ACID CATALYZED CONDENSATIONS OF CYCLIC
KETONES: I. ATTEMPTED SYNTHESIS OF
PHENANTHRENE

by

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INTRODUCTION

Polycyclic hydrocarbons and their derivatives constitute
a portion of organic chemistry that has received a good deal
of attention, both synthetically and theoretically. Although
little practical value may be derived from most of the hydro-
carbons themselves in an economic sense, many of their
derivatives find a great deal of use in various fields.
This is especially true of the lower members of the series,
particularly naphthalene, anthracene, and phenanthrene.

Theoretically they have received much attention with
relation to structural features, particularly with respect
to comparison of the aromatic members with benzene. They
generally show a great deal of the resonance energy and the
aromatic character so pronounced in benzene. However, they
have somewhat lower resonance energy values than benzene.

Economically, derivatives of these compounds find
considerable use in various industries such as in the dye
and pharmaceutical fields. They form a class of compounds
which are, in general, physiologically active and whose
activity ranges from carcinogenic character, through hormones
and dietary factors, to antibiotics such as aureomycin and
terramycin.

Phenanthrene is the lowest member of the angularly
condensed hydrocarbons and, although the hydrocarbon itself

has little practical value, its derivatives are quite
important in many phases of pharmaceutical chemistry.

A great many naturally occurring compounds are
phenanthrene derivatives. Among these are morphine, codeine,
and related alkaloids, the D vitamins, the resin acids,
various cardiac active glycosides, and many hormones such
as the sex hormones and cortisone. It would be of value,
therefore, to develop a general synthesis of substituted
phenanthrenes for both synthesis and structure elucidation
of these natural products.

This work was carried out both as an attempted method
for the preparation of 9-phenanthrol and as part of a long
range project involving the application of both the acid
catalyzed condensation of cyclic ketones and the Reformatsky
reaction to the synthesis of various polycyclic hydrocarbons.

The successful preparation of 9-phenanthrol by the
proposed synthesis would open a route to substituted
phenanthrenes, especially the 1,5- and 2,6- disubstituted
compounds. In addition, it was found during the course of
the work that intermediates might be obtained which would
lead to the 1,5,9- and 2,6,10- trisubstituted compounds.
These substituents are valuable as points of modification
of structure as substituents may not be placed in some of
these positions by reactions involving phenanthrene itself.
Since most substitution reactions of phenanthrene yield
rather complex mixtures, with substituents becoming attached

to various points of the nucleus, it is also preferable from
the point of yield to synthesize the nucleus with the desired
substituents already present.

The original synthesis may be represented as follows:
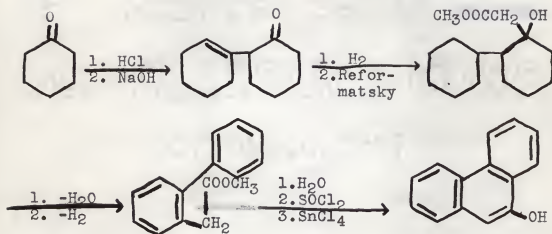
It was found however, that major difficulties were inherent
in this scheme, and thus could not be followed completely.

HISTORY

Phenanthrene is a colorless compound, which exhibits
a weak blue fluorescence in solution, and melts at 100°C.
It may be obtained from the distillation of coal tar. It
occurs in the same fraction as anthracene, from which it
may be separated by solution in carbon disulfide or
pyridine.

There are, at present, several methods for the synthesis
of phenanthrene and its derivatives. The easiest of these

is that of Haworth (10), which consists of succinoylation
of naphthalene followed by a Clemmensen reduction of the
keto group and a ring closure of either the acid with sulfuric
acid, or the acid chloride with stannic chloride, aluminum
chloride, or other Friedel-Crafts catalyst. Succinoylation
substitutes at both the 1- and 2- positions, but the two
acids may be separated rather easily, and in many cases the
same final phenanthrene is obtained from both and makes
separation unnecessary.

is that of Haworth (10), which consists of succinoylation

+ 2- isomer

+ 2- isomer

+ 4- isomer
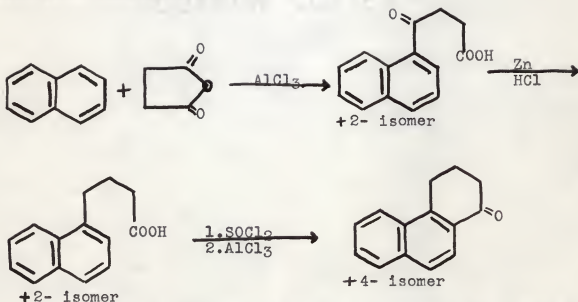
    Substituted phenanthrenes may be obtained in many cases
by varying the reactants. These fall into three general
categories: (a) succinoylation of certain substituted
naphthalenes, such as the 1- or 2- alkyl compounds, (b) the
use of alkyl substituted succinic anhydrides which leads to
two products which may in general be separated, and (c)
Grignard reactions of either or both of the keto compounds
formed as intermediates.

Procedure (a) leads to 9- alkyl substituents if the 1- substituted naphthalene is used, and 1- alkyl phenanthrenes if the 2- substituted naphthalene is used. Procedure (b) leads to 2- and 3- substituted phenanthrenes from the two possible products. It has been found that only two products are formed since the carbonyl group farthest removed from the alkyl group is the one which becomes attached to the ring. Procedure (c) leads to either 1- or 4- substituted phenanthrenes, depending on which isomer is used (8).

