PONDER, Billy Wayne. SYNTHETIC APPROACHES
TO THE CYCLIC ETHYLENE KETAL OF
CYCLOPENTADIENONE.

Iowa State University of Science and Technology
Ph.D., 1961
Chemistry, organic

SYNTHETIC APPROACHES TO THE CYCLIC

ETHYLENE KETAL OF CYCLOPENTADIENONE

by

Billy Wayne Ponder

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Organic Chemistry

Approved:

In Charge of Major Work

Head of Major Department

Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1961

TABLE OF CONTENTS

INTRODUCTION

Much work during the past century has been centered around the preparation and isolation of unique unsaturated five membered ring carbocyclic systems. Prominent among this work has been the synthesis of the cyclopentadienyl anion by Thiele[1] and the diazocyclopentadiene system by Doering and DePuy.[2] The stability of these systems is generally attributed to their possession of aromatic character by virtue of their adherence to the rule of aromaticity. Although the two examples above serve to support the general 4n + 2 rule of aromaticity, much effort has been directed toward finding exceptions to this rule. In particular, many attempts have been made to isolate cyclopentadienone, a completely conjugated diene-one system. This compound would be a valuable exception to the rule and should lead to new or altered concepts of electronic interactions in ring systems. Although highly substituted monomeric cyclopentadienones and the dimeric unsubstituted cyclopentadienone have been synthesized and isolated, the unsubstituted monomer has never been isolated.

Another molecule which would be of theoretical interest in its own right and which could possibly lead directly to

---

[1] J. Thiele, _Ber._, _34_, 68 (1901)

[2] W. von E. Doering and C. H. DePuy, _J. Am. Chem. Soc._, _75_, 5955 (1953)

monomeric cyclopentadienone is the cyclic ethylene ketal of cyclopentadienone. Since this molecule is analogous to cyclopentadiene in its degree of unsaturation, it would likewise be expected to possess a fair degree of stability in its monomeric state. Such a new molecule would be a valuable intermediate in the synthetic route to bridged ketones.

The object of this work was to investigate the synthesis and isolation of the cyclic ethylene ketal of cyclopentadienone.

HISTORICAL

Synthetic work centering around the synthesis and isola-
tion of cyclopentadienone and its derivatives has occupied the
Organic chemists for almost a century. Interest was initiated
in this area in 1887 with the observation by Japp and Burton[3]
that acetone condenses with benzil in the presence of base to
yield "anhydracetonebenzil". Acid treatment of this cyclo-
pentenolone system gave a compound $C_{34}H_{24}O_2$ which they were
unable to identify at that time, but which was shown in some
of their later work[4] to be the dimer of diphenylcyclopenta-
dienone. They rationalized that the cyclopentenolone system
had first gone to diphenylcyclopentadienone, which then
dimerized. This is shown in Eq. 1.

(Eq. 1)
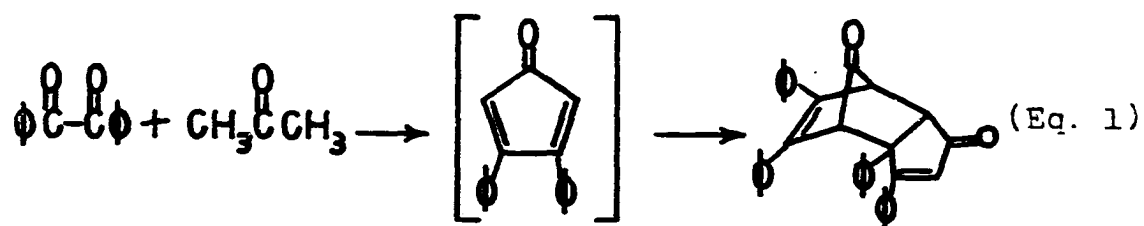
In their work on chlorinated, α-hydroxyacids, Zincke and

---

[3]F. R. Japp and C. I. Burton, J. Chem. Soc., 51, 420
(1887)

[4](a) F. R. Japp and G. D. Lander, J. Chem. Soc., 71, 123
(1897); (b) F. R. Japp and A. N. Meldrum, J. Chem. Soc., 79,
1024 (1901)

Gunther[5] obtained the dimer of tetrachlorocyclopentadienone, which lost carbon monoxide upon heating to give perchloroindenone. In some later work, Zincke and coworkers[6] investigated some of the reactions of the dimer, one of which was its oxidative degradation to tetrachlorophthalic anhydride. In 1894, Claisen and Ewan,[7] in their work on reaction products of dibenzyl ketone and oxalyl methyl ethers, obtained a compound whose analysis suggested an empirical formula corresponding to that of diphenyldihydroxycyclopentadienone. They did not, however, ascertain whether this compound was monomeric or dimeric.

Lowenbein and Ulich[8] were one of two groups who simultaneously prepared the first monomeric cyclopentadienone by reacting diphenyl maleic anhydride with phenylacetic acid, treating the resulting benzal diphenylmaleid with phenyl magnesium bromide and then acid. The formation of this compound, known as tetracyclone, is shown in Eq. 2. Ziegler and Schnell[9] also prepared tetraphenylcyclopentadienone at the same time as Lowenbein and Ulich, but by an independent route.

[5]T. Zincke and H. Gunther, Ann., 272, 243 (1892)

[6](a) T. Zincke and K. H. Meyer, Ann., 367, 1 (1909); (b) T. Zincke and W. Pfaffendorf, Ann., 394, 7 (1912)

[7]L. Claisen and T. Ewan, Ann., 284, 245 (1894)

[8]A. Lowenbein and G. Ulich, Ber., 58B, 2662 (1925)

[9]K. Ziegler and B. Schnell, Ann., 445, 266 (1925)

(Eq. 2)
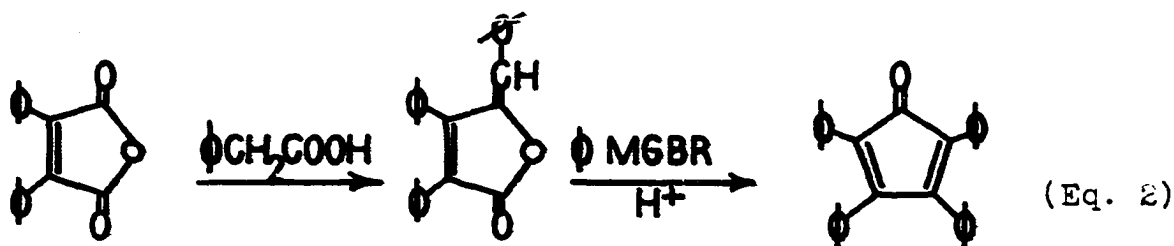
They treated tetraphenyl cyclopentadiene with para-nitroso-dimethylaniline and hydrolyzed the resulting condensation product with acid to the tetraphenylcyclopentadienone.

Tetraphenylcyclopentadienone has been prepared in various ways by subsequent investigators who were interested in exploring the chemistry of this first cyclopentadienone monomer. Dilthey and Quint[10] prepared the monomer in a two step sequence in which they condensed dibenzyl ketone with benzil in basic solution and then dehydrated the resulting hydroxycyclopentenone with aqueous acid to give the dienone, m. p. 218°C. The maleic anhydride adduct of this monomer loses carbon monoxide quantitatively upon heating to give tetraphenyl-phthalic anhydride. They prepared various other tetrasubstituted cyclopentadienones in order to test their applicability as chromophoric agents for use in the synthetic dye industry. Dilthey and Schommer[11] were the first to prepare triphenyl-

---

[10] W. Dilthey and F. Quint, J. prakt. Chem., 128, 139 (1930)

[11] W. Dilthey and W. Schommer, J. prakt. Chem., 136, 293 (1933)

cyclopentadienone, I, and although it exists as its dimer, they were successful in thermally cracking it back to its monomer and trapping it with maleic anhydride.
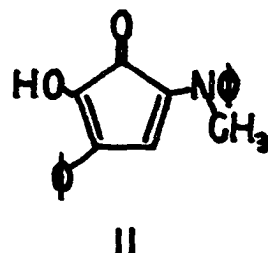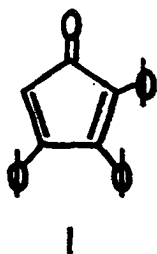
From their work on the rearrangement of oximes and phenylhydrazones, Diels et al.[12] were able to obtain 2-(N-methylanilido)-4-phenyl-5-hydroxycyclopentadienone, II.

Allen and Spanagel[13] became interested in the cyclopenta-dienone field while investigating the reactions of anhydrace-tonebenzil with certain halogen compounds. They prepared the dimer of diphenylcyclopentadienone from 3,4-diphenyl-4-hydroxy-cyclopentenone by treating it with base. They also reinvesti-gated some of the earlier work done by Japp and Burton[14] in relation to the structure and properties of the cyclopenta-dienone dimers. The rigorous scrutiny given to this system by Allen served to strengthen certain conclusions drawn by pre-

[12]O. Diels, O. Buddenberg, and S. Wang, Ann., 451, 223 (1927)

[13]C. F. H. Allen and E. W. Spanagel, J. Am. Chem. Soc., 54, 4338 (1932)

[14]F. R. Japp and C. I. Burton, op. cit., p. 420

vious investigators as well as to point up some new ones. In line with previous evidence, they showed that the dimers have a carbonyl bridge across an unsaturated six-membered ring and can be thermally degraded to substituted dihydroindenones. They also found that by heating the dimers in the presence of maleic anhydride, they were able to obtain Diels-Alder adducts from both the dihydroindenones as well as the monomeric cyclopentadienones. One such adduct isolated by Allen and Sheps[15] is shown in Eq. 3.

