent, Mosettig and Van deKamp obtained a 64% yield of 3-acetyl-phenanthrene and a 15% yield of the 2-acetylphenanthrene (28). Both of these ketones were recrystallized from methyl alcohol.

The position of the acetyl groups were determined by oxidizing with a two percent sodium hypochlorite solution to the corresponding carboxylic acids. The general reaction is as follows:

\[
R-O-CH_3 + 3NaOCl \rightarrow R-O-ONa + 2NaOH + CH_3Cl_3.
\]

This method of Mosettig and Van deKamp was the one used in this thesis for the preparation of 3-acetylphenanthrene. The following is an illustration of the reaction which takes place.

\[
\text{Phenanthrene} + H_3C-C-Cl \xrightarrow{\text{Nitrobenzene solvent}} \text{Acetyl Chloride Addition Complex} + HCl \xrightarrow{-2 \text{ to } 5^\circ C} \text{3-Acetylphenanthrene Mixture of complex aluminum salts.}
\]
When the 3-acetylphenanthrene was first prepared, a purification was attempted by recrystallization from methyl and ethyl alcohols alone. The reason for this type of purification was that no vacuum distillation apparatus was available by which pressures as low as two-to-three millimeter could be obtained. Later one, a vacuum distillation apparatus was set up and the pressure could be lowered to a range of three-to-five millimeter.

The first time the 3-acetylphenanthrene was attempted, the phenanthrene was dissolved in nitrobenzene and the mixture was cooled to 0°C before the aluminum chloride was added slowly to the reaction flask. This mixture was cooled to 5-10°C before the acetyl chloride was added. Upon the addition of the acetyl chloride, all at once, the temperature rose to 25°C. This resulted in the formation of much tar as was evidenced when the purification by crystallization was attempted. Five recrystallizations of the compound were made, two with methyl alcohol and three with ethyl alcohol. Despite the number of recrystallizations, the needle-like crystals still remained a dark brown, even though much of the oil and tar had been removed. At this point, an attempt to decolorize the material with charcoal was made. After two such attempts the product was still a brown color, but not as dark as before. Later on, a different sample was purified by the charcoal method and it was noticed that in order to eliminate all of the charcoal from the oil, a large excess of alcohol had to be used. Consequently, if
all of the charcoal had been removed from the first sample, there is a possibility that the recrystallized material would have been the white needles desired.

The second time the 3-acetyl compound was attempted, just enough acetyl chloride was added to initiate the reaction. The temperature immediately rose from 0°C to 7°C above zero. When the temperature started to fall again, the addition of the acetyl chloride was continued at a very slow rate, making sure that the temperature did not rise above 7°C. With this second preparation, the crude impure material was almost as light colored as that which had been recrystallized a number of times.

In the first preparation, the ether extractions were dried with sodium sulfate and in the second preparation, magnesium sulfate was used as the drying agent. This change in the drying agent is believed to have caused the trouble in the distillation of the compound. The particles of magnesium sulfate were so fine that they could not be filtered from the ether extractions. This statement is based on the fact that the distillation of the first two preparations, taken together, resulted in a twenty-six gram recovery from 50 grams of the crude material, while in subsequent distillations, where magnesium sulfate alone had been used as a drying agent, approximately four to five grams of material was recovered from approximately 35 grams of crude. With the final preparations of the compound, sodium sulfate was used as the drying agent and the result
was that a 27 gram yield was obtained, which is almost the practical yield obtained by Moseittig and Van deKamp.

In all of the distillations, the material which did not distill appeared to be a resin. It was thought that this resin formation could have been due to prolonged heating at high temperatures. The smallest claison flask available for this vacuum distillation was a 500 milliliter flask and the lowest pressure obtained was five millimeter.

When removing the 26 grams of distillate, from the first two preparations, from the receiver, the flask was warmed slightly which immediately cause a discoloration due to some polymerization. Consequently, the material would not crystallize and so another attempt was made to prepare the compound.

The third time the compound was attempted, the ether extractions were evaporated off in the air with the formation of clumps of crystals during the evaporation. Upon breaking these clumps a definite needle-like crystal formation could be seen. Before the evaporation, this ether extraction was dried with magnesium sulfate.

With the distillation of this product, the 500 milliliter claison flask was substituted by a regular 125 milliliter distilling flask. A light yellow oil was received within an eleven degree range of 185-196°C at five millimeter pressure. This oil was recrystallized from methyl alcohol which yielded 4.5 grams of yellow needles melting within the range 70-71.5°C.
A great deal of residue was left in the distilling flask after the distillation, which gave the appearance of a polymerized compound more than a regular tar. At this time, all of the oils which did not crystallize from the previous distillations were put through a charcoal recrystallization in methyl alcohol. Upon filtration, it was noticed that the oil, which settled out immediately, was not completely free from the charcoal. A large excess of alcohol was added and the mixture was again heated. More of the charcoal was removed from the oil upon filtration. Upon evaporation of the alcohol, an oil was again obtained which would not completely crystallize. Consequently, another vacuum distillation was tried on the material. During this distillation, the first fraction was received between 155-160°C and started to solidify in the receiver. The temperature then rose to 185°C and another small fraction was collected. Until recrystallization was attempted, it was thought that the fraction collected between 155-160°C was the true boiling point of the 3-acetylphenanthrene and the higher temperature, 185°C, was that of the polymerized ketone. Upon recrystallization, the first fraction had a melting point of 90°C which indicated that this was some phenanthrene which had not completely reacted. When the second fraction was recrystallized from methyl alcohol, nothing settled out for five days. After this time, small clumps of needle-like crystals had formed on the bottom of the beaker. After two more days, the viscous yellow oil
had again settled out with the crystals. In this distillation, a 125 milliliter distilling flask was again used and as per usual over half of the material remained in the distilling flask. The concluded reason for this was as follows. The distance to the side arm of the flask is much shorter than in the 500 milliliter claisson flask, but the width of the side arm is much smaller and consequently a lot of material was returned to the bulb of the flask as it could not go through the side arm. The conclusion drawn was that the material had to be heated for a longer period of time before the entire quantity could be distilled, and due to this heating, the compound was polymerized. As was proved later on, this theory was not entirely correct.