The Pschorr (17) synthesis involves a Perkin type condensation of an o-nitrobenzaldehyde with an arylacetic acid as the original step. This is followed by reduction to the amine, diazotization, and thermal ring closure with copper. This method has been modified a good deal by many investigators.

One of the most important of these is the oxindole modification of Windaus and Eickel (22), which leads to 9- substituted phenanthrenes by the following scheme:
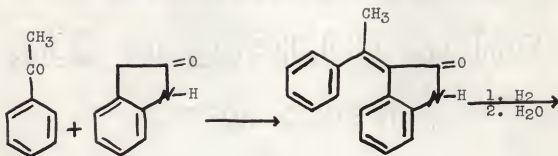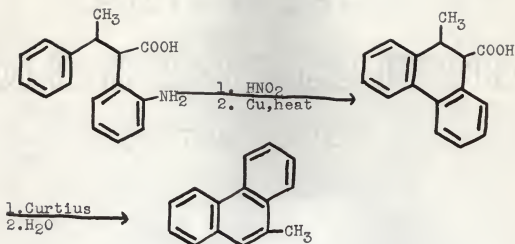
Bardhan and Sengupta (3) used an acetoacetic ester alkylation of 2-carbethoxycyclohexanone with 2-phenylethylbromide, followed by a dehydrative ring closure, and Bogert, et al (5) and Cook and Hewett (7) used a Grignard reaction with 2- phenylethylmagnesium bromide and cyclohexanone followed by the same type of dehydrative ring closure. Both of these syntheses are subject to a good deal of modification to obtain various derivatives of phenanthrene.

In 1949, Bagchi, et al (2), synthesized octahydro-9-phenanthrol utilizing the Reformatsky reaction on 2-cyclohexenylcyclohexanone, followed by a dehydrative ring closure. This proved to be the most direct route to this compound and its derivatives known at that time. It therefore seemed reasonable that, with certain modifications, Bagchi's procedure might be adapted to the synthesis of phenanthrene and substituted phenanthrenes. The 2-cyclohexenylcyclohexanone may be readily prepared by the acid catalyzed condensation of cyclohexanone and this procedure may be

readily adapted to the condensation of various substituted
cyclohexanones, which are in turn available from the
corresponding phenols.

The acid catalyzed ketone condensation has been known
for some time, especially in connection with the synthesis
of dodecahydrotriphenylene from cyclohexanone and of
mesitylene from acetone, through the condensation of three
molecules of the ketone. By varying the reaction conditions,
however, one may obtain a good yield of the product formed
by the condensation of only two molecules of ketone.

Various investigators have proposed methods of synthesis
of 2-cyclohexenylcyclohexanone, or its isomer
2-cyclohexylidenecyclohexanone. Of these, that of Rapson
(18) is the easiest and affords the cleanest reaction product
in the highest yields.

The Reformatsky reaction has been varied likewise a
good deal and many procedures are available. One of the
best of these is that of Bachmann and Dreiding (1), which
involves the addition of zinc and bromoester in small
portions to the carbonyl compound while refluxing.

The ring closures of various types that have been used
with this type of synthesis vary only in the dehydrating
reagent used, with phosphorous pentoxide and sulfuric acid
being the most commonly used agents.

EXPERIMENTAL

Preparation of 2-Cyclohexylidenecyclohexanone (I)
by the method of Gault, et al (9)

A mixture of 100 g. of 60 per cent sulfuric acid and 100 g. of cyclohexanone was allowed to stand for twenty-four hours. The mixture was then steam distilled and the distillate salted out with sodium carbonate. The resulting mixture was extracted three times with benzene, the benzene was removed by distillation and the product was distilled under reduced pressure. The fraction boiling at 153-160°C. at 25-29 mm. pressure was collected. This material was a colorless liquid which turned a pale yellow on standing. The yield was 35.2 g. (38.8 per cent).

Preparation of 2-Cyclohexylidenecyclohexanone (I)
by the method of Mannich (14)

To a solution of 54 ml. of concentrated sulfuric acid in 316 ml. of methanol was added 106 ml. of cyclohexanone. The resulting solution was refluxed for ten hours and the product worked up in the same manner as above. A 9 per cent yield of product was obtained.

Preparation of 2-Cyclohexenylcyclohexanone (II)

Anhydrous hydrogen chloride was passed into 28.5 g. of cyclohexanone until saturated. The mixture was allowed to

stand for one hour and then saturated again with hydrogen chloride. The resulting liquid was allowed to stand overnight and then was shaken vigorously with excess 40 per cent sodium hydroxide solution for approximately one-half hour. The two layers were separated and the upper layer was washed with water. The product was dried over anhydrous magnesium sulfate and distilled under reduced pressure, b.p. 140-145°C. at 12-15 mm. pressure. The yield was 10 g. (40 per cent).

Treatment with 2,4-dinitrophenylhydrazine according to the procedure of Johnson (12) yielded two products. Separation of these two products by fractional crystallization yielded an orange derivative, m.p. 145.5-147°C. as the major product, and a yellow derivative, m.p. 108-113°C.(impure). Analysis. Calculatate for $C_{18}H_{22}O_4N_4$: C,60.3; H, 6.2; N, 15.6. Found: C,   ; H .