(Eq. 3)
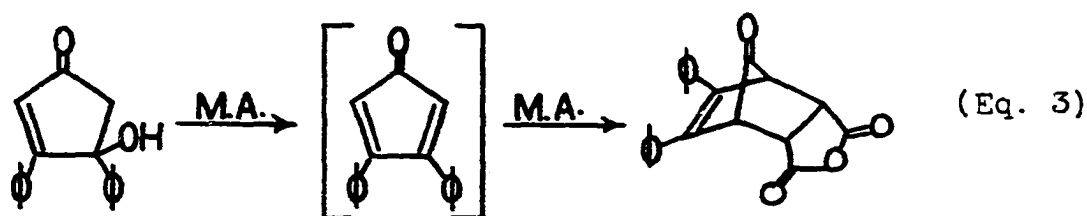
Allen and VanAllan[16] investigated the degree of dissociation of various dimers in a variety of solvents. By analyzing the maleic anhydride adducts obtained from 2,5-dimethyl-3,4-diphenylcyclopentadienone at 80°, they found that it was 20% dissociated at this temperature.

Utilizing their experience, as well as all the available literature data in the field of cyclopentadienone chemistry up

---

[15]C. F. H. Allen and L. J. Sheps, Can. J. Research, 11, 171 (1934)

[16]C. F. H. Allen and J. VanAllan, J. Am. Chem. Soc., 64, 1260 (1942)

to 1950, Allen and VanAllan[17] proposed some rules relating
degree of substitution of the cyclopentadienone ring to sus-
ceptibility to dimerization. Their rules state: 1) any
cyclopentadienone having fewer than three substituents will
exist as a non-dissociating dimer; 2) when there are three
substituents, the dienone will exist as a non-dissociating
dimer except when there are two aryl groups next to the car-
bonyl; 3) when all four positions of the dienone are substi-
tuted, a dissociable dimer results when the substituents in
the 2 and 5 positions are methyl and an alkyl, otherwise the
substance is a monomer.

Krynitsky and Bost[18] were able to prepare the diethyl
ketal of tetrachlorocyclopentadienone by treating hexachloro-
cyclopentadiene with sodium ethoxide in ethanol. Newcomer and
McBee[19] were able to duplicate these results and also succeed-
ed in forming various Diels-Alder adducts of the ketal through
reaction with various dienophiles. The ketal undergoes
hydrolysis to give dicyclopentadienone.

Various derivatives of unsubstituted cyclopentadienone
have been prepared. An oxime derivative was prepared by

[17]C. F. H. Allen and J. VanAllan, J. Am. Chem. Soc., 72,
5165 (1950)

[18]J. A. Krynitsky and R. W. Bost, J. Am. Chem. Soc., 69,
1918 (1947)

[19]S. J. Newcomer and E. T. McBee, J. Am. Chem. Soc., 71,
946 (1949)

Thiele[20] in 1900 by reacting the cyclopentadienyl anion with ethyl nitrite. The product proved to be the dimer, III, and could not be cracked back to the monomer by heating. The phenylhydrazone derivative of cyclopentadienone has also been prepared by Eibner and Laue[21] by the reaction of the cyclopentadienyl anion with benzene diazonium chloride. Doering and DePuy[22] prepared diazocyclopentadiene, IV, by reaction of cyclopentadienyl lithium with para-toluenesulfonylazide.

III   IV
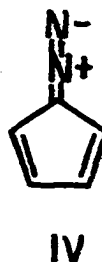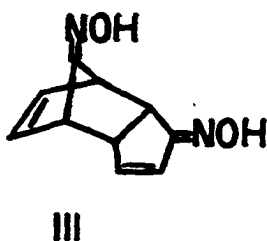
In an attempt to isolate cyclopentadienone, Alder and Flock[23] pyrolyzed 1-ketodicyclopentadiene. The products that were isolated were dicyclopentadiene, 8,9-dihydroindene, and 8,9-dihydroindenone. The pyrolysis path apparently proceeded through the formation of the two intermediates cyclopentadiene and cyclopentadienone, whose subsequent dimerization with each other as well as themselves gave rise to the observed products.

[20]J. Thiele, Ber., 33, 666 (1900)

[21]A. Eibner and O. Laue, Ber., 39, 2022 (1906)

[22]W. von E. Doering and C. H. DePuy, op. cit., p. 5955.

[23]K. Alder and F. H. Flock, Ber., 87, 1916 (1954)

DePuy and Zaweski[24] possibly observed the momentary existence of cyclopentadienone during the preparation of the dimer from the base treatment of the O-alkyl pyridinium salt of 3,5-dibromocyclopentene.

Again in 1960, DePuy and Lyons[25] showed the transitory existence of cyclopentadienone by pyrolyzing the anthracene adduct of cyclopentadienone, which in turn was prepared from anthracene and cyclopentene-3,5-dione. They were successful in isolating 8,9-dihydroindenone, a product which arises by way of dimerization of cyclopentadienone with subsequent loss of the bridged carbonyl as carbon monoxide.

Recently, DePuy and Isaks[26] have studied several methods of generating the cyclopentadienone molecule in solution. They found that 4-bromocyclopent-2-enone, when treated with mild base, gave dicyclopentadienone in very high yields. This is shown in Eq. 4. Although cyclopentadienone was not

(Eq. 4)
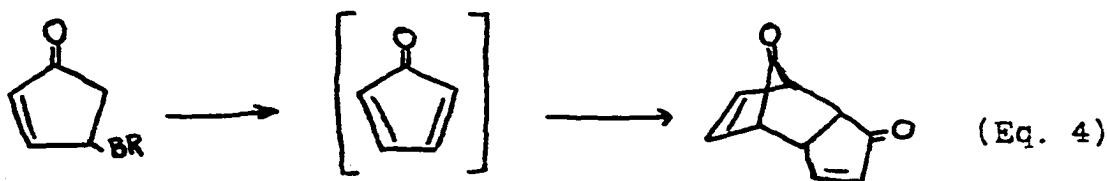
[24]C. H. DePuy and E. F. Zaweski, _J_. _Am_. _Chem_. _Soc_., _81_, 4920 (1959)

[25]C. H. DePuy and C. E. Lyons, _J_. _Am_. _Chem_. _Soc_., _82_, 631 (1960)

[26]C. H. DePuy and M. Isaks, _J_. _Am_. _Chem_. _Soc_., to be published in _83_, _ca_. 1961

isolated as such, they were able to investigate some of the
chemistry of this interesting molecule. Through generation
of the molecule in the presence of various dienes and dieno-
philes, it was found that cyclopentadienone is a good dieno-
phile but a poor diene.

Many bridged ketones have been prepared since the prep-
aration of the first one by Japp and Burton[27] in 1887. Most
of these have arisen through work on the cyclopentadienone
system, and consequently contain a bridged system across an
unsaturated six-membered ring.

There are, however, two instances[28] in the old literature
in which saturated and bridged six-membered bicyclic ketones
are said to be formed. In each instance, a semicarbazone was
isolated from the liquid mixture resulting from the pyrolysis
of salts of hexahydroterephthalic and hexahydroisophthalic
acids. However, a re-examination of this work was carried out
by Allen et al.[29] and no bicyclic ketones could be isolated.
The compounds isolated had the properties of 1-methyl-3-
cyclohex-2-enone, V. Allen and VanAllan[30] prepared the first

[27]F. R. Japp and C. I. Burton, op. cit., p. 420.

[28](a) N. Zelinsky, Ber., 34, 3796 (1901); (b) O. Stark,
Ber., 45, 2369 (1912)

[29]C. F. H. Allen, T. Davis, D. W. Stuart, and J.
VanAllan, J. Org. Chem., 20, 306 (1955)

[30]C. F. Allen and J. VanAllan, J. Org. Chem., 20, 323
(1955)

saturated bicyclic ketone when they catalytically reduced
allethrolone to VI. Dimethylfulvene has been used in many
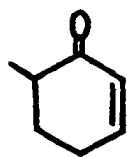
V
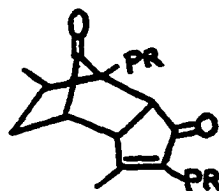
VI

cases to condense with dienophiles in the Diels-Alder reaction
to give a bridged compound with an exocyclic double bond at
the 7 position. This ethylenic linkage may then be cleaved
with ozone to the corresponding bridged keto group.

The fact that these bridged, unsaturated bicyclic systems
tend to lose carbon monoxide quite easily upon heating has
hindered the investigation of the reactions of the 7-keto
group. However, it has been shown that the bridged carbonyl
may be reduced to the hydroxy function by a variety of re-
agents. These 7-hydroxy substituted bicyclic derivatives
have received much attention from several investigators.

Another type of reaction known to the bridged carbonyl
is its cleavage by means of alcoholic alkaline solutions[31] to
give rise to carboxylic acids.

[31]C. F. H. Allen and J. VanAllan, J. Org. Chem., 10, 333
(1945)

DISCUSSION

Although much work has been done on various highly substituted dicyclopentadienones, little was known about the chemistry and possible transformations of the unsubstituted dimer. This may be attributed in part to the fact that until recently, a convenient preparative route to the unsubstituted dimer was unknown. DePuy and Zaweski[32] showed that by cleavage of the O-alkyl pyridinium salt of 3,5-dibromocyclopentene with base, a low yield of dicyclopentadienone could be obtained. It was later shown by DePuy and Ponder[33] that a very good yield of dicyclopentadienone could be obtained by first preparing the corresponding dioxime as reported earlier, and then hydrolyzing this to the diketone with levulinic acid as shown in Eq. 5. This hydrolysis route made the dimer readily

$$(Eq. 5)$$
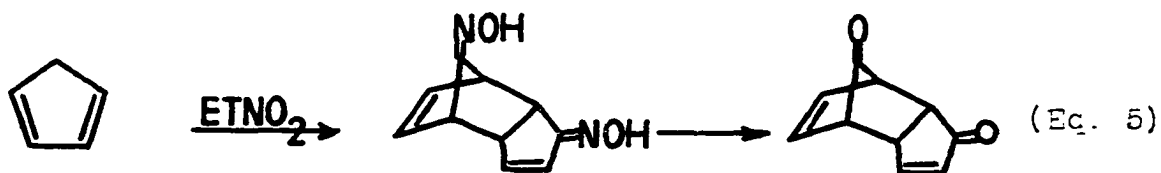
available for investigation of its little known reactions and synthetic applications.