While the above mentioned oils were separating and crystallizing, the preparation of 3-acetylphenanthrene was tried two more times. A little modification was used this time. The aluminum chloride was slowly added to the nitrobenzene forming the nitrobenzene-aluminum chloride complex with the following color changes:

yellow → yellow-green → dark forest green → dark greenish-brown with the last addition of the catalyst to the nitrobenzene. This mixture was filtered through glass wool in order to remove those particles which would not dissolve and then cooled before the addition of the phenanthrene dissolved in nitrobenzene. During this addition, the temperature
was not allowed to rise above 3°C. The addition took one-half hour. All of the acetyl chloride was added at one time after the temperature had been lowered to -1.5°C.

Hydrolysis of the material proceeded quite easily. However, at the end of the steam distillation, it was noticed that some solid material was also being collected. The distillation was stopped and a small amount of the solid was collected and dried. A melting point of 96°C was observed and it was concluded that all of the phenanthrene had not reacted and was being carried over by the small amount of nitrobenzene still being distilled.

The material remaining in the steam distilling flask was extracted with ether, dried with magnesium sulfate, the ether removed by distillation, and finally the vacuum distillation of the viscous oil. The temperature rose to 155-160°C and quite suddenly the side arm of the distilling flask was clogged with the distilled crystallized material. The side arm and the top of the distilling flask as well as the receiver was warmed with a free flame in order to melt the solid matter. Before the side arm was re-opened, the oil in the distilling flask was being forced up into the small capillary used to admit air to minimize the bumping. After one-half hour, the side arm was free and the remainder of the distillation was carried on comparatively easy.
However, over three-fourths of the material remained in the flask as a resin. Upon recrystallization, the distillate had a melting point of 92°C which was probably a mixture of phenanthrene and a small amount of 3-acetylphenanthrene.

Because of the presence of so much phenanthrene and so little 3-acetylphenanthrene, this mixture was discarded. Therefore, the preparation of 3-acetylphenanthrene was attempted for the fifth time.

As before, the aluminum chloride and phenanthrene were dissolved separately in nitrobenzene. This time the phenanthrene-nitrobenzene mixture was cooled to 3°C and then the aluminum chloride-nitrobenzene mixture, cooled to 15°C, was added to the phenanthrene mixture. The temperature rose to 7°C after the total addition. The entire mixture was cooled to 0°C before the acetyl chloride was added, all at one time. The temperature rose rather rapidly to 5°C, followed by a slower rise to 7°C. After hydrolysis and extraction with ether, the ether layer was washed with sodium bicarbonate for the following purpose. Since, it was assumed, that the material which continually remained in the distillation flask was the polymerized ketone, and since acids are good catalysts for ketonic polymerization, the idea arose that possibly enough acid had been soluble in the ether to cause the polymerization. Therefore sodium bicarbonate was used to wash the ether layer free of any hydrochloric acid, so that it could not cause polymerization during the distillation process.
A portion of the washed ether was dried with magnesium sulfate and the remaining portion was dried with sodium sulfate. The ether was removed by distillation and the remaining solid was vacuum distilled. During the distillation of the ether a solid appeared. Some of this solid was removed from the distilling flask, washed with a little ether, dried and a melting point taken. A melting point of 135-140°C was obtained from the crude product. These crystals were then assumed to be those of the 2-acetylphenanthrene which have a melting point of 142°C. 

As to the vacuum distillation, it was attempted with a free flame. The neck, and as much of the side arm and bulb of the distilling flask as was practical was covered with asbestos. The lowest pressure obtained was seven millimeter and the temperature was 226-231°C. This distillation was definitely not a success, as a lot of the impurities were carried over along with the oil, making the distillate a very dark brown oil. Upon recrystallization from methyl alcohol, approximately one-half of that distilled was soluble in the alcohol. The crystals obtained were a pale yellow having a melting point of 70-72°C and weighing 4.5 grams.

Further purification of the compound already obtained was attempted. A fifty percent ether-alcohol mixture was used. A few well-formed crystals appeared, with the polymerized oil also settling to the bottom. This attempt was not too great of a success as the compound was too soluble.
in the mixture. The oil adhering to the crystals was removed by washing with cold methyl alcohol. A trial was made by ether alone. Smaller crystals and in lesser quantity was obtained. Some of the oil again came out of solution along with the crystals and was removed as above. The phenanthrene-nitrobenzene mixture was added. Hot methyl alcohol was used to dissolve the excess polymerized oil from the 2-acetylphenanthrene. This was not too great a success as a considerable quantity of the 3-acetyl compound was dissolved along with the oil. Then crystals which remained were the whitest obtained. The method which was the easiest and the most practical was the use of methyl alcohol cooled in an ice bath and then used to wash the crystals. The crystals which resulted still retained a little yellow tinge. Four grams of 3-acetylphenanthrene was obtained in this manner. This, combined with the four grams already obtained, was reduced by a Clemmensen to the 3-ethylphenanthrene.