Preparation of 2-Cyclohexylcyclohexanone

Redistilled 2-cyclohexenylcyclohexanone (II) (0.1 mole) was immediately dissolved in absolute ethanol, 5-6 g. of 10 per cent palladium-charcoal were added, and the mixture was placed under forty pounds per square inch of hydrogen at 80-100°C. with shaking. The theoretical amount of hydrogen (10 p.s.i.) was absorbed over a period of approximately three hours. The material was removed from the hydrogenation apparatus, filtered, and the ethanol removed by distillation. The resulting liquid gave negative results with potassium

permanganate and bromine in carbon tetrachloride and a
positive reaction with 2,4-dinitrophenylhydrazine.

Preparation of Methyl 2-Cyclohexyl-1-hydroxycyclohexyl-acetate (III)

Approximately 50 ml. of anhydrous, thiophene-free
benzene and 9 g. (.05 moles) of crude 2-cyclohexylcyclo-
hexinone were placed in a dry, three-neck flask fitted with
a stirrer, condenser, and separatory funnel and protected
from moisture with calcium chloride tubes. The solution
was then refluxed with stirring and 11.5 g. (.075 moles) of
methyl bromoacetate were added dropwise over a period of 45
minutes, while small portions of dry, clean, 20 mesh zinc
metal were added every 5-10 minutes. This mixture was then
refluxed for an additional two hours with stirring and then
cooled in an ice water bath. The complex was decomposed by
addition of a mixture of 50 ml. of glacial acetic acid and
50 ml. of water, followed by addition of 120 ml. of ice
water. The product was extracted three times with ether and
the combined ether layers washed four times with approximately
2.5 per cent ammonium hydroxide. The combined washings were
extracted once with ether and the combined ether layers were
dried over anhydrous magnesium sulfate. The ether was
removed by distillation under reduced pressure and 6.6 g.
(51.6 per cent based on 2-cyclohexenylcyclohexanone) of crude
product was obtained, m.p. 55-59°C. Recrystallization from

methanol-water yielded colorless needles, m.p. 59-60°C.
The compound gave negative results with potassium permanganate
and bromine in carbon tetrachloride. Analysis. Calculated
for $C_{15}H_{26}O_3$: C, 70.8; H, 10.3. Found: C,   ; H,   .

Preparation of 2-Cyclohexyl-1-hydroxy-cyclohexylacetic Acid (IV)

Two grams of methyl 2-cyclohexyl-1-hydroxycyclohexylacetate
were placed in a flask containing 90 ml. of methanol and 50 ml.
of 5 per cent sodium hydroxide. The resulting solution was
refluxed for 30 minutes. The liquid was evaporated to a
volume of about 50 ml., extracted with ether and acidified to
litmus with 10 per cent hydrochloric acid. The precipitate
was filtered and recrystallized from benzene. The yield was
1.81 g. (95 per cent). This acid is a colorless solid, m.p.
137.5-139°C.

A neutralization equivalent indicated a molecular weight
of 241 ≢1 (calculated molecular weight 240). The compound
gave negative results with potassium permanganate and with
bromine in carbon tetrachloride. Analysis. Calculated for
$C_{14}H_{24}O_3$: C, 70.0; H, 10.1. Found: C,   ; H,   .

Preparation of Methyl 2-Cyclohexylcyclo-hexenylacetate (V)

In a dry three-neck flask fitted with a stirrer and a
condenser and protected by a calcium chloride tube, were
placed 50 ml. of anhydrous, thiophene-free benzene and 3 g.

of methyl 2-cyclohexyl-1-hydroxycyclohexylacetate (III). The
solution was heated to boiling with stirring and 5 g. of
phosphorous pentoxide was added in small portions over a
period of one hour. The mixture was refluxed for an
additional hour and was then treated with 150 ml. of ice water.
This mixture was extracted three times with ether and the
ether layers washed with water. The combined ether layers
were dried over anhydrous magnesium sulfate, filtered, and
the ether removed by distillation. Vacuum distillation of
the resulting liquid yielded 2.3 g. (82 per cent) of color-
less liquid, boiling at $146-152^\circ$C./4-6 mm. This liquid
turned pale yellow on standing. The compound gave a slow
reaction with potassium permanganate and a rapid reaction
with bromine in carbon tetrachloride with the evolution of
hydrogen bromide.

Into a solution of one ml. of pyridine in 10 ml. of
ether was placed .472 g. of methyl 2-cyclohexyl-1-hydroxy-
cyclohexylacetate (III). The solution was cooled in an ice
bath and one ml. of thionyl chloride was added dropwise with
stirring. The mixture was allowed to stand overnight and
then mixed with 30 ml. of water to which 5 drops of
hydrochloric acid had been added. To the resulting mixture
25 ml. of ether were added and the layers separated. The
ether layer was washed with water and then dried over
anhydrous magnesium sulfate. The ether extract was filtered

and the ether was removed by distillation under reduced
pressure yielding a quantitative amount of starting material.