---

[32] C. H. DePuy and E. F. Zaweski, op. cit., p. 4920.

[33] C. H. DePuy and B. W. Ponder, J. Am. Chem. Soc., 81, 4629 (1959).

In line with previous observations in bridged ketone
systems, the diketone readily loses carbon monoxide at temper-
atures not too far above its melting point. Although this
would seem to hinder investigations of the reactions of the
bridged carbonyl, it proved not to be a serious problem when
the reactions were conducted in a suitable solvent.

The dimeric ketone readily absorbs two molecular equiva-
lents of hydrogen gas over a palladium on charcoal catalyst
to give the saturated diketone. The unsaturated diketone is
essentially unchanged by 0.1 $\underline{N}$ acid or base in refluxing
methanol.

The bridged ketone group is the most vulnerable point in
the diketone molecule, and undergoes reactions without affect-
ing the α,β-unsaturated carbonyl group. Stirring a methan-
olic solution of the diketone with sodium borohydride for a
few minutes at room temperature gives a quantitative conver-
sion to the 1-keto-8-hydroxy compound, II. This ketol is
at first an oil, which may be crystallized from hexane to
give a nice, white crystalline solid with m. p. of 133°.
This compound was of interest to us in connection with some
work reported by Woodward and Katz.[34] These workers observed
a novel rearrangement of a hydroxy substituted dicyclopenta-
diene system similar to our system. In connection with their

---

[34]R. B. Woodward and T. J. Katz, _Tetrahedron_, _5_, 70
(1959).

work on the mechanism of the Diels-Alder reaction, they ob-
served that by heating either pure XVI or XVIII in an evacu-
ated tube at 137°, an equilibrium mixture of the two isomers
was obtained. A symmetrical intermediate of type XVII was
invoked to explain this phenomenon.
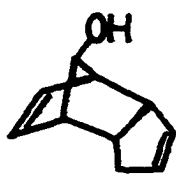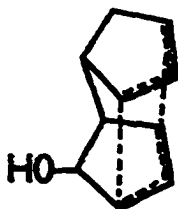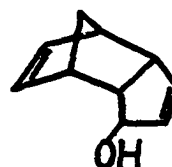
XVI   XVII   XVIII

We were led by the obvious mechanistic interest of this
rearrangement to explore the possibility of a similar re-
arrangement in the l-keto-8-hydroxy system, II. One would
expect that if such a rearrangement from XIX to XXI was ob-
served, it should be greatly facilitated by the stabilizing
influence of the carbonyl group upon the intermediate XX. If,
on the other hand, the rearrangement did not occur, an explana-
tion would seem to be that the system is reluctant to approach
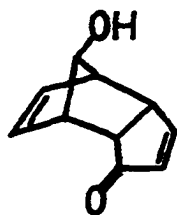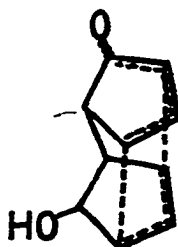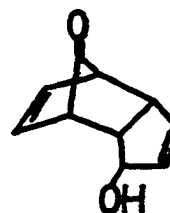
XIX   XX   XXI

a cyclopentadienone type intermediate as required by XX.

With these points of interest in mind, the isomer XIX was prepared and subjected to the rearrangement conditions by placing in an evacuated tube and heating to 138° for several hours. Infrared analysis of the product revealed no rearranged isomer, but only the presence of the starting isomer. From a purely thermodynamic point of view, one might expect an equilibrium of the two isomers to lie predominantly in favor of isomer XIX, since the strain attendant with a bridged carbonyl such as XXI is not present. It therefore appeared in order to approach the equilibrium from isomer XXI to see if rearrangement of this to the more favorable isomer XIX would occur. Since the bridged carbonyl group is so reactive, it was obvious that some easily removable protecting group would have to be applied to it before attempting to reduce the α, β-unsaturated ketone group. It was found that the bridged carbonyl could be readily converted to the cyclic ethylene ketal by heating its benzene solution with ethylene glycol in the presence of para-toluenesulfonic acid. In this manner the mono ketal, III, a white solid with m. p. of 95° was formed. The α, β-unsaturated carbonyl group was reduced by heating III in refluxing methanol with sodium borohydride for one hour. The 1-hydroxy-8-ketal, IV, was obtained as a clear, viscous oil, b. p. 120° at 0.1 mm. Having protected the bridged ketone group during the reduction, we attempted

to regenerate it to furnish the desired 1-hydroxy-8-ketone
system, V. The hydrolysis of this ketal proved to be more
of a problem than originally anticipated. Stirring an aqueous
methanolic solution of the ketal in the presence of para-
toluene-sulfonic acid either at room temperature or at reflux
failed to cleave the ketal. By exploring various conditions,
it was found that refluxing an aqueous solution of the ketal
in 1 N hydrochloric acid was sufficient to regenerate the
ketone. However, the product from the hydrolysis was a mix-
ture of isomer V and the diketone, I. The presence of the
diketone in the product still remains unclear. It may be
pointed out that the rather strenous conditions necessary
for the hydrolysis could be due to the unfavorable energetics
involved in replacing a relatively unstrained ketal function
by a highly strained ketone group.

The difficulties involved in obtaining sufficiently large
amounts of the pure 1-hydroxy-8-keto isomer slowed the prog-
ress of this phase of the investigation considerably. How-
ever, several preliminary experiments with the impure isomer
were accomplished. When the isomer was heated in an evacu-
ated tube at 137°, the molecule suffered loss of the bridged
carbonyl, as evidenced by disappearance of the carbonyl
absorption in the infrared. A second attempt at 100° re-
sulted in essentially no change in the molecule. However, by
heating in refluxing toluene, it was found that the original

infrared carbonyl absorption at 5.6μ of isomer V was shifted
to 5.8μ. Although this served to indicate that some type of
rearrangement was taking place, the fact that the α, β-
unsaturated grouping in isomer II absorbs at 5.87μ casts some
uncertainty on the structure of the rearranged product.

At this point in the investigation, there appeared a
report by Yates and Eaton[35] on some isomerization studies in
the tetrachlorodicyclopentadiene series. They noted a re-
arrangement of the bridged ketone group to the more stable
α, β-unsaturated carbonyl compound. They also proposed a
symmetrical intermediate similar to the one of Woodward and
Katz to explain this change. They found that the α, β-
unsaturated ketone was the only product of the rearrangement,
thereby confirming our similar observation of the same fact
in our series. Since the results of Yates and Eaton were
essentially in agreement with the results we had obtained
thus far, the further investigation of this aspect of our
system did not seem worthwhile. The experience gained in
the experimental techniques, however, proved helpful in look-
ing at some of the interesting intermediates of this system.

We were interested particularly in the 1-hydroxy-8-
ketal, IV, and its relation to cyclopentadienone. The syn-
thesis of cyclopentadienone has long been the goal of many

---

[35]P. Yates and P. Eaton, Tetrahedron Letters, No. 11, 5
(1960).

chemists, but to date, no one has been successful in isolating the molecule. It appeared to us that a simple derivative of cyclopentadienone, such as the cyclic ketal, would be a valuable synthetic intermediate since the cyclopentadienone monomer could then be generated "in situ" to give various bridged ketones. The cyclic ethylene ketal should possess stability comparable to cyclopentadiene itself, since both contain a saturated carbon atom in the five membered ring.

One interesting pathway to this cyclic ketal seemed to be through the 1-hydroxy-8-ketal system prepared previously. If this molecule could be "cracked" back to its monomers, this would lead to the cyclopentadienone ketal, VI, directly. The hydroxy ketal, IV, was therefore pyrolyzed by heating in a small distillation apparatus at reduced pressure while nitrogen gas was passed through the system. The distillate was collected in a Dry Ice-acetone bath and the products analyzed by GPC. This revealed the presence of at least six components: two major ones and four minor ones. Although no product identifiable as the ketal of cyclopentadienone could be isolated, a small amount of cyclopentenone was identified by comparison with an authentic sample. A deep blue color, characteristic of an azulene system, was also noted in the distillate during the last stages of the pyrolysis.

With the failure of the above method, a more direct route to the synthesis of the cyclic ethylene ketal of cyclopenta-

dienone was undertaken. Wanzlick et al.[36] had previously prepared the cyclic ethylene ketal of cyclopentenone by a route involving chlorination of cyclopentanone, conversion of the chloroketone to the ketal, and then dehydrohalogenation with potassium hydroxide. Even though several attempts by later workers to duplicate their results, especially the isolation of the chloroketone, were unsuccessful, this route still appeared attractive in our case. It was found that rapid distillation of the chloroketone through a 30 inch Vigreaux column under aspirator vacuum gave a 70 percent yield of the product. The conversion of this chloroketone to its ketal followed by dehydrohalogenation also went in good yields to give the cyclopent-2-enone, X, identical to that reported by Wanzlick.

The problem now resolved itself into one of introduction of an additional double bond into the cyclopentene ring. Several available methods of accomplishing this objective were investigated and are described in the following discussion.

The first attempt involved the allylic substitution of a benzoate or acetate group into the cyclopentene ring, with the projected aim of pyrolytic elimination of the product to give the diene ketal as shown in Eq. 6. Since the cuprous

---

[36]H. W. Wanzlick, G. Gollmer, and H. Milz, Ber., 88, 69 (1955).

$$\Delta \quad + \ HOAC \qquad (Eq.\ 6)$$
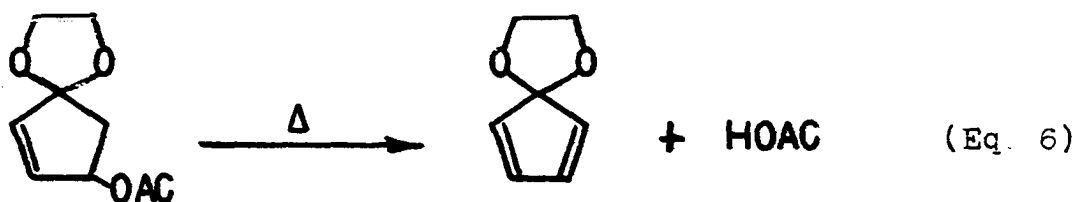
bromide catalyzed allylic substitution method of Karasch et al.[37] is known to be accompanied by little or no rearrangement products, this method was considered appropriate for our purpose. However, one serious drawback to this method when applied to the cyclopentenone ketal system was the extremely low conversion to the desired acetate or benzoate. Although some starting olefin could be reclaimed from the reaction mixture, its recovery was a laborious process, and the low yield of acetate and benzoate seemed hardly enough to make this pathway worthwhile.