During this reduction period, 3-acetylphenanthrene was attempted by the procedure as the last two preparations. The aluminum chloride-nitrobenzene was cooled to 1°C before the addition of the phenanthrene. The temperature was not allowed to rise above 3°C during this addition. The acetyl chloride was added when the temperature had again fallen to only 0°C. After the addition, the temperature rose to 6°C and fell very slowly back to 0°C. The mixture was stirred for one-half hour and then the ice was removed and allowed to
rise to room temperature.

After almost all of the nitrobenzene was steam distilled, the oil began to solidify in the condenser. This was again identified as phenanthrene. It was noted that the last time phenanthrene was received at the end of the steam distillation process, the phenanthrene-nitrobenzene mixture was added to the aluminum chloride mixture as in this trial. It was also noted that when the aluminum chloride mixture was added to the phenanthrene mixture, no phenanthrene was recovered in the steam distillation. In order to confirm the suspicion that complete reaction would take place only when the aluminum chloride mixture is added to the phenanthrene mixture, the 3-acetyl derivative was prepared for the last time. The steam distillation of this attempt proceeded quite smoothly without the phenanthrene being received to any degree during the steam distillation.

Both of these attempts were followed by extraction with ether and dried with sodium sulfate instead of magnesium sulfate. Sodium sulfate is a little more granular than the magnesium sulfate and could be filtered off quite easily. It is an assumption that the extremely small particles of magnesium sulfate went through the filter paper and thus catalyzed the polymerization of the ketone when heated. With the distillation of these two preparations, approximately 27 grams was received with each distillation. Only a small amount of material remained in the distilling flask.

Upon vacuum distillation of the first of the last two
distillations, a small fraction was collected between 155-180°C, and the remainder, consisting of 27 grams, was collected between 185-195°C at four millimeters pressure. The main portion of this latter fraction was collected within a four degree range, 190-194°C.

When recrystallization was attempted, the oil was quickly taken up by the hot methyl alcohol, but upon the least bit of cooling, crystals were immediately precipitated. The solution was again heated and the alcohol immediately decanted from the solid material which did not go into solution. To the crystals which remained in the flask more alcohol was added, heated and decanted. This was done four times in all before the entire solid went into solution. The melting points of the four different extractions were:

1) softening around 72°C and the entire sample melted at 98°C,
2) softening at 62°C and melted completely at 78°C,
3) there was marked melting between 68-72°C, 98-100°C and the last portion melted between 130-133°C (this was probably a mixture of phenanthrene, 3-acetyphenanthrene, and 2-acetylphenanthrene),
4) no softening until 140-143°C where the entire sample melted. This was probably 2-acetylphenanthrene which has a melting point of 142°C.

All portions except that which melted between 62-78°C was discarded. This portion, consisting of nine grams was again recrystallized fractionally without too much success. Approximately four and one-half grams of the product was lost in this process. That which remained was later combined
with another quantity of material and re-distilled.

The vacuum distillation of the seventh and last preparation of the 3-acetylderivative was carried out with 27 grams of distillate being obtained. After recrystallization two fractions were obtained. One was brownish in color and possessed a melting point between 60-70°C. The lighter yellow colored fraction had a melting point of 64-72°C. A small amount of each fraction was recrystallized with no change in melting point. Consequently, the product of this distillation and the 4.5 grams from the sixth distillation were again distilled.

With this distillation, three fractions were taken, the first from 150-180°C, the second from 180-190°C and the third from 190-200°C. The pressure was reduced to between three and four millimeters. The distillate from the third fraction crystallized rather rapidly compared to previous solidifications of the desired product before recrystallization. Before recrystallization, this product of 26 grams had a melting point of 69-71.5°C. Twenty-two grams were recovered from the crystallization, which possessed the same melting point as before. The crystals were allowed to dry completely before a reduction was attempted.
The two most common ways used to reduce ketonic compounds to the corresponding hydrocarbons are the Wolff-Kishner and Clemmensen reductions. The general reaction of each is as follows:

**a) Wolff-Kishner reduction**—This reduction can be performed with either a sealed tube containing sodium acetate or else without the sealed tube in the presence of potassium hydroxide and ethylene glycol.

\[
\begin{align*}
R'-C=O + HNNH & \rightarrow R-C-N-NH \quad \text{sealed tube} \\
\text{tube} & \rightarrow R-C-H + \text{N}_2
\end{align*}
\]

**b) Clemmensen reduction**—the Clemmensen method of reducing the carbonyl group to a hydrocarbon depends upon the use of amalgamated zinc with an acid like hydrochloric acid (24).

\[
\begin{align*}
R'-C=O + \text{ZnHg} & \rightarrow R-C-H \\
\text{Clemmensen} & \rightarrow R'-C-H
\end{align*}
\]

Other methods of reduction usually reduce the ketone group only as far as the carbinol. These reductions include the Grignard reaction with the alkyl magnesium halide to form the tertiary alcohols, the Ponndorf-Weerwein reduction, and the reaction of 3-ethylphenanthrene with aluminum hydride or "hydrogen Grignard."
reaction with aluminum alkoxides to form a secondary alcohol, and the lithium aluminum hydride or "hydrogen Grignard" reaction which reduces ketones to secondary alcohols.