Preparation of 2-Cyclohexylcyclo-
hexenylacetic Acid (VI)

The procedure used for the preparation of methyl
2-cyclohexylcyclohexenylacetate (V) was followed with 2 g.
of 2-cyclohexyl-1-hydroxycyclohexylacetic acid (IV) and 3.5 g.
of phosphorous pentoxide. Vacuum distillation yielded 1.3 g.
(71 per cent) of colorless liquid, boiling point 175-180°C./
4-6 mm.

A solution of 25 ml. of methanol, 1 g. of methyl
2-cyclohexylcyclohexenylacetate (V), and .256 g. of sodium
hydroxide was refluxed for 30 minutes after which most of the
methanol was removed by distillation. Acidification with 10
per cent hydrochloric acid followed by extraction with ether,
drying of the ether, and distillation yielded .86 g. (91 per
cent) of colorless liquid, boiling point 174-180°C./4-6 mm.

This acid turned pale yellow upon standing. It gave
a slow reaction with potassium permanganate and a rapid
reaction with bromine in carbon tetrachloride with the
evolution of hydrogen bromide. It formed a solid
p-bromophenacylester, m.p. 81-82°C. from ethanol. Analysis.
Calculated for $C_{22}H_{27}O_3Br$: C, 63.0; H, 6.5. Found: C,   ;
H,   .

Dehydrogenation Attempts with Methyl 2-Cyclohexylcyclo-hexenylacetate (V) and Methyl 2-cyclohexyl-1-hydroxy-cyclohexylacetate (VI)

All attempts to dehydrogenate these compounds in the usual manner were unsuccessful. Heating with palladium-charcoal from 200-350°C. for 1-8 hours yielded no isolable product.

A small amount of methyl 2-cyclohexylcyclohexenylacetate (V) was placed in a length of 8 mm. pyrex glass tubing on a column of 10 per cent palladium-charcoal about 3 cm. high. The tube was placed in a Wood's metal bath at 300-350°C. for 8 hrs., extracted with ether, filtered, and distilled. An oil was obtained which yielded a picrate which was quite impure. Repeated fractional crystallization yielded a small amount of picrate, m.p. 138-141°C. from ethanol.

Dehydrogenation of 2-Cyclohexylcyclohexenyl-acetic Acid (VI)

Into a test tube containing 1-2 g. of 10 per cent palladium-charcoal was placed 0.700 g. of 2-cyclohexyl-cyclohexenylacetic acid. This mixture was heated in a Wood's metal bath at 250-300°C. for two hours and at 300-350°C. for six hours. The reaction product was taken up in ether, filtered, and the ether extracted three times with 10 per cent sodium bicarbonate solution. The ether was then removed by distillation and a crude oil was obtained.

Acidification of the sodium bicarbonate extract with 10 per cent hydrochloric acid yielded about 40 mg. of a colorless acid, probably biphenyl-2-acetic acid, m.p. 111-113°C. after recrystallization from ethanol. The reported melting point is 116°C. (Schonberg and Warren, 20).

Vacuum distillation of the non-acidic oil yielded 280 mg. of 2-methylbiphenyl, boiling point 95-100°C./.5-.7 mm.

The distilled 2-methylbiphenyl was placed in a flask containing 30 ml. of water and 0.8 g. of potassium permanganate. This mixture was refluxed for one and one-half hours and the excess potassium permanganate destroyed by addition of sodium bisulfite. The solution was then filtered, extracted with ether, and acidified with 10 per cent hydrochloric acid. About 20 mg. of o-phenylbenzoic acid was isolated, m.p. 106-108°C. after recrystallization from an alcohol-water mixture. The reported melting point is 110°C. (Jacobsen, 11).

Further distillation of the crude dehydrogenation oil yielded about 100 mg. of phenanthrene, boiling point 125-140°C./.3-.5 mm. Recrystallization from ethanol yielded colorless crystals, m.p. 96-97°C., reported 100°C. (Shriner and Fuson, 21). Treatment with picric acid yielded a crystalline picrate, m.p. 143-143.5°C., reported 144°C. (Shriner and Fuson, 21).

Preparation of $\Delta^{10,11}$ -Perhydro-9-phenanthrone (IX)

A mixture of 10 ml. of polyphosphoric acid and 2 g. of
methyl 2-cyclohexyl-1-hydroxycyclohexylacetate (III) was
heated on a steam bath with swirling until all of the solid
had dissolved and then for an additional 2-3 minutes. The
solution was then placed in an oil bath at 115-120°C. for
3-4 minutes, cooled, and about 100 ml. of water added. The
resulting mixture was extracted twice with ether, the ether
layers washed with water, and dried over anhydrous magnesium
sulfate. The ether solution was filtered and the ether was
removed by distillation. Vacuum distillation of the resulting
oil yielded 0.8 g. of oil boiling at 120-140°C./4-6 mm. and
0.8 g. (49.3 per cent) of a substance, probably $\Delta^{10,11}$ -per-
hydro-9-phenanthrone (IX), boiling at 170-190°C./4-6 mm.,
2,4-dinitrophenylhydrazone (Johnson, 12) m.p. 225-226.5°C.,
reported 226-227°C. (Pinkney, et al, 16).