Another method which seemed promising by virtue of the fact that DePuy and Isaks[38] had already shown it to be extremely successful in a similar system was that of allylic bromination of the cyclopentene ring by the use of N-bromosuccinimide to give XI. The bromine atom substituted in the 4 position of the ring would give an active substituent which

---

[37]M. S. Karasch, G. Sosnovsky, and N. C. Yang, J. Am. Chem. Soc., 81, 5819 (1960).

[38]C. H. DePuy and M. Isaks, J. Am. Chem. Soc. [To be published in 83, ca. 1961.]

could possibly be eliminated directly to the desired diene

ketal, VI, or which would serve as a useful handle for any

later conversions which might become necessary in the syn-

thetic scheme. After many unsuccessful attempts at accom-

plishing the bromination step, it was found that high dilu-

tion was the key to the successful conversion of the olefin

to the 4-bromo derivative. All attempts to isolate the bro-

mide, however, either by distillation under high vacuum or

by recrystallization techniques were unsuccessful. The bromo-

ketal proved to be a very unstable compound which could only

be worked with in carbon tetrachloride solution. This seemed

at first to be a serious drawback to the further exploitation

of this compound for our synthetic scheme, but later experi-

ments (vide infra) showed this assumption to be invalid. The

fact that the perfection of the bromination step now made the

bromide easy to come by as well as the possibility of such

wide variation of double bond insertion approaches served to

make the bromide a key intermediate in our synthetic route.

Attempts at direct elimination of the bromide with

potassium t-butoxide in t-butanol or with quinoline led only

to decomposition products. The bromoketal could, however, be

readily converted to the corresponding N,N-dimethylamine de-

rivative, XII, "in situ" by the addition of anhydrous di-

methylamine to the carbon tetrachloride solution at low tem-

perature. Fractionation of the crude amine at reduced pres-

sure gave a dull red liquid, b. p. 65° (1.5 mm.), which was shown to contain the expected tertiary amine by analysis of its picrate derivative. The red coloration caused some concern at first until a UV analysis showed no appreciable absorption. It was later noted that adequate washing of the crude amine with water during workup served to remove most of the color. The amine proved difficult to purify, but vacuum fractionation through a 13 inch Vigreaux column gave a product whose GPC analysis showed to be 70 percent of the desired amine. Two other components, in roughly equal proportions, made up the remaining 30 percent.

The tertiary amine was smoothly converted to the amine oxide, XIII, upon oxidation with hydrogen peroxide. Through preliminary attempts to pyrolyze this amine oxide, it appeared that pyrolysis was taking place smoothly within the expected temperature range until about 50 percent completion, at which point tar formation in the pyrolysis flask began to predominate. However, the inability to isolate, or even detect the diene ketal, VI, in the pyrolysate began to cast doubt upon the validity of the apparent smooth pyrolysis as well as the structure of the tertiary amine itself. Through analogy with typical bromination reactions with N-bromosuccinimide in allylic systems, the tertiary amine was assigned structure XII. It was recognized, however, that rearrangement of the free radical intermediate during bromination or bromination at the ethereal carbon atom of the ethylenic linkage would lead

to structures XXII and XXIII respectively. In order to
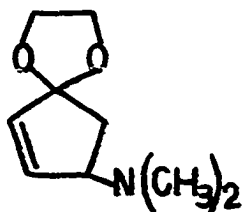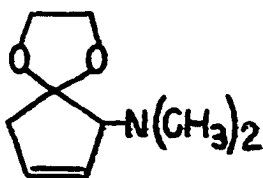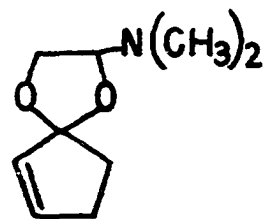
XII   XXII   XXIII

establish the structure of the tertiary amine at this crucial

stage of our synthetic route, a nuclear magnetic resonance

spectrum was obtained on the purified compound. This spectrum

snowed the peaks (relative to tetramethylsilane as an internal

standard): 350 c.p.s., $\tau = 4.17$, a quartet assigned to the

olefinic proton at C_3 split by the olefinic proton at C_2 and

the proton at C_4; 340 c.p.s., $\tau = 4.54$, a quartet assigned

to the olefinic proton at C_2 split by the olefinic proton at

C_3 and the proton at C_4; 230 c.p.s., $\tau = 6.17$, a strong

singlet assigned to the four equivalent protons on the

ethereal ethylenic linkage; 219 c.p.s., $\tau = 6.55$, a complex

multiplet assigned to the proton at C_4 split by the olefinic

protons at C_2 and C_3 and by the two nearly equivalent protons

at C_5; 134 c.p.s., $\tau = 7.77$, a strong singlet assigned to

the six equivalent on the N,N-dimethylamino group; 122 c.p.s.,

$\tau = 8.0$, a doublet, one of which is further split into a

doublet, assigned to the two nearly equivalent protons at C_5

split by the proton at C_4. These assignments are in accord

with, and unequivocally establish the structure of the ter-
tiary amine as XII.

Having now established the structure of the tertiary
amine, a continuation of our efforts at insertion of the addi-
tional double bond into the cyclopentene ring was begun. The
preliminary amine oxide pyrolyses did not make this route
look very encouraging, but it was nevertheless explored far-
ther in hopes that the right conditions for a successful
pyrolysis could be found. Although several pyrolysis attempts
with large samples of amine oxide failed to yield the mono-
meric diene ketal, they did lend encouragement by the fact
that a small amount of the dimeric ketal, XV, was isolated.
This indicated that the pyrolysis was indeed occurring to a
small extent and that the problem now was one of the isolation
of the monomer before its dimerization.

The dimeric ketal isolated from the above amine oxide
pyrolysis proved to be only one of several components in the
pyrolysis product. Attention was therefore turned to the
pyrolysis of the corresponding quaternary ammonium hydroxide,
XIV, in hopes that any competing rearrangement products which
might arise from the amine oxide pyrolysis would be elimin-
ated. The tertiary amine was converted to its methyl bromide
derivative and this in turn was converted to its hydroxide by
means of aqueous silver oxide. Pyrolysis of this quaternary
ammonium hydroxide proceeded quite smoothly and more com-

Fig. 1 Nuclear magnetic resonance spectrum of 4-(dimethylamino)-
cyclopent-κ-enone cyclic ethylene ketal (90μliters in
400μliters of CCl_4)

4.17   4.34   6.17 6.35   7.77 8.0   10.0
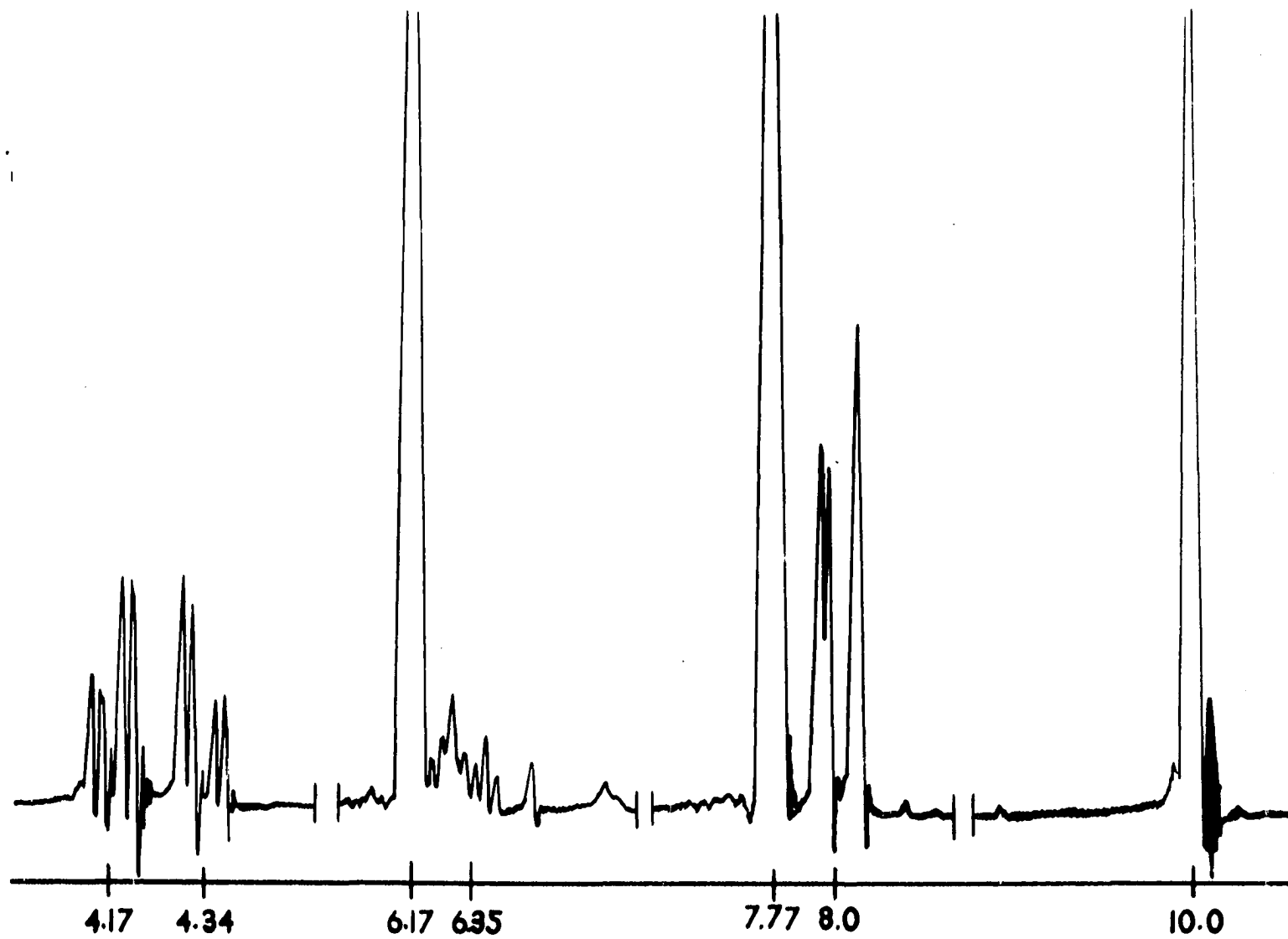
pletely than in the case of the amine oxide. The pyrolysis procedure was essentially the same in the two cases and precautions were taken to keep the pyrolysate at low temperatures at all times to prevent dimerization of any diene ketal monomer present. No maleic anhydride adduct could be obtained from the pyrolysate, however. The only product isolated from the quaternary ammonium hydroxide pyrolyses was again the dimer, XV, of the expected diene ketal which was surprisingly pure.