The Clemmensen method is used as it is the most practical method for the reduction of the acetylphenanthrenes to the hydrocarbons of ethylphenanthrene.

This reduction is used not only for the simple phenanthryl ketones, but also on those phenanthrene compounds of more complicated structure (11). To illustrate, \( \beta \)-(3-phenanthroyl) propionic acid can be obtained by succinoylation of the phenanthrene nucleus, followed by a Clemmensen to produce \( \gamma \)-(3-phenanthryl)butyric acid.

\[ \text{ZnHg HCl} \quad \text{Clemmensen} \]

Haworth and Mavin (23) prepared the 2- and 3-ethyl phenanthrene by means of a Clemmensen without the toluene layer. The 2-ethylphenanthrene was obtained as a white solid when recrystallized from methyl alcohol, while the 3-ethylphenanthrene remained a colorless liquid.

Mosettig and Van deKamp also used the Clemmensen reduction, but obtained low yields. However, their purpose

for the reduction was only for identification, so they did not try various ways to increase the yields (30).

The specific action of the Clemmensen reduction on 3-acetylphenanthrene is as follows.

\[
\text{3-Acetylphenanthrene} + \text{H}_2 \xrightarrow{\text{ZnHg + HCl}} \text{Reflux 45 Hours} \rightarrow \text{3-Ethylphenanthrene}
\]

The method for the reduction in this thesis was that suggested by Dr. G. Toraballa, who used this method in connection with her work at the University of Michigan.

The 4.5 grams obtained from the first distillations were coupled with the four grams obtained by washing the polymerized oil from the crystallized 3-acetylphenanthrene with methyl alcohol, and then reduced by means of a Clemmensen.

The mixture was refluxed briskly for 65 hours with the addition of hydrochloric acid and glacial acetic acid every nine hours. The organic toluene layer was decanted after this period of heating. The water and acid layer was diluted and extracted with benzene. The benzene extractions and the toluene layer was dried with sodium sulfate.

After as much of the solvent as possible was removed, a heavy viscous oil remained. This oil had a very dark

green fluorescent. A picrate was attempted with 0.4 grams, but the original oil would not go into solution with the ethyl alcohol. While in the hot alcohol, the oil became brown and was soft. When cooled, this oil became hard and very brittle. The reason for the failure to obtain the picrate was probably due to the large amount of impurities present in comparison to the amount of 3-ethylphenanthrene produced.

Without further purification, the remainder of the 3-ethylphenanthrene was subjected to another Friedel-Crafts. A reduction of the 22 grams of 3-acetylphenanthrene from the final preparation was started. The reaction mixture was allowed to reflux for 46 continuous hours before cooling. Sodium sulfate was again used to dry the benzene extractions and the toluene layer. After the removal of the solvents, a small portion of the remaining oil was put aside, while the remainder was again acetylated.

An attempt was made to form a picrate of that which had been withdrawn. Instead of crystals separating upon cooling, a dark brown viscous oil separated which failed to crystallize after standing for over a week.

For instance, acylation of benzene results only in the production of monoketones, while a diacylated fluorene does not inhibit further acylation (39).

(39) Thomas, J. A., unpublished data.
To the knowledge of the author of this thesis, 3-ethyl-9-acetylphenanthrene has never been prepared. There is no reason, however, for saying that the compound cannot be produced as the compound from which the acetylation was attempted was polynuclear and contained no carbonyl groupings. If the carbonyl group had not been reduced to a straight chain and the original compound, phenanthrene, was not polynuclear, then there is some possibility that acylation would not take place. However, many polynuclear compounds, larger than phenanthrene, have been acylated (10).

The ease of substitution in the benzene ring depends upon the aromaticity of the compound to be substituted. The presence of a ketonic group in the benzene ring decreases the aromaticity of benzene, and reaction, except under extreme conditions, is totally inhibited unless there are also present several highly activating groups which may facilitate the introduction of a second acyl group. Since increased aromaticity facilitates acylation of ketones, the presence of a ketonic group in polynuclear hydrocarbons does not inhibit further acylation (39).

For instance, acylation of benzene results only in the production of monoketones, while a diacylated fluorene

has been prepared by condensing benzoyl chloride with 2-benzoylfluorene and aluminum chloride. 2,7-dibenzoylfluorene was obtained.

\[
\text{Benzoyl Chloride} \rightarrow \text{AlCl}_3
\]

In many cases there has been some rearrangement upon the acylation of an alkyl phenanthrene. This is especially true of the methylphenanthrenes (8).

However, in this experiment, the ease with which the reaction was carried out is due to the presence of both a polynuclear compound and a straight chain in place of a ketone grouping. The reaction is as follows.

When over one-half of the reaction was finished, the organic matter started to decompose and a short time thereafter, the oil was black and started to stick to the sides of the flask. When the reaction was complete, the contents remained in the flask and were dried with sodium and extracted with ether. The ether soluble portion was dried with sodium and ether. The ether insoluble portions were filtered, washed and dried. The yield was 7.5 grams after the reduction and an attempt to remove most of the solvent was made. This product still contained some of the solvent as is evidence by the dark color of the solid.

\[
\text{3-Ethyl Phenanthrene} + \text{Acetyl Chloride} \rightarrow \text{3-Ethyl-9-Acetylphenanthrene}
\]

The product from the reduction of the 3-acetylphenanthrene was again subjected to a Friedel-Crafts reaction. There was approximately 7.5 grams after the reduction and an attempt to remove most of the solvent was made. This product still contained some of the solvent as is evidenced by the quantity. Nitrobenzene was added and the mixture cooled to 0°C. The aluminum chloride was added in small portions to nitrobenzene and then mixed with the cooled hydrocarbon. During this mixing, the temperature was allowed to rise to 5°C, followed by cooling the mixture to -2.5°C.