To obtain seed crystals a chromatogram was made of the
material dissolved in hexane on an activated silica column.
The column was developed with Skelly B and eluted with
benzene after which the solvent was removed by evaporation.
The first fractions contained little material, but this was
followed by a band which yielded the major portion of the
desired ketone (IX), which spontaneously crystallized upon
standing for two days, m.p. 78-81°C. Crystallization from
                                        yielded colorless crystals, m.p.
C., reported 89°C. (Pinkney, et al, 16).

Spectra

The ultra-violet absorption spectra of 2-cyclohexenyl-
cyclohexanone-2,4-dinitrophenylhydrazone and $\Delta^{10,11}$-per-
hydro-9-phenanthrone-2,4-dinitrophenylhydrazone were obtained
in chloroform solution with a Beckmann Model DU spectro-
photometer with a one cm. cell and using maximum sensitivity.

DISCUSSION

In 1907 Mannich (14) reported the preparation of
2-cyclohexylidenecyclohexanone (I) by the condensation of
two moles of cyclohexanone in methanolic sulfuric acid.
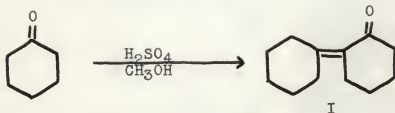
Gault, et al, (9) reported the same compound using 60 per
cent aqueous sulfuric acid. Both of these procedures were
reported to give good yields, generally being 80 per cent
or better.

However, Rapson (18) reported that saturation of cyclo-
hexanone with anhydrous hydrogen chloride, followed by treat-
ment with sodium hydroxide or pyridine yielded the theoretical
amount of 2-cyclohexenylcyclohexanone (II).

II
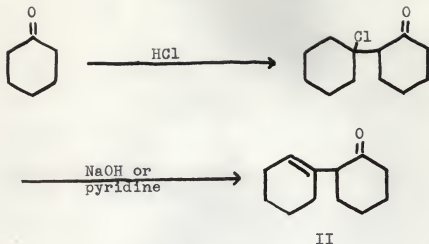
These three procedures were followed and it was found that Rapson's method was not only the easiest, but afforded the best yield, although a quantitative yield of product was never approached.

Treatment of the product obtained by the procedure of Rapson with 2,4-dinitrophenylhydrazine reagent yielded two products, an orange derivative and a yellow derivative. These products were separated difficultly by fractional crystallization, but the yellow derivative (the more insoluble of the two) could not be isolated in pure form as it was transformed to the orange derivative upon warming in ethanol, the crystallization solvent.

The ultra-violet spectra of these two derivatives were then taken (Plate I). The two compounds gave identical spectra with absorption maxima at 370 mμ indicating unconjugation (4), (6), (19).

Since these two derivatives are not isomers with respect
to the position of the carbon-carbon double bond and yet
have rather widely differing melting points, it seems likely
that they are isomers involving the carbon-nitrogen double
bond. It also seems likely that the yellow compound is the
cis- compound, since it is converted to the orange compound
by warming in ethanol and it is well-known that trans-
compounds are generally more stable than their cis- isomers.
The fact that the cis- compound has a good deal lighter
color than the trans- in the solid state is then reasonable
from probable steric factors. Apparently the cyclohexyl
ring interferes with the aromatic ring in such a way as to
force it somewhat out of the plane of the double bond and
thus decrease the resonance of the system. This may be
correlated with the fact that the yellow derivative can only
be isolated, and then in impure form, from a solution con-
taining a large excess of the orange, or trans-, derivative.
Apparently the equilibrium set up between the two forms in
ethanol or in chloroform (spectral solvent) is so far in
favor of the trans- form that at the dilution used for the
spectra (about 1 mg./100 ml.), the cis- form is not present
in high enough concentration to significantly affect the
observed spectrum.

Rapson (18) reported that 2-cyclohexenylcyclohexanone
(II) could be reduced rapidly by hydrogen using palladium
on strontium carbonate to yield 2-cyclohexylcyclohexanone.

It was found, however, that 2-cyclohexenylcyclohexanone
decomposed slightly on standing and attempts to hydrogenate
this slightly impure compound with palladium-charcoal,
platinum, or Raney nickel were all unsuccessful. During
the course of these experiments solvents used were 95 per cent
ethanol, absolute ethanol, and absolute ethanol containing
a few drops of hydrochloric acid.

The hydrogenation was accomplished finally by
redistilling the 2-cyclohexenylcyclohexanone, immediately
adding five to six grams of ten per cent palladium-charcoal,
and hydrogenating this mixture at forty pounds per square
inch pressure and heating to 80-100°C. This material slowly
absorbed hydrogen (approximately three pounds pressure drop
per hour).

2-Cyclohexylcyclohexanone reacts smoothly with methyl
bromoacetate in the presence of zinc metal in a typical
Reformatsky reaction to yield methyl 2-cyclohexyl-1-hydroxy-
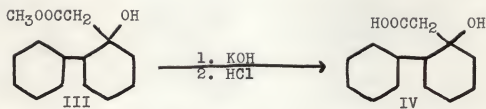cyclohexylacetate (III).
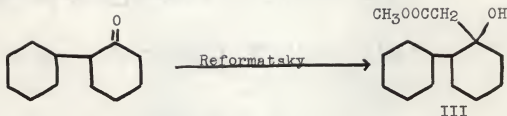
The procedure used was essentially that of Bachmann
and Dreiding (1). A small amount of iodine was added as
an initiator and the zinc and methyl bromoacetate were added
in small portions as the reaction progressed. The reaction

exhibited an induction period of approximately 15-30 minutes, after which it proceeded vigorously with the production of the grayish-green color typical of the Reformatsky reaction. Continued refluxing was necessary to obtain good yields, however, and at the end of the reflux period the solution was a dark gray color. The 2-cyclohexylcyclohexanone was not purified after hydrogenation except to remove the hydrogenation solvent by distillation. The crude material was then subjected to the Reformatsky reaction and the overall yield from 2-cyclohexenylcyclohexanone was slightly over 50 per cent.