In summary, three different methods of arriving at the cyclic ethylene ketal of cyclopentadienone were investigated. The first method involved the pyrolysis of the 1-hydroxy-8-ketal system, IV. Although this did not give the expected diene ketal, it was evident from the isolation of some cyclopentenone that "cracking" was taking place. It seems likely that the high temperatures involved in this cracking process were sufficient to destroy any monomeric ketal as soon as it was formed.

The second approach was a more direct one of pyrolyzing the amine oxide of 4-(N,N-dimethylamino)cyclopent-2-enone cyclic ethylene ketal. This method involved lower temperatures than the previous one, but it was complicated by the fact that a mixture of products was obtained. This made the rapid isolation of the desired product impossible, and was thought to account for the fact that only dimeric ketal was

isolated.

The third method was that of pyrolysis of the quaternary ammonium hydroxide. This method seemed to be the most promising, since it proceeded quite smoothly and the product was not contaminated with any side reaction products. Again, however, only dimeric ketal was isolated. Although no monomeric diene ketal was isolated in these pyrolyses, they did give some indication of the stability of this monomer. It appears that the diene ketal is not as stable as one would predict from comparison to cyclopentadiene, and perhaps the molecule should be more correctly compared to cyclopentadienone in stability. In this respect, lower temperatures should favor the isolation of the diene ketal, and a longer ranged program with this objective would perhaps be in order.

EXPERIMENTAL

Reagents

Following is a list of the materials used in the experimental work, the source of the chemicals, and descriptions of any subsequent purification of the chemicals:

Anhydrous dimethylamine - Eastman white label grade was used without further purification.

Azobis(isobutyronitrile) - This was obtained from Chemical Intermediates and Research Laboratories, Inc., Cuyahoga Falls, Ohio. It was recrystallized from anhydrous methanol or anhydrous diethylether to give a white, crystalline product, m. p. 103.5-104°.

Chlorine gas - A five pound cylinder was obtained from the Matheson Company, East Rutherford, New Jersey.

Cyclopentanone - Matheson, Coleman, and Bell reagent grade, b. p. 128-130°, was used without further purification.

Diethylene glycol - This was obtained from Carbide and Carbon Chemicals Company, New York, and used as received.

Ethylene glycol - Purified grade from Fisher Scientific Company was used without further purification.

Hydrogen peroxide - A 30% solution, reagent grade, was obtained from Allied Chemical, New York.

Levulinic acid - A portion of the levulinic acid was generously supplied by the Quaker Oats Company of Chicago.

This was redistilled through a Vigreaux column at 152-154°
and 20 mm. The remainder of thee acid was purchased from
Eastman(technical) and was redistilled as above.

Methyl bromide - Eastman practical grade was used without further purification.

N-bromosuccinimide - Eastman practical grade was recrystallized from water to give white, flaky plates which were dried in a desiccator to a constant m. p. of 173°.

para-Toluenesulfonic acid --Matheson, Coleman, and Bell practical grade was recrystallized from chloroform to give white, extremely hygroscopic crystals, m. p. 106-107°.

Palladium on charcoal - A 5% palladium on charcoal powder was obtained from The American Platinum Works, Newark, New Jersey.

Quinoline - Eastman white label was used without further purification.

Sodium borohydride - This was obtained from Metal Hydrides, Inc., and used as received.

t-Butyl peracetate - Lupersol number 7, a 75% ter.-butyl peracetate solution in benzene was obtained from Lucidol Division of Wallace and Tiernan, Inc., Buffalo, New York.

b-Butyl perbenzoate - This perester was obtained from Lucidol Division of Wallace and Tiernan, Inc., Buffalo, New York.

Fig. 2. Synthetic scheme
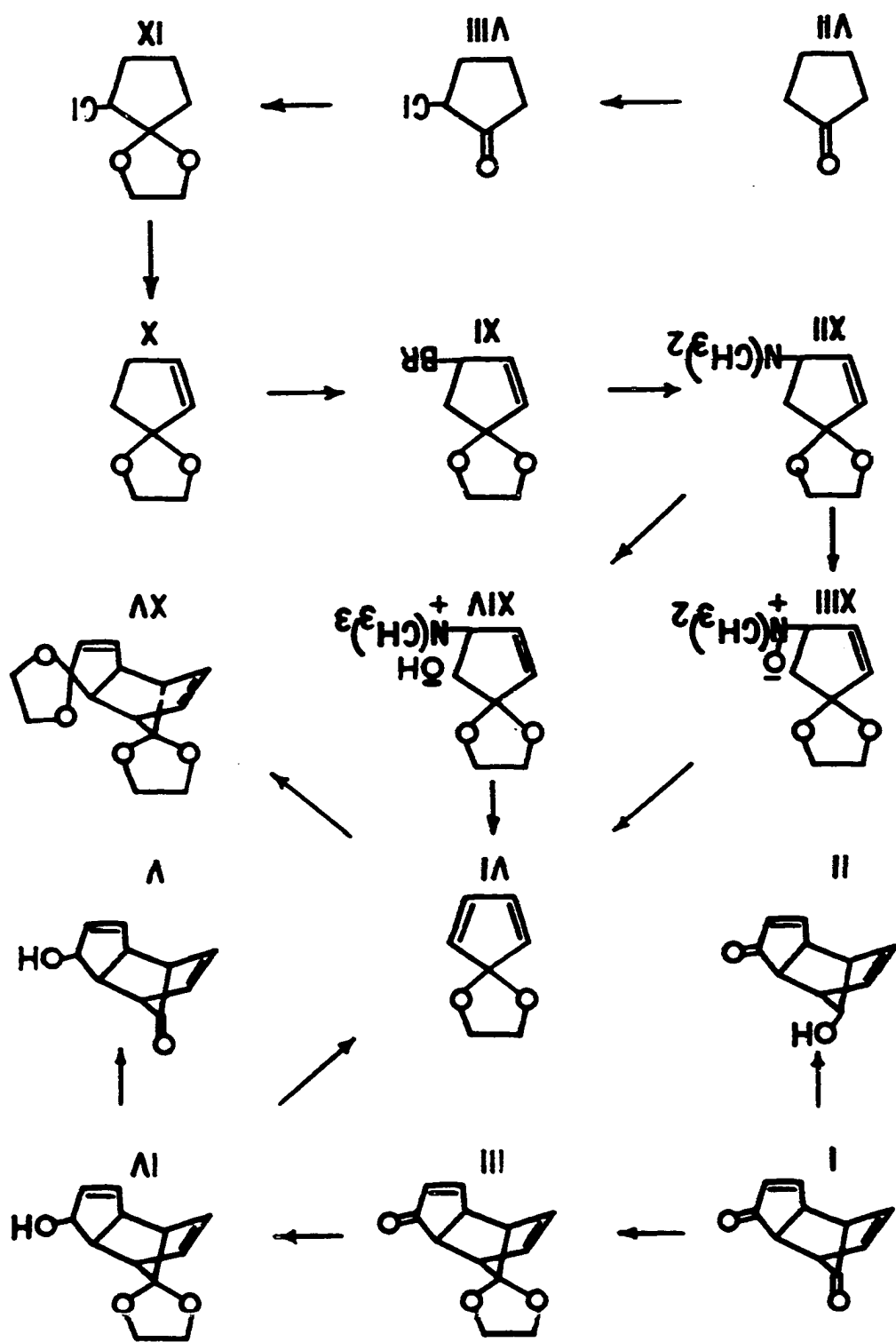
Preparations

1,8-Dioximino-4,7-methano-3a,4,7,7a-tetrahydroindene

The procedure is essentially that of Doering and DePuy[39] in which 23 g. (1 mole) of sodium metal was dissolved in 1 liter of absolute ethanol and cooled to 5° in an ice-water bath. To this solution was added dropwise, with vigorous stirring, a mixture of 71 g. (0.95 mole) of ethyl nitrite[40] and 83 g. (0.95 mole) of freshly distilled cyclopentadiene.* The temperature was not allowed to rise above 10° during the addition. After addition was complete, stirring was continued for one hour, then 500 ml. of water were added and the solution concentrated at 15 mm. and 40° to remove most of the ethanol. The remaining solution was then extracted with ether until the extracts were clear and carbon dioxide was bubbled into the aqueous solution overnight. A black solid, consisting of sodium bicarbonate and the dioxime, precipitated and

---

[39]W. von E. Doering and C. H. DePuy, op. cit., p. 5955.

[40]L. Gattermann and H. Wieland, "Laboratory Methods of Organic Chemistry," New York, N. Y., The Macmillan Company, 1937, p. 147.