The entire quantity of acetyl chloride was added all at once with an immediate decrease of five degrees to -7.5°C before rising slowly to 0°C. The reason for this phenomena drop in temperature has not been found as yet. This reaction mixture was stirred in an ice-bath for 10 hours. The hydrolysis and steam distillation proceeded very smoothly.

When over one-half of the nitrobenzene had been distilled, the organic layer started to darken and a short time thereafter, the oil was black and started to stick to the sides of the flask. When cooled, the water layer was decanted and extracted with ether. The black solid material which remained in the flask was hardened against the walls of the flask. As much of the material as possible was removed from the walls of the flask and extracted with ether. The ether soluble portions was dried with sodium sulfate, followed by the evaporation of the ether. A dark oil
resulted.

The ether insoluble fraction was filtered and dried. This resulted in a brown powdery substance weighing 0.8 grams. An oxime was attempted with 0.4 grams of the solid using the pyridine-alcohol method. Upon hydrolysis of the excess hydroxylamine hydrochloride, a small amount of solid remained undissolved. This water insoluble matter was recrystallized from ethyl alcohol. Upon cooling, a film formed on the top of the ethyl alcohol. When the alcohol had completely evaporated, several small needles had formed in the crucible. A melting point was taken which appeared to be approximately 130°C. Not enough was obtained for further recrystallization or even for another melting point in this impure state.

The ether soluble portion was also subjected to oxime formation. Four-tenths grams were used on the initial trial. Only part of this was soluble in the alcohol solution and the insoluble portion was filtered off. The weight of this solid was 0.2 grams, leaving only 0.2 grams which could have reacted. After hydrolysis, the thick greenish oil which remained was crystallized from ethyl alcohol. A light yellow flocculent precipitate formed upon cooling. However, when an attempt was made to collect a quantity sufficient for a melting point, this flocculent material possessed an oily nature and no melting point could be determined. Another recrystallization was made with no better results.
An oxime was made with the remainder of the ether soluble fraction. There was 3.1 grams in addition to the 0.4 grams already used. The hard solid material which remained after heating weighed 1.85 grams. The filtrate which contained the excess hydroxylamine hydrochloride, pyridine, alcohol and the desired oxime possessed a greenish color. Upon cooling, crystals, probably hydroxylamine hydrochloride started to appear. After evaporation of the pyridine and alcohol, the material was hydrolysed with the crystallized solid going into solution and a thick greenish-colored oil floating on top. This oil was put into an alcohol solution with the same yellow flocculent precipitate appearing upon cooling. A small part of this precipitate was washed with a little acetone. A white solid resulted, which, when collected, presented a waxy property and consequently a melting point could not be obtained. That which was not treated with acetone was recrystallized from alcohol after a melting point could not be obtained because of its oily nature. After this recrystallization, the precipitate which formed still was very oily, and no melting point could be obtained.

The final reduction product was again acylated by means of a Friedel-Crafts reaction. This time the 3-ethylphenanthrene-nitrobenzene mixture was cooled to -3°C before the addition of the aluminum chloride and nitrobenzene mixture. Following the addition, an increase of temperature to 10°C was noted. This mixture was cooled to -2°C before the
addition of acetyl chloride. All of the acetyl chloride was added at one time followed by an immediate increase in temperature to 5°C. The first time the acylation was tried on the 3-ethylphenanthrene, there was a five degree decrease in temperature before a rise in temperature occurred.

The reacting mixture was stirred for five hours and kept cold for approximately ten hours. This was followed by hydrolysis and steam distillation to remove the nitrobenzene.

After the flask and its contents had cooled, the water layer was decanted and extracted with ether. As before, the matter which was a viscous oil during the steam distillation hardened upon cooling. An attempt was made to loosen the hard mass from the walls of the flask without too much success. Consequently, ether was added to the flask and stoppered so that the ether would not evaporate too fast.

In this manner, the flask and its contents were allowed to stand for two days before the ether was decanted and fresh ether added.

The ether extractions from the water layer were dried with sodium sulfate. The drying agent was filtered off and the ether evaporated.

At this point, the investigation of the thesis was stopped.
EXPERIMENTAL PROCEDURES

PURIFICATION

After a trial recrystallization of five grams of phenanthrene, 100 grams were purified in the following manner. The 100 grams were divided into two 50 gram portions. Each portion was placed in separate one liter round-bottom flasks along with 500 milliliters of ethyl alcohol. This mixture was refluxed for one-half hour and then filtered, using a hot water funnel. Upon cooling, the phenanthrene immediately precipitated. The solvent was filtered off by suction and the white plates of phenanthrene were spread on large filter paper to dry. Eighty-two grams of purified phenanthrene were recovered in this manner. The white plates of phenanthrene had a melting point of 98-100°C.