The initial reaction after the induction period is often quite vigorous and care must be taken to control it. As this first reaction subsides the remaining portion reacts smoothly.

Treatment of methyl 2-cyclohexyl-1-hydroxycyclohexyl-acetate (III) with methanolic sodium hydroxide followed by acidification with dilute hydrochloric acid gave a nearly quantitative yield of 2-cyclohexyl-1-hydroxycyclohexylacetic acid (IV).

Treatment of methyl 2-cyclohexyl-1-hydroxycyclohexyl-acetate (III) with phosphorous pentoxide in refluxing benzene

was found to give a good yield (65-85 per cent) of methyl
2-cyclohexylcyclohexenylacetate (V).
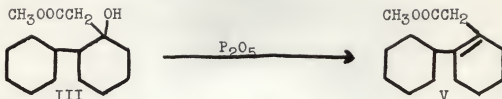
This unsaturated ester is a high boiling, colorless
liquid which gives a slow reaction with potassium permanganate
and a rapid reaction with bromine in carbon tetrachloride
with the evolution of hydrogen bromide. On standing it
decomposes slightly with the appearance of a pale yellow
color. The infra-red spectrum of this compound showed a
carbon-carbon double bond absorption at 6.01μ, which
indicates lack of conjugation with the ester carbonyl. The
carbonyl absorption band was present at 5.74μ.

The structure V would be expected to be correct rather
than Va or Vb from these results. The fact that bromine
substituted rather than following the usual course of addition
may then be explained. The structure Va would be expected

to add bromine in the usual manner and furthermore, does not
fit the spectral data. Structure Vb would be expected to
fit the experimental facts, and may be correct. However,

the double bond is usually formed in such a manner that it becomes as substituted as possible, thus making structure V the most likely. The carbon alpha to the carbonyl group is double activated to substitution, both by the carbonyl and the double bond, thus making it reasonable that substitution should occur. The addition, asis shown by the slow reaction with potassium permanganate, is apparently hindered by the bulk of the attached groups, thus slowing it a good deal and allowing substitution to predominate.

During the course of these experiments it was found that the hydroxyl group was unexpectedly resistant to dehydration. The material can be distilled unchanged and treatment with thionyl chloride and pyridine following the method of Bachmann and Dreiding (1) failed to accomplish the dehydration.

The preparation of 2-cyclohexylcyclohexenylacetic acid (VI) was accomplished by two methods. Treatment of methyl 2-cyclohexylcyclohexenylacetate (V) with methanolic potassium hydroxide resulted in a nearly quantitative yield of the acid.
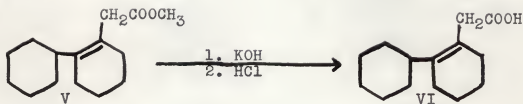

Dehydration of 2-cyclohexyl-1-hydroxycyclohexylacetic acid (IV) with phosphorous pentoxide in the same manner as

with the corresponding ester yielded 70-75 per cent of the
theoretical amount of the unsaturated acid.

This compound is a viscous oil which could not be
crystallized. It reacts slowly with potassium permanganate
and rapidly with bromine in carbon tetrachloride with the
evolution of hydrogen bromide. On standing it decomposes
slightly with the formation of a pale yellow color.

The infra-red spectrum of the compound showed an
associated acid oxygen-hydrogen stretching band at 3.71μ,
a broad unassociated acid oxygen-hydrogen stretching band
at 2.97μ to 3.16μ, a carbonyl absorption at 5.87μ, and a
carbon-carbon double bond absorption at 6.04μ (unconjugated).

Bagchi et al, (2) reported that treatment of 2-cyclohexenyl-
1-hydroxycyclohexylacetic acid (VII) with phosphorous
pentoxide yields 1,2,3,4,5,6,7,8-octahydro-9-phenanthrol
(VIII).
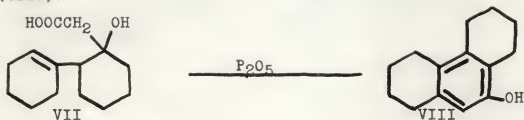
From the results obtained in this work it appears that
the presence of the double bond in the 2-cyclohexyl group
is a necessary requirement for this ring closure to be
accomplished.