*The commercially available dimer (Eastman technical) may be cracked by heating in a flask equipped with a short, glass helices packed, column. The flask must be heated to 150-170° and the monomer is collected in a receiver placed in an ice-water bath as it distills at 40-41°. The monomer is then stored over calcium chloride at 0° until ready for use.

was filtered and extracted with ether in a Soxhlet extraction apparatus. This ether extract gave 48 g. of a pale yellow solid. Continuous ether extraction of the aqueous solution gave an additional 25 g. of the dioxime. Total yield was 73 g. (80%). The dioxime has a m. p. of 176-178°(dec.).

Various solvents were tried in order to further purify the dioxime by recrystallization. Due to its extreme insolubility, no suitable solvent system could be found to carry out the recrystallization. The dioxime is sparingly soluble in boiling ethanol to give a yellow solution, but no precipitate could be obtained upon cooling in an ice-water bath. After a day of standing at room temperature, however, a small amount of the dioxime did precipitate, m. p. 176-178°. In most instances, merely washing the crude dioxime with cold 95% ethanol left it suitably pure for most uses.

1,8-Diketo-4,7-methano-3a,4,7,7a-tetrahydroindene(I)

A mixture of 10 g. (0.05 mole) of the dioxime and 102 ml. (1 mole) of levulinic acid* was made 0.1 $\underline{N}$ in hydrochloric acid and stirred for three hours while heating on a steam bath. After this time, the solution had darkened considerably and it was cooled and 200 mls. of water added. After extracting several times with methylene chloride, the combined

---

*Caution: Levulinic acid, if gotten into the eyes, causes blindness, with no known antidote!

extracts were washed with water, with saturated sodium bi-
carbonate solution, and finally with saturated sodium chlor-
ide solution. After removal of the solvent by distillation
under reduced pressure, a dark brown residue of the diketone
remained. The diketone may be recrystallized by heating the
brown residue in refluxing hexane and then pouring off the
clear, saturated solution and cooling it in an ice-salt water
bath. This gave 5.6 g. (70%) of nice white crystals. The
solid has a m. p. of 100-101° and I. R. absorption peaks at
5.6μ and 5.85μ.

Anal. Calc'd. for $C_{10}H_8O_2$: C, 74.99; H, 5.03; Found:
C, 74.96; H, 5.23.

1-Keto-8-hydroxy-4,7-methano-3a,4,7,7a-tetrahydroindene(II)

The procedure was patterned after the method of Beckett
et al.[41] 1.88 g. (0.012 mole) of dicyclopentadieneone was
dissolved in 25 ml. of dry methanol and with external cooling
and vigorous stirring, 0.5 g. (0.014 mole) of sodium boro-
hydride was added in small portions over a period of ten
minutes. After addition was complete, the solution was
stirred for 5 minutes at room temperature before adding 10
ml. of water and extracting with methylene chloride. After
drying over anhydrous sodium sulfate, the solvent was removed

---

[41]A. H. Beckett, K. C. Harper, A. D. J. Balon, and T. H.
E. Watts, _Tetrahedron_, _5_, 319 (1959).

to give 1.04 g. (84%) of a clear, viscous oil which may be recrystallized from hexane to give a white crystalline solid, m. p. 132°C. An infrared spectrum of this solid revealed the expected disappearance of the bridged carbonyl absorption at 5.6μ as well as the appearance of the characteristic hydroxyl absorption.

Attempted rearrangement of 1-keto-8-hydroxyl-4,7-methano-3a,4,7,7a-tetrahydroindene(II)

The rearrangement conditions were the same as those reported by Woodward and Katz.[42] A 0.2 g. sample to the keto alcohol was placed in a 10 by 75 cm. pyrex test tube and the tube evacuated and sealed off. The sample was then suspended above the surface of a refluxing xylene solution for 24 hours. After cooling, the tube was opened and the product examined by infrared. The infrared spectrum failed to reveal any change in the keto alcohol. Treatment of the keto alcohol with either 0.1 N acid or base also failed to effect any change in the molecule.

8-(Cyclic ethylene ketal)-1-keto-4,7-methano-3a,4,7,7a-tetrahydroindene(III)

Into a 250 ml. three-necked flask equipped with a stirrer, an addition funnel, and a Dean-Starke water sepa-

---

[42]R. B. Woodward and T. J. Katz, op. cit., p. 70.

rator was placed 5.59 g. (0.035 mole) of freshly sublimed dicyclopentadienone, 0.3 g. of para-toluenesulfonic acid catalyst and 140 mls. of benzene. The solution was heated to reflux with a heating mantle and, with vigorous stirring, a benzene solution of 2.2 ml. (0.038 mole) of ethylene glycol was added dropwise. After addition was complete, the mixture was stirred at reflux for 24 hours. At this time, 1.1 ml. of water had separated (0.7 ml. theoretical), and the mixture was cooled, washed twice with 2 N sodium hydroxide, once with water, and finally dried over anhydrous sodium sulfate. The benzene was removed at 40° and reduced pressure to give 7.0 g. (98%) of a colorless oil. This oil, when subjected to an attempted recrystallization from hexane, separates again as an oil which then crystallizes on standing. Sublimation of this solid at 65° and 0.1 mm. gave an analytical sample of white needles, m. p. 95°.

Anal. Calc'd. for $C_{12}H_{12}O_3$: C, 70.57; H, 5.92; Found: C, 70.63; H, 5.88.

8-(Cyclic ethylene ketal)-1-hydroxy-4,7-methano-3a,4,7,7a-tetrahydroindene(IV)

A solution of 7.12 g. (0.035 mole) of the ket-ketal in 25 ml. of dry methanol was placed in a small three-necked flask and, with cooling and vigorous stirring under a nitrogen atmosphere, 1.5 g. (0.04 mole) of sodium borohydride was added over a period of 15 minutes. The solution was then

refluxed for one hour before 15 ml. of water were added and
the solution extracted three times with small portions of
methylene chloride. After washing these combined extracts
with water and saturated sodium chloride solution, the
methylene chloride was removed and the product distilled at
125° and 0.2 mm. to give 5.75 g. (80%) of a clear, viscous
oil. The infrared spectrum indicated the presence of both an
alcohol and ketal function.

1-Hydroxy-8-keto-4,7-methano-3a,4,7,7a-tetrahydroindene(V)

A 0.6 g. sample of the ketal-alcohol prepared previously
was dissolved in 15 ml. of methanol and made 1.0 $\underline{N}$ in hydro-
chloric acid. The solution was refluxed for 2 hours with
stirring and then extracted with methylene chloride. This
extract was washed first with saturated sodium bicarbonate
solution, then with water, and finally with saturated sodium
chloride solution. After drying over anhydrous sodium sul-
fate, the solvent was removed to give 0.47 g. of an oily
product whose infrared spectrum indicated to be a mixture of
the expected keto-alcohol and the corresponding diketone.
The desired 1-hydroxy-8-keto-4,7-methano-3a,4,7,7a-tetra-
hydroindene was isolated by elution chromatography using an
alumina column.

Rearrangement of 1-hydroxy-8-keto-4,7-methano-3a,4,7,7a-tetrahydroindene(V)

Three 0.2 g. samples of the 1-hydroxy-8-keto compound were placed in 10 by 75 mm. pyrex test tubes and evacuated and sealed off according to the procedure of Woodward and Katz.[43] One tube was then used for each of the following conditions:

Refluxing xylene (b. p. 137°C)   The sample was suspended above a refluxing xylene solution for five hours and then after cooling and opening, an IR was taken in chloroform solution. Examination of the spectrum shows no carbonyl absorption at all, and hence gives evidence that the compound has most likely decarbonylated. This is analogous to the case of dicyclopentadienone which decarbonylates in the vicinity of 135°C.

Refluxing water (b. p. 100°C)   The sample was suspended above refluxing water for 24 hours, and again the tube was cooled, opened, and an IR taken in chloroform solution. The spectrum shows the bridgehead carbonyl absorption at 5.6μ as in the original compound before heating, but a small carbonyl absorption at 5.8μ suggests that some rearrangement is taking place and that a temperature greater than 100° but less than 135° would favor complete rearrangement.

---

[43] R. B. Woodward and T. J. Katz, op. cit., p. 70.

Refluxing toluene (b. p. 111°C)   The sample was sus-
pended above a refluxing toluene solution for 24 hours and
after cooling and opening, an IR taken in chloroform solution.
The spectrum shows a complete rearrangement of the starting
product to give a compound with a carbonyl absorption at 5.8μ.

2-Chlorocyclopentanone[44](VIII)

A three liter, three necked round bottom flask was set
up in the hood and equipped with a stirrer, a gas inlet tube
which extended to the bottom of the flask, and a gas outlet
tube. A chlorine gas cylinder was connected to the inlet
tube by means of a gas trap and a three-way stopcock to pre-
vent liquid from the flask being sucked back into the gas
cylinder upon sudden changes in pressure. A mixture of 500 g.
(5.94 moles) of cyclopentanone, 290 g. (2.90 moles) of calcium
carbonate, 320 ml. of water, and 290 g. of a 40% solution of
calcium chloride was added to the flask. A stream of chlorine
gas from the cylinder was passed rapidly into the flask while
the solution was being stirred vigorously. An ice-salt water
bath was made ready so that the flask could be quickly im-
mersed should the reaction become too exothermic. After about
one-half hour of chlorine addition, a pale greenish-yellow
color had been built up in the cyclopentanone layer of the

[44]H. W. Wanzlick, G. Gollmer, and H. Milz, op. cit.,
p. 69.

rapidly stirred solution. At this point, a UV lamp was held on the reaction mixture for about 10 minutes, at which time the pale greenish-yellow color vanished immediately, and cooling by means of the ice-salt water bath was necessary. After this momentary display of exothermicity, the reaction proceeded smoothly and maintained its own reaction temperature with little or no external cooling necessary. After the reaction was over, as evidenced by the disappearance of the calcium carbonate slurry and the termination of carbon dioxide evolution through the gas outlet tube, the chlorine stream was turned off, and the reaction mixture cooled. The upper organic layer was separated from the lower aqueous layer by means of a separatory funnel and the aqueous layer extracted once with chloroform. After combining the organic layer and the chloroform extract, the solution was distilled through a 29 inch asbestos wrapped Vigreaux column under reduced pressure using an aspirator. The 2-chlorocyclopentanone distills at 87-90° at 23 mm. to give 360 g. (69%) of product. A GPC analysis of this fraction showed it to be sufficiently pure for use without redistillation. Redistillation of the forerun gives 130 g. of unreacted starting material.