3-Acetylphenanthrene

The phenanthrene, purified by the method just described was subjected to acylation by the Friedel-Crafts method. Forty grams of phenanthrene were dissolved in 200 milliliters of concentrated hydrochloric acid which was cooled to between 0°C to-5°C. When cool, the non-volatile fraction was extracted with ether, as was the water layer. Altogether, approximately one liter of ether was used. The ether insoluble portion was filtered off and the ether extractions were dried with sodium sulfate. While this mixture was cooling, 63 grams of aluminum chloride were added to 300 milliliters of nitrobenzene which has also cooled to 0°C. The aluminum chloride-nitrobenzene mixture was then added to the reaction flask keeping the temperature at 0°C, or below, during this addition. 

For hydrolysis, a quantity of ice was put into a five liter round-bottom distillation mixture was poured in small quantities over the ice with intermittent shaking.
was also cooled to 10°C. The aluminum chloride-nitrobenzene mixture was then added slowly to the reaction flask keeping the temperature at 5°C, or below, during this addition. This addition took approximately one-half hour. During all of these coolings and additions, the mixture was being stirred. This mixture was cooled to approximately -4°C before the addition of 24 milliliters of freshly distilled acetyl chloride. This acetyl chloride was added all at one time and the temperature rose immediately to 5°C before dropping slowly down to -3°C again. This mixture was stirred for an additional one-half hour and then the stirring was stopped and the cold medium removed. The flask and its contents were allowed to stand for twelve hours, the reaction mixture slowly warming to room temperature during this time.

For hydrolysis, a quantity of ice was put into a five liter round-bottom flask and the reaction mixture was poured in small quantities over the ice with intermittent shaking. Fourty milliliters of concentrated hydrochloric acid were then added and the mixture was thoroughly shaken. Steam distillation followed in order to remove the nitrobenzene. The remaining reagents were added in this order—40 milliliters of concentrated hydrochloric acid and 50 milliliters of acetic acid respectively, 61.3 milliliters of toluene and finally, 22 grams of 3-ethylphenanthrene. This mixture was heated by a hot plate and was allowed to reflux briskly for 30 hours. During this refluxing period, 12.4 milliliters of

After removal of the ether solvent, the remaining
material was vacuum distilled with the 3-acetylphenanthrene being received between 190-200°C at three to four millimeter pressure. This distillate was recrystallized from methyl alcohol, the crystals still retained a slight yellow color, and a melting point of 69-71.5°C was obtained. Twenty-two grams of 3-acetylphenanthrene was obtained after several recrystallizations from the original distillate of 27 grams.

3-Ethylphenanthrene

The twenty-two grams of 3-acetylphenanthrene was reduced by a Clemmensen reduction.

Seventy-five grams of clean granulated zinc were shaken for five minutes with a mixture of 11.5 milliliters of water, 4.75 milliliters of concentrated hydrochloric acid and 7.5 grams of mercuric chloride. The solution was then decanted and the amalgamated zinc was washed once with water and dried.

Sixty-two grams of amalgamated zinc were placed in a two-liter round-bottom flask fitted with two condensers. The remaining reagents were added in this order: 46.5 milliliters of concentrated hydrochloric acid and acetic acid respectively, 61.9 milliliters of toluene and lastly, the 22 grams of 3-acetylphenanthrene. This mixture was heated by a hot plate and was allowed to reflux briskly for 46 hours. During this refluxing period, 12.4 milliliters of
concentrated hydrochloric acid and 3.1 milliliters of concentrated acetic acid were added every nine hours. At the end of the 46 hours of refluxing, the toluene layer possessed a green fluorescence. The reduction mixture was cooled, the toluene layer decanted off and the water and acid layer was extracted with benzene after further dilution with water. The toluene layer and the benzene extractions were dried with sodium sulfate. Later, after removal of the drying agent, the solvents were removed with the aid of a water aspirator and a little heat. A picrate was attempted, but no crystals could be obtained. The 3-ethylphenanthrene was subjected to another acylation without further purification.

**3-ethyl-9-acetylphenanthrene**

Without further purification, the 3-ethylphenanthrene was subjected to a Friedel-Crafts acylation to form 3-ethyl-9-acetylphenanthrene.

The product from the reduction was dissolved in 75 milliliters of nitrobenzene, placed in a one liter three-necked flask fitted with a mechanical stirrer, thermometer and condenser with a dropping funnel on top, and cooled to -3°C. Seventeen grams of aluminum chloride were dissolved in 100 milliliters of nitrobenzene, cooled to 15°C and then the mixture was added to the reaction flask keeping the temperature below 5°C. The mixture was stirred all this time.
The reaction mixture was then cooled to \(-2^\circ C\) before the addition of seven milliliters of acetyl chloride all at once. The temperature rose to \(5^\circ C\) and then fell back slowly to \(0^\circ C\).

The mixture was stirred and kept cold for the next ten hours and then allowed to come to room temperature. This mixture was hydrolyzed by pouring into ice and hydrochloric acid and then steam distilled. After the nitrobenzene was off, the non-volatile material was cooled and extracted with ether. Two different portions were obtained. One was soluble in the ether, and the other portion was not soluble in ether. The ether extractions were dried with sodium sulfate.
ILLUSTRATIONS OF EXPERIMENTAL APPARATUS
**Friedel-Crafts Reaction**

This arrangement was used for both Friedel-Crafts reactions to produce the 3-acetylpbenanthrene and the 3-ethyl 9-acetylpbenanthrene.

Rubber stoppers were used for the three necks of this flask. The stopper of one neck was fitted with a thermometer and a dropping funnel. The thermometer was inserted so as to be as close to the bottom of the flask as possible, but yet not touching the bottom and also out of the way of the stirrer which was inserted through the center neck. A mercury seal was also connected to the stopper in this center neck.