All attempts to dehydrogenate either methyl 2-cyclohexyl-
1-hydroxycyclohexylacetate (III) or methyl 2-cyclohexyl-

cyclohexenylacetate (V) were unsuccessful with respect to isolating any practical amount of identifiable material. The methyl 2-cyclohexyl-1-hydroxycyclohexylacetate (III) dehydrated at high temperatures in the presence of 10 per cent palladium-charcoal but the products obtained were intractable oils which could not be identified. Methyl 2-cyclohexylcyclohexenylacetate (V) boils at a temperature considerably below efficient dehydrogenation temperatures. This results in violent spattering and bumping when the condensed liquid comes in contact with the heated catalyst, and immediate volatilization of the liquid. Oils were the only isolable products obtained. Various temperature ranges and periods of contact were attempted during these experiments, but no results could be obtained with any of the conditions tried. Dehydrogenation was attempted with sulfur, also, but again no identifiable product was obtained.

However, an attempt to dehydrogenate a small amount of methyl 2-cyclohexylcyclohexenylacetate (V) was made in a length of 8 mm. pyrex glass tubing and an oil was obtained which formed a picrate. Apparently there were several products present because the picrate was quite impure. Repeated fractional crystallization yielded a substance, m.p. 138-141°C., which is probably phenanthrene picrate (reported m.p. 144°C. (Shriner and Fuson 21)).

The failure of this reaction to yield the expected product is probably due to the low boiling character of the

unsaturated ester. It is likely that vapor phase dehydrogenation would succeed.

Attempts to hydrogenate methyl 2-cyclohexylcyclohexenylacetate (V) at low pressures using palladium-charcoal, platinum, or Raney nickel and heating were all unsuccessful. These results may be due to steric hindrance present in the compound or to the presence of impurities.

The dehydrogenation of 2-cyclohexylcyclohexenylacetic acid (VI) proceeded quite well, forming three different products. Besides the expected 2-methylbiphenyl, a small amount of acid was isolated, which was probably biphenyl-2-acetic acid, although too small an amount was obtained for efficient purification. Phenanthrene was also obtained in low yield.
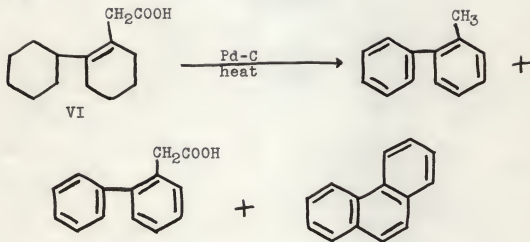
From the non-acidic material 2-methylbiphenyl was isolated in much the largest amount of the three products. This product was identified by treatment with potassium

permanganate to form o-phenylbenzoic acid, which was identified by its melting point.

The approximate percentages of total product in which each of these compounds were isolated were: 2-methylbiphenyl 66 per cent, biphenyl-2-acetic acid 9.5 per cent, and phenanthrene 23.8 per cent.

The isolation of phenanthrene indicates that a ring closure takes place thermally with the unsaturated acid. This probably occurs with the biphenyl-2-acetic acid to form 9-phenanthrol, which then undergoes a replacement of hydroxyl with hydrogen at these high temperatures in the presence of palladium and hydrogen. This is supported by the observations of Schonberg and Warren (20), who reported the conversion of 9-phenanthrol to phenanthrene by heating with zinc in a current of hydrogen.

It was found that treatment of methyl 2-cyclhexyl-1-hydroxycyclohexylacetate (III) with polyphosphoric acid and heating yielded 50 per cent of the theoretical amount of $\Delta^{10,11}$-perhydro-9-phenanthrone (IX).

This compound reacts rapidly with potassium permanganate and forms a bright red 2,4-dinitrophenylhydrazone. The ultra-violet spectrum of this 2,4-dinitrophenylhydrazone

(Plate I) showed a maximum at 395 mμ, indicating con-
jugation of the double bond (6), (13), (15).

The ketone was reported as a solid (Pinkney, et al 16),
but the crude oil obtained resisted ordinary attempts to
crystallize it. The substance obtained was a rather com-
plex mixture as was shown by a chromatogram of the material.
Three fluorescent bands were observed and at least one non-
fluorescent band was obtained. The first fraction obtained
upon elution of the column was a colorless oil which crystallized
upon standing. This material proved to be $\Delta^{9,11}$-perhydro-
9-phenanthrone (IX).

This compound might prove to be an intermediate in the
preparation of 9-substituted phenanthrenes through hydro-
genation of the double bond followed by Grignard reaction
of the keto group, dehydration, and dehydrogenation. This
leads to the 2,6,10- and 1,5,9- trisubstituted phenanthrenes
if substituted cyclohexanones are used in the first step of
the synthesis.