Cyclic ethylene ketal of 2-chlorocyclopentanone(IX)

A mixture of 100 g. (0.84 mole) of 2-chlorocyclopentanone, 220 ml. of benzene, and 0.5 g. of paratoluenesulfonic

acid was placed in a 500 ml. three necked flask equipped with
an addition funnel, stirrer, and a Dean-Starke water sepa-
rator. The solution was heated by means of a heating mantle
to reflux and 61.3 ml. (0.9 moles) of ethylene glycol slowly
added over a period of 90 minutes with stirring. The initial
solution of chloroketone and benzene was colorless, but as
addition of the ethylene glycol was started, it turned
progressively from a light yellow to a deep green. During
the last stages of the addition, hydrochloric acid fumes could
be detected coming out the top of the condenser. After five
hours from the start of the reaction, 17.5 ml. of water had
been drawn off, and water separation had virtually stopped.
The reaction mixture was cooled and then washed twice with
2.0 $\underline{N}$ sodium hydroxide solution and once with water. The
benzene was then removed under reduced pressure, and the
organic residue distilled through a 11 inch Vigreaux head
to give 113.0 g. (82.5%) of the 2-chlorocyclopentanone ketal
with b. p. 102-104° at 29 mm.

A GPC analysis showed the ketal to be sufficiently pure
for use without redistillation.

Cyclic ethylene ketal of cyclopentenone(X)

A mixture of 112 g. (2.0 mole) of potassium hydroxide
pellets and 220 ml. of diethylene glycol was placed in a
500 ml. three necked flask equipped with a stirrer, addition

funnel, and a reflux condenser containing a capillary attach-
ment. The flask was heated in a Woodsmetal bath at 170° with
stirring until all the potassium hydroxide had dissolved.
Then 2.0 g. of ammonium chloride was added to the dark brown
solution, and as the temp erature was raised to 200°, 110 g.
(0.67 mole) of the chloroketal was added over a period of
40 minutes. Heating was continued for 1 1/2 hours after
addition was complete. A Vigreaux distilling head was then
attached and all the distillate under 110° at 15 mm. was col-
lected in one fraction. The distillate was diluted with
water, the organic layer separated, and the aqueous layer ex-
tracted twice with ether. After drying the combined ether
extracts and organic layer over anhydrous sodium sulfate, the
ether was removed and the organic residue fractionally dis-
tilled to give 64 g. (75%) of olefin, b. p. $65-67^O$ at 18 mm.
A 2,4-DNP derivative was prepared; m. p. 165°.

Hydrogenation of cyclopent-2-enone ketal(X)

A suspension of 0.02 g. of a 5% palladium on charcoal
catalyst in 10 ml. of 95% ethanol was placed in an atmos-
pheric hydrogenation apparatus and was stirred for one hour
in an atmosphere of hydrogen. A solution of 0.126 g. (10^{-3}
mole) of cyclopent-2-enone ketal in 10 ml. of 95% ethanol was
added, and stirring was continued for 24 hours. The hydrogen
gas absorption after this time amounted to 22.2 ml. after

correction to standard conditions. Filtration of the palladium on charcoal and distillation of the ethanol gave the saturated ketal.

4-Bromocyclopent-2-enone ketal(XI)

Into a previously dried 300 ml. three necked flask equipped with a stirrer, condenser, and addition funnel was placed 14.2 g. (0.08 mole) of N-bromosuccinimide and 200 ml. of carbon tetrachloride. Approximately 0.1 g. of azobis(isobutyronitrile) initiator was added, and with stirring, the contents of the flask was heated to reflux by means of a steam bath. A solution of 10.0 g. (0.08 mole) of cyclopent-2-enone ketal in 50 ml. of carbon tetrachloride was added over a period of 20 minutes and the mixture was then stirred while heating for an additional 10 minutes. The solution was cooled in an ice-water bath and then filtered with suction to remove the succinimide formed in the reactio... A recovery of the succinimide showed the reaction to be essentially quantitative. The carbon tetrachloride was removed at 35° under reduced pressure, and several attempts were made to purify the remaining dark organic residue by vacuum distillation. Although various techniques were tried, all attempts to distill the 4-bromocyclopent-2-enone ketal led to total decomposition of the material. An attempt at isolating the bromo compound at low temperatures by recrystallization tech-

niques **was** also unsuccessful. An infrared spectrum of the crude reaction mixture served to identify the 4-bromocyclopent-2-enone ketal, and it was subsequently used without separation from the carbon tetrachloride solvent.

Attempted dehydrobromination of 4-bromocyclopent-2-enone ketal

A solution of 0.04 mole of 4-bromocyclopent-2-enone ketal in 100 ml. of carbon tetrachloride was placed in a 100 ml. flask and 19.3 ml. (0.149 mole) of quinoline added. The carbon tetrachloride was then removed by distillation and the remaining solution refluxed for two hours with the oil bath at 170°. The solution had taken on a jet black color at the end of this time, and although distillation under reduced pressure gave a small amount of a clear liquid, it appears to be mainly quinoline as adjudged from infrared spectra. This liquid slowly gives a maleic anhydride adduct upon standing, but again this appears to be a quinoline-maleic anhydride adduct.

A second attempt at dehydrobromination involved the use of potassium t-butoxide and a procedure similar to that of House et al.[45] A solution of 0.04 mole of 4-bromocyclopent-2-enone ketal in 100 ml. of carbon tetrachloride was stirred

---

[45]H. O. House, V. Paragamian, R. S. Ro and D. J. Wluka, J. Am. Chem. Soc., 82, 1455 (1960).

at room temperature while 0.06 mole of potassium t-butoxide in t-butanol was added. The solution became warm upon mixing, and after stirring at room temperature for three hours, the clear solution was poured into ice water. The organic layer was separated, dried over anhydrous sodium sulfate, and distilled under reduced pressure. This gave a small amount of brown liquid which, on subjection to a GPC analysis, was shown to consist of one major component and two minor ones. Infrared spectra of these individual components failed to reveal any evidence for the presence of the diene ketal(VI).

Cuprous bromide[46]

In a 250 ml. erlenmeyer flask was dissolved 19.2 g. (0.12 mole) of cupric sulfate in 100 ml. of water by heating, then 17.6 g. (0.17 mole) of sodium bromide was added. A solution of sodium sulfite prepared from 7.0 g. of sodium bisulfite, 4.5 g. of sodium hydroxide, and 50 ml. of water was added slowly with swirling to the copper sulfate solution. The erlenmeyer flask was then cooled in an ice-water bath and the cuprous bromide allowed to settle. The liquid was carefully decanted, the solid was transferred quickly to a suction filter, and then washed five times with small por-

---

[46]Louis F. Fieser, "Experiments in Organic Chemistry," 3rd ed., Boston, D. C. Heath and Company, 1957, p. 196.

tions of glacial acetic acid. It is essential not to expose the white solid to the atmosphere any more than is necessary. In order to achieve this objective, the wash solution is sucked through the funnel rather slowly and when only a thin layer of liquid covers the solid, the next portion of wash solution is poured in. The walls of the funnel should be washed each time with washing solution. After the acetic acid wash, the solid is next washed with three portions of absolute ethanol, then with six portions of anhydrous ether, and finally sucked dry for 30 seconds. It was then quickly transferred to a previously dried watch glass and dried in an oven at 75-100° for 30 minutes to give 10 g. (58%) of a pale green solid. This was kept **stored** in a desiccator until ready for use.

4-Acetoxycyclopent-2-enone ketal

The procedure was essentially that of Kharasch et al.[47] A solution of 15 g. (0.119 mole) of cyclopent-2-enone ketal and 0.014 g. of cuprous bromide catalyst was heated to a temperature of 90°, and with vigorous stirring, 8.6 g. (0.05 mole) of t-butyl peracetate slowly added over a period of 40 minutes. The progress of the reaction was followed by periodic examination of infrared spectra of the crude reaction mixture to detect disappearance of the per-ester absorp-

[47]M. S. Kharasch, George Sosnovsky, and N. C. Yang, op. cit., p. 5819.

tion band. **After three and one-half hours, the reaction appeared to be complete.** The solution was washed with 2 N sodium carbonate and then with water. Appreciable resinification had occurred in the organic layer, so it was extracted with ether and this ether extract filtered through a small plug of cotton to remove the polymeric solid material. After drying over anhydrous sodium sulfate, the ether was then removed and the organic product distilled under reduced pressure. An appreciable amount of starting olefin was recovered, plus a small amount of 4-acetoxycyclopent-2-enone ketal, b. p. 82-84° at 1 mm. The infrared carbonyl absorption was at 5.78 μ.

In an attempt at increasing the yield of the acetate, the above procedure was modified to correspond closely to that of Story[48] in which benzene was used as a solvent for the reaction. Again, however, only a small amount of the acetate was obtained upon distillation of the product at reduced pressure.

4-Benzoyloxycyclopent-2-enone ketal

The procedure followed was that of Story.[49] A solution of 10 g. (0.08 mole) of cyclopent-2-enone ketal in 40 ml. of benzene was placed in a flask with 0.02 g. of cuprous bromide

---

[48]P. R. Story, J. Am. Chem. Soc., 82, 2085 (1960).

[49]Ibid., p. 2085.

catalyst. As the solution was brought to reflux, 7.72 g. (0.04 mole) of t-butylperbenzoate was added dropwise over a period of 20 minutes with vigorous stirring. The progress of the reaction was followed by periodic examination of the infrared spectra of the crude reaction mixture. The solution was kept at reflux temperature for two hours until the reaction was judged complete by the disappearance of the perester band from the infrared spectrum. The solution was washed with 2 $\underline{N}$ sodium carbonate, and acidification of this extract gave 4.62 g. of benzoic acid. After removing most of the benzene solvent, the organic residue was subjected to a vacuum distillation through a short Vigreaux column using a microburner as the source of heat. A small fraction of product distilled, b. p. 120° at 1 mm., before decomposition in the still pot was complete, and although spectral evidence was consistent with the expectations for the benzoate product, it appeared that the product was still a mixture of components.