To the third neck was connected a condenser and calcium chloride tube. From the top of the calcium chloride tube a piece of rubber tubing was attached which lead to a hydrogen chloride trap in order to condense the vapors of hydrogen chloride which would be evolved during the reaction.

The cold medium generally used was a salt and ice bath which surrounded the lower part of the three-necked flask.
Steam Distillation

The steam distillation apparatus was used to remove the nitrobenzene from the hydrolyzed material of the Friedel-Crafts reaction.

The steam generator consisted of a five-liter round-bottom flask which was fitted with a rubber stopper having three openings. In one opening was placed a four foot piece of eight millimeter glass tubing which was inserted to the bottom of the flask, the remaining portion protruding outside of the flask upright. This upright tube was to serve as a safety tube. In the second opening, a short piece of tubing was placed which had a piece of rubber tubing and a clamp on the outside portion. This was used to release the excess steam at the end of the distillation. The third outlet lead to the distilling flask. Between the steam generator and the distilling flask was a rubber connection and clamp which was used to open and close the steam-inlet tube leading to the distilling flask. The steam-inlet tube is bent so as to extend to the bottom of the flask. The steam outlet tube, which leads to the condenser, passes just through the stopper. A receiver is placed at the open end of the condenser in order to catch the distillate.
Vacuum Distillation

This set-up was used in all of the distillations of 3-acetylphenanthrene. Tight fitting rubber stoppers were used at all of the openings, and the connections were of pressure tubing or eight millimeter glass tubing. All connections were painted with collodion to make sure that they were air-tight.

The distilling flask was equipped with a 360°C thermometer and a capillary. The capillary was made of eight millimeter glass tubing and in order to regulate the amount of air admitted into the system, a piece of rubber pressure tubing, with a screw clamp, was put over the outside end of the capillary. The distillate was collected in the receiver which consisted of either a 500 milliliter round-bottom or a 500 milliliter claison flask. In order to condense the material there was a film of water flowing over the surface of the receiver. This was done by supporting a piece of bent glass, which was connected to ordinary rubber tubing attached to the faucet, over the receiver and catching the water by means of a funnel leading to the drain by means of a connected rubber hose.

The receiver was connected by pressure tubing to a 500 milliliter suction flask which was used as a trap. This suction flask was connected to an ice-trap which was used to condense any volative material which might be in
the system. Dry ice and acetone or ice and concentrated hydrochloric acid was used to produce the cold medium. This ice-trap was connected to a 300 milliliter suction flask. To this 300 milliliter flask was also connected the manometer and a 500 milliliter suction flask. Both of these suction flasks were used as traps. From the 500 milliliter suction flask protruded a stopcock used to either shut off the air at the beginning of a distillation or to admit air at the end of a distillation. To this suction flask, a calcium chloride - potassium hydroxide drying tube was attached. This was to remove any acidic or basic fumes which might be in the system and also to remove any water vapor which might be present. This drying tube lead to the oil pump which was used to evacuate the system.
The object of this thesis was the preparation of 3-ethyltriphenylene but only three steps in its formation was performed. The purified phenanthrene was acylated by means of a Friedel-Crafts reaction to obtain the ketone, 3-acetylphenanthrene. After recrystallization, the compound was reduced to 3-ethylphenanthrene using the Clemmensen method of reduction. This product was not purified, but immediately subjected to a Friedel-Crafts reaction in the hopes of obtaining 3-ethyl-9-acetylphenanthrene.

The conclusions drawn from the investigation of this thesis are as follows:

1. The order of addition of the reacting material to the flask in the Friedel-Crafts reaction for the preparation of 3-acetylphenanthrene must be in the following order--the phenanthrene in nitrobenzene solution followed by the slow addition of the aluminum chloride in nitrobenzene solution.

2. The polymerization of the ketone during vacuum distillation was due to the use of the wrong drying agent. Sodium sulfate must be used instead of magnesium sulfate.

3. Some of the 3-acetylphenanthrene was reduced by the Clemmensen reduction as was evidenced by the production of a green fluorescence after brisk refluxing for a number of hours.

4. The compound put through the second Friedel-Crafts was acylated or else there would have been no rise in temperature.
upon the addition of the acetyl chloride.

5. After the acylation, two different fractions of material were obtained. One fraction was soluble in ether, and the other fraction was not soluble in ether. It has not been determined which fraction contains the desired 3-ethyl-9-acetylphenanthrene.

1. A method by which 3-acetylphenanthrene could be obtained in a pure state by recrystallizations alone and with a good yield. The removal of the polymerized oil and the dark coloration of the crystals are the prime objects.

2. In the reduction of 3-acetylphenanthrene to 3-ethyl phenanthrene, the development of a method of reduction which would not take as long but yet produce high yields of the desired product could be sought.

3. As to the purification of the 3-ethylphenanthrene, a method of purification, besides distillation, could be sought. Many times a picrate could be used as a means of purification, but this method usually causes a reduction in yield, and sometimes a picrate even fails to form.

4. In the acylation of 3-ethylphenanthrene, two portions were obtained, one which was soluble in ether and the other one was not soluble in ether. The determination as to whether or not both of these were organic followed by methods for purification of these two portions by simple mechanical means could be studied.

5. An investigation of these two portions as to the carbon, hydrogen and oxygen content would be of definite advantage.
At the close of this thesis only three experiments had been performed. Nevertheless, there are many points which could stand further investigation. Some of these are:

1. A method by which 3-acetylphenanthrene could be obtained in a pure state by recrystallizations alone and with a good yield. The removal of the polymerized oil and the dark coloration of the crystals are the prime objects.