Ultra-violet absorption spectra

I. 2-Cyclohexenylcyclohexanone-2,4-dinitrophenylhydrazone.

II. $\triangle^{10,11}$ -perhydro-9-phenanthrone-2,4-dinitrophenylhydrazone.

PLATE I
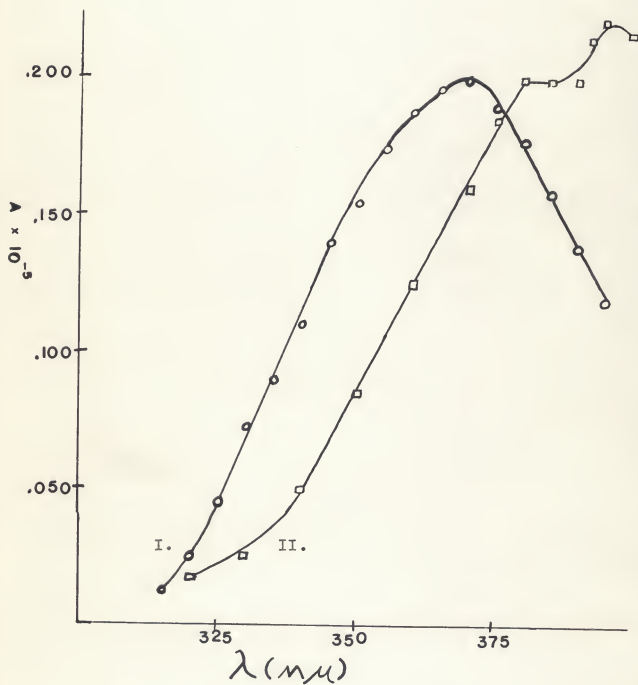
SUMMARY

Methyl 2-cyclohexyl-1-hydroxycyclohexylacetate and 2-cyclohexyl-1-hydroxycyclohexylacetic acid have been synthesized by means of a Reformatsky reaction starting with 2-cyclohexylcyclohexanone. These hydroxy compounds have been found to be exceptionally resistant to the usual dehydration reactions.

Methyl 2-cyclohexylcyclohexenylacetate and 2-cyclohexyl-cyclohexenylacetic acid have been prepared by treatment of the corresponding hydroxy compounds with phosphorous pentoxide. It was found that methyl 2-cyclohexylcyclohexenyl-acetate could not be dehydrogenated by the usual methods, although the corresponding acid underwent dehydrogenation in the expected manner.

It has been found that treatment of 2-cyclohexyl-1-hydroxycyclohexylacetic acid with phosphorous pentoxide does not yield a tricyclic compound such as Bagchi (2) obtained using 2-cyclohexenyl-1-hydroxycyclohexylacetic acid. This indicates that the double bond is a necessary requirement for this ring closure.

$\Delta^{10,11}$-perhydro-9-phenanthrone has been prepared by treatment of methyl 2-cyclohexyl-1-hydroxycyclohexylacetate with polyphosphoric acid, thus leading to the possible synthesis of 1,5,9- and 2,6,10- trisubstituted phenanthrenes.

ACKNOWLEDGMENT

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ACID CATALYZED CONDENSATIONS OF CYCLIC
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PHENANTHRENE

by

JOHN EDWARD KATON

B. S., Bowling Green State
University, 1951

AN ABSTRACT OF A THESIS

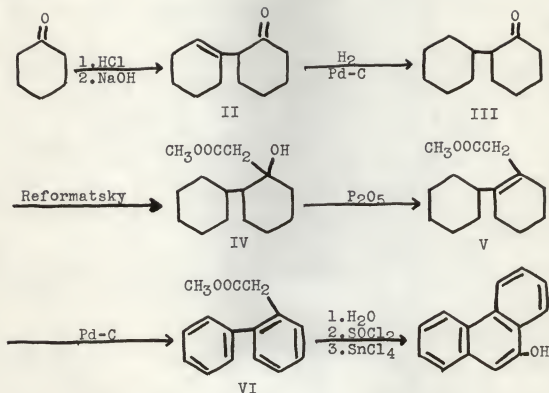submitted in partial fulfillment of

requirements for the degree

MASTER OF SCIENCE

Department of Chemistry

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1955

An attempt to synthesize 9-phenanthrol was made following
the route:

However, it was found that the dehydrogenation step
presented difficulties which would require extended work
to overcome.

2-Cyclohexenylcyclohexanone (II) was prepared by the
hydrogen chloride catalyzed condensation of cyclohexanone,
followed by dehydrohalogenation. This compound was dif-
ficultly reduced to 2-cyclohexylcyclohexanone (III) and this
material was subjected to the Reformatsky reaction to produce
methyl 2-cyclohexyl-1-hydroxycyclohexylacetate (IV) in 52
per cent yield based on 2-cyclohexenylcyclohexanone (II).

It was found that IV was surprisingly difficult to dehydrate by the usual methods, but treatment with phosphorous pentoxide yielded 82 per cent of methyl 2-cyclohexylcyclo-hexenylacetate (V).

The ester V was found to boil at a temperature too low for efficient dehydrogenation and thus could not be converted to methyl biphenyl-2-acetate.

However, the corresponding acid could be dehydrogenated smoothly to yield a mixture of products. The main product of this reaction was the expected 2-methylbiphenyl. There was also obtained some phenanthrene, which indicates that the reaction
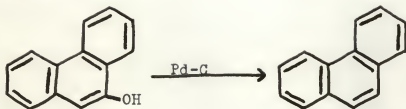
will occur.

It was found that ring closure of methyl 2-cyclohexyl-1-hydroxycyclohexylacetate (IV) could be effected by treatment with polyphosphoric acid.
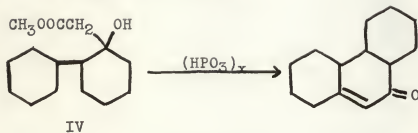
This compound might lead to 9-substituted phenanthrenes by further typical synthetic procedures. Since 2- and 4- substituted cyclohexanones should undergo the primary condensation, this procedure leads to a possible new route to 2,6,10- and 1,5,9- trisubstituted phenanthrenes, as well as 2,6- and 1,5- disubstituted and 9- monosubstituted phenanthrenes.