4-(N,N-dimethylamino)cyclopent-2-enone ketal(XII)

A solution of 40 g. (0.317 mole) of cyclopent-2-enone ketal was brominated according to the previous procedure. The solution of the 4-bromocyclopent-2-enone ketal in 800 ml. of carbon tetrachloride was placed in a one liter, three necked flask equipped with a stirrer, a reflux condenser, and

a gas inlet tube extending to the bottom of the flask. The solution was cooled to -5° in an ice-salt water bath and 100.5 ml. (1.58 moles) of anhydrous dimethylamine was placed in a small flask connected to the gas inlet tube and the solution was stirred vigorously as the dimethylamine evaporated from the addition flask into the carbon tetrachloride solution of the bromide. A copious amount of flocculent precipitate formed as addition proceeded, and after addition was complete, the mixture was stirred overnight at room temperature. The brown solution was washed twice with 2 N sodium hydroxide, once with water, and then dried over anhydrous sodium sulfate. The carbon tetrachloride was removed at 35° under reduced pressure and the remaining organic material fractionated through a short Vigreaux distilling head; 37.7 g. (70.5%) of the crude amine, which has a deep wine color, was isolated, b. p. 65° at 1.5 mm. A GPC analysis of this crude amine on a tris(cyanoethyoxy)-propane column at a temperature of 160° showed one major component (70%) and two minor ones.

<u>Anal</u>. Calc'd. for $C_9H_{15}O_2N$: C, 63.88; H, 8.94; N, 8.28; Found: C, 61.23; H, 8.79; N, 5.24.

Methyl iodide was added to a portion of the amine to give a vigorous and exothermic reaction. The oily product was recrystallized from absolute ethanol to give a light brown, hygroscopic solid, m. p. $148-150^{\circ}$(dec.).

Anal. Calc'd. for $C_{10}H_{18}O_2NI$: C, 38.55; H, 5.90;

N, 4.50; I, 40.70; Found: C, 38.31; H, 5.89; N, 4.60; I,

39.36.

A solution of 100 mg. of the amine was treated with 5

ml. of a saturated solution of picric acid in absolute ethanol.

A good crop of yellow crystals was obtained and was recrystal-

lized from 95% ethanol to give nice yellow flakes, m. p. 170-

171°C.

Anal. Calc'd. for $C_{15}H_{18}O_9N_4$: C, 45.23; H, 4.55; N,

14.07; Found: C, 45.49; H, 4.68; N, 13.65.

4-(N,N-dimethylamino)cyclopent-2-enone ketal N-oxide(XIII)

The procedure was essentially that of Meinwald et al.[50]

A solution of 3.85 g. (0.023 mole) of amine in 10 ml. of

methanol was cooled to -10° in an ice-salt water bath and

7.7 g. (0.068 mole) of 30% hydrogen peroxide was added over

a period of 20 minutes. After standing overnight, the re-

action mixture was cooled to 0° and a methanolic suspension

of 50 mg. of platinum[51] was added and the solution stirred

an additional five hours. The decomposition of excess hydro-

gen peroxide was complete at this time, as indicated by lead

_____

[50] J. Meinwald, D. W. Dicker, and N. Danieli, J. Am.
Chem. Soc., 82, 4090 (1960).

[51] R. Feulgen, Ber., 54, 360 (1921).

sulfide test paper. The platinum was removed by filtration and the methanol removed at 40° under reduced pressure to . give the N-oxide (17 g.) as a clear tan oil. A small portion of absolute ethanol was added and again removed at 40° under reduced pressure to remove most of the water still present. The remaining oil was used directly for the subsequent pyrolysis reaction.

A 100 mg. sample of this N-oxide gave a good crop of picrate crystals, m. p. $132-133^{\circ}$ from 95% ethanol.

Anal. Calc'd. for $C_{15}H_{18}O_{10}N_4$: C, 43.48; H, 4.38; N, 13.52; Found: C, 43.95; H, 4.58; N, 13.31.

Pyrolysis of 4-(N,N-dimethylamino)cyclopent-2-enone ketal N-oxide(XIII)

A 10.5 g. portion of the crude N-oxide was placed in a 250 ml. three necked flask equipped with a nitrogen gas inlet tube, a stirrer, and a short, large diameter outlet tube. The outlet tube was in turn connected to a small trap maintained at room temperature and then to a trap immersed in a Dry Ice-acetone bath. The system was evacuated to approximately 10 mm. pressure as a slow stream of nitrogen was passed through the system. The amine oxide was then stirred vigorously as the flask was immersed in an oil bath previously heated to 75°. Pyrolysis occurred over a three hour period as the temperature was gradually raised to 100°. This gave 5 grams of a slightly yellow liquid which collected in the trap at

room temperature and 3.5 grams of distillate in the Dry Ice-
acetone trap. The contents of the two traps were combined,
water was added, and the solution extracted with two 24 ml.
portions of ether. After washing the combined ether extracts
with 5% hydrochloric acid, the ether layer was dried over
anhydrous sodium sulfate and the solvent then removed. This
gave 0.5 g. of a slightly yellow oil which did not give an
adduct with maleic anhydride or para-benzoquinone. The infra-
red spectrum indicated the oil to be the dimer (XV) of the
expected diene ketal (VI).

A portion of the aqueous layer was treated with a satu-
rated solution of picric acid in absolute ethanol to give
crystals of the tertiary amine picrate, m. p. 170-171$^{\text{o}}$. After
making the aqueous solution basic, it was extracted with car-
bon tetrachloride to remove the tertiary amine and then re-
duced to one-fifth of its original volume. Treatment of a
portion of this solution with a saturated solution of picric
acid in absolute ethanol gave nice crystals, m. p. 145$^{\text{o}}$, of
the N,N-dimethylhydroxylamine picrate.

Anal. Calc'd. for $C_8H_{10}O_5N_4$: C, 33.11; H, 3.47; N,
19.31; Found: C, 33.18; H, 3.58; N, 19.13.

Cyclopent-2-enone ketal-4-trimethylammonium hydroxide(XIV)

A solution of 25.4 g. (0.15 mole) of the tertiary amine
in 100 ml. of anhydrous ether was cooled to 0$^{\text{o}}$ in an ice-water

bath. With vigorous stirring, 10 ml. (0.165 mole) of methyl bromide was added to the solution. The reaction mixture was then stirred two hours as the temperature was allowed to come to 25°. At this point, a large volume of pale white precipitate had separated which proved too hygroscopic to isolate by filtration techniques. The ether was therefore removed by distillation under reduced pressure to give 33.4 g. (84.5%) of the quaternary ammonium bromide, which was used without further purification. The quaternary ammonium hydroxide was obtained by stirring a mixture of the corresponding bromide with two equivalents of commercial silver oxide (previously washed with methanol) in aqueous solution at room temperature for 18 hours. The silver salts were removed by filtration and the filtrate was evaporated to a sirup under aspirator vacuum and 40°. This gave 21.2 g. (84%) of the crude quaternary ammonium hydroxide which was used directly for the thermal decomposition.

Pyrolysis of the 4-trimethylammonium hydroxide of cyclopent-2-enone ketal(XIV)

The pyrolysis procedure was essentially the same as that described previously for the amine oxide pyrolysis. The distillate from the thermal decomposition of 21.2 g. of the crude quaternary ammonium hydroxide was diluted with water and then extracted with ether. After drying over anhydrous sodium sulfate, the ether was removed to give 2.0 g. of a white solid

which, after sublimation, had a m. p. of 90°. This was iden-
tified from an infrared spectrum as the dimer XV of the ex-
pected diene ketal (VI).

Anal. Calc'd. for $C_{14}H_{16}O_4$: C, 67.73; H, 6.50; Found:
C, 67.58, 67.36; H, 6.63, 6.59.

SUMMARY

Several reactions of dicyclopentadienone have been investigated. The dimer may be reduced easily to the saturated diketone with palladium on charcoal catalyst. The bridged carbonyl group in the dimer is very reactive and may be reduced to the alcohol without affecting the α,β-unsaturated ketone group. An interesting rearrangement of this system was studied. It appears that rearrangement of the 1-hydroxy-8-keto system, V, to the more stable 1-keto-8-hydroxy system, II, has been observed and the evidence is discussed.

Three approaches to the synthesis of the cyclic ethylene ketal of cyclopentadienone have been investigated. The first one involved an attempt to "crack" the 1-hydroxy-8-ketal system, IV, to the desired ketal. The reverse Diels-Alder reaction appears to have occurred, but the high temperatures involved probably account for the destruction of the monomeric cyclic ketal.

The second synthetic approach was along a more conventional route which gave more positive results than the previous method. Cyclopentanone was chlorinated, the chloroketone was converted to its cyclic ethylene ketal, and dehydrohalogenation gave cyclopentenone ketal. The crucial step in this synthesis was the conversion of this ketal to the new compounds, 4-bromocyclopent-2-enone ketal and 4-(N,N-dimethylamino)cyclopentenone ketal. Conversion of the

tertiary amine to the N-oxide with subsequent pyrolysis gave a mixture of products, one of which was the dimer of cyclopentadienone ketal.

In order to eliminate the side reaction products which accompany the amine oxide pyrolysis, the third synthetic approach was the pyrolysis of the corresponding quaternary ammonium hydroxide. This gave a very pure product, but again, only the dimeric cyclopentadienone ketal was isolated. It appears that the cyclic ethylene ketal of cyclopentadienone is less stable than originally anticipated. It should therefore more correctly be compared to cyclopentadienone than to cyclopentadiene in its stability. In this respect, a program based on low temperature isolation techniques would be in order for future synthetic approaches to the monomer.

ACKNOWLEDGEMENTS