2. In the reduction of 3-acetylphenanthrene to 3-ethyl phenanthrene, the development of a method of reduction which would not take as long but yet produce high yields of the desired product could be sought.

3. As to the purification of the 3-ethylphenanthrene, a method of purification, besides distillation, could be sought. Many times a picrate could be used as a means of purification, but this method usually causes a reduction in yield, and sometimes a picrate even fails to form.

4. In the acylation of 3-ethylphenanthrene, two portions were obtained, one which was soluble in ether and the other one was not soluble in ether. The determination as to whether or not both of these were organic followed by methods for purification of these two portions by simple mechanical means could be studied.

5. An investigation of these two portions as to the carbon, hydrogen and oxygen content would be of definite advantage
for further study.

6. The position of acylation of 3-ethylphenanthrene to form an acetyl-ethylphenanthrene could be determined by degradation and synthesis. This could be done with both the ether soluble and ether insoluble portions.


The present study of acetylation of side products from phenanthrene and related ethers and ketones will be described in detail. Further studies on the synthesis of a new five-membered heterocycle will be described in a subsequent paper.


The present study of acetylation of benzyl phenanthrene and its derivatives has been completed. Further studies on the synthesis of benzylphenanthrene and benzylphenanthrene derivatives will be described in a subsequent paper.

ANOTATED BIBLIOGRAPHY


A discussion of the Chromium, copper oxides for the hydrogenation of organic compounds. Very similar to the process used in the hydrogenation of phenanthrene.


The preparation of 1-phenanthrene aldehyde from phenanthrene by the Sonn and Müller method. Includes the process for the formation of a new five-membered ring.


The preparation and reduction of benzoyl phenanthrene to the corresponding alcohol. The alcohol was later reduced to benzylphenanthrene. Same process can be used to produce straight chain alkylphenanthrenes.


According to the Bechman rearrangement, the oximes of acetylphenanthrene would rearrange to give either the acid or an aminophenanthrene as an end product.

The phenanthryl halides were obtained from the aminophenanthrenes through a diazotization process.


The preparation of 2-methyltriphenylene from 3-methylphenanthrene through acetylation and ring condensation at the 9-position. Process similar to that of this thesis.


From 4-keto-1,2,3,4-tetrahydrophenanthrene obtained the benzophenanthrene using the sodio-malonic ester method.


Rearrangement of the 4-methylphenanthrene during acetylation to form 3-acetyl-5-methyl phenanthrene. The 4-methyl was obtained from the condensation of a β-napthyl butyric acid.


The use of o-toluoyl chloride in the Friedel-Crafts reaction to form o-toluoyl-phenanthrene.

The acylation of bigger molecules by the Friedel-Crafts method.


The extending of the carbon chain to form $\beta$-Phenanthroylbutyric acid.


Discussion of the carcinogenic activity of methylcholanthrene and derivatives of 3,4-Benzopyrene.


A discussion of the reactivity of phenanthrene and the means of preparation and purification.


General information on the Friedel-Crafts reaction.

(15) Clar, E., "Über die Konstitution des Perylens: die Synthesen des 2,3, 10.11-Dibenz und des 1,12-Benz-Perylens und Betrachtungen über die Konstitution des..."

Purification of phenanthrene using a maleic anhydride - nitrobenzene solution.


Information concerning the purification of phenanthrene through the oxidation of the anthracene present to the quinone.


General information concerning the phenanthrene compounds.


The preparation and purification of the 2-, 3-, and 9-sulfonic acids of phenanthrene.


The preparation of the phenanthryl amines from phenanthrene dibromides with 9-phenanthrol as one of the intermediate products.


Methods of reducing ketones to the corresponding alcohols.

General discussion of the Friedel-Crafts reaction on the phenanthrene nucleus.


The use of the Perrier modification in the Friedel-Crafts reaction and discussion of the directing influence of the solvent.


The various purposes of the Friedel-Crafts reaction.


The reduction of the 2- and 3-acetylphenanthrenes to the respective ethyl phenanthrenes.


Methods of reducing ketones to the corresponding hydrocarbons.


The reaction of 3-phenanthrol when subjected to acylation.

Further investigation of the effect of acetylation upon the phenanthrols.


1-Phenanthrol obtained as a by-product in the preparation of the amino alcohols.


Preparation and purification of the 2-, and 3-acetylphenanthrenes.


Preparation of the above mentioned aldehydes by the Rosenmund method.


Reduction with zinc in acidic and basic solutions lead to the formation of pinacols rather than to the desired product. Used the Clemmensen reduction to form the hydrocarbons.

The preparation of the bromo-acetyl compounds by the use of elemental bromine.


Discussion of the Friedel-Crafts reaction.


The nitration of phenanthrene and the reduction of the nitro group to form the amines.


Purification of phenanthrene by the nitric acid oxidation method.


The hydrogenation of phenanthrene and the three different derivatives obtained.


Further investigation of hydrogenation showed definite shifting of the double bonds during the hydrogenation process of phenanthrene.

The preparation of 1-phenanthrol from \( \alpha \)-naphthol paraconic acid.


The preparation of the phenanthrene aldehydes by the Sonn and Müller method.


Information concerning the mechanism and uses of the Friedel-Crafts reaction.


The preparation of 9-carboxylic acid from 9-bromphenanthrene.
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