PART I

THE CATALYTIC REDUCTION OF ORTHO, META AND PARA

NITROBENZOYL CHLORIDES

PART II

ATTEMPTED DIENE SYNTHESES

By

RICHARD C. TOLLEFSON

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HISTORICAL

The so-called "Rosenmund Reduction" of acid chlorides
for the preparation of aldehydes was first introduced by
Rosenmund[26] in 1918. On the basis of a survey of the previous
work on the reduction of acid chlorides and some preliminary
work of his own, he became convinced that the reaction could
be made to function provided that the proper experimental
conditions could be found. Early problems involved the
application of lower temperatures to prevent the further
reduction of aldehyde, the use of a closed apparatus to study
the consumption of hydrogen, and the separation of the hydrogen
chloride formed which poisoned the catalyst.

Preliminary experiments[26] were carried out on the
reduction of benzoyl chloride using five percent palladium on
barium sulfate as a catalyst. Using solid calcium carbonate
to eliminate the hydrogen chloride it was found that the
higher the temperature of the reduction the greater the yield
of aldehyde and the less the time required for the reduction.
Hydrocarbon solvents such as xylene and cumene were found to
be the best solvents for the catalytic reduction of acid
chlorides to aldehydes and in using these solvents the use
of calcium carbonate to eliminate the hydrogen chloride was
found to be unnecessary since hydrogen chloride was not
soluble in these solvents at the temperatures at which
reductions were carried out. In these same preliminary
experiments it was shown that in spite of the excess hydrogen

used, the reduction stopped at the aldehyde stage. On the basis of these preliminary experiments a number of acid chlorides were subjected to catalytic reduction in boiling xylene using five percent palladium on barium sulfate as the catalyst. Benzaldehyde, butraldehyde and stearaldehyde were prepared in ninety-seven, fifty and ninety-five percent yields respectively, from their corresponding acid chlorides.

Although five percent palladium on barium sulfate as a carrier was recommended as the catalyst for acid chloride reduction,[26] it was found that basic nickel carbonate which had been reduced in a stream of hydrogen at $310\text{-}320^\circ$[22] would serve equally well. Schliewiensky[39] later attempted to use this nickel catalyst to prepare aldehydes from acid chlorides and was unsuccessful. It was pointed out by Rosenmund[32] that special conditions not then published were necessary for reduction and that in originally describing the use of nickel it had been stated that under certain conditions little or no aldehyde was formed.

The catalytic method using palladium-barium sulfate catalyst was later successfully employed for the preparation of gallaldehyde.[27]

Further studies of the catalytic reduction of acid chlorides showed the reaction to be more complex than had at first been realized. Yields of aldehyde were found to fluctuate so widely as to be barely ascertainable in certain cases. In 1921 Rosenmund and Zetzsche[28] published the first

of a series of investigations whose purpose was to study (1)
the effect of foreign materials on the catalyst and (2) to
eliminate accidental influences in the catalytic reduction of
acid chlorides and thus make the reduction more reliable for
the preparation of aldehydes. This investigation led to the
following conclusions.

(1) Pure materials yield hardly weighable amounts of
aldehyde whether the reaction is carried out at
the boiling point of benzene, toluene, xylene or
cumene.

(2) The amount of catalyst, the partial pressure of the
hydrogen or the velocity of its introduction produce
no effect on the yield of aldehyde formed.

(3) The addition of certain foreign materials favors
the yield of aldehyde. In fact, the addition of a
proper amount of a quinoline-sulfur regulator
completely stops the reduction at the aldehyde
stage.

(4) By using solvents which have not been carefully
purified or which are not in a pure state,
fluctuating yields of aldehyde are obtained.

These observations led Rosenmund and Zetzsche into the
field of Specific Catalysis. It was their opinion that the
addition of foreign materials to the palladium-barium sulfate
catalyst lent specificity to its action, that is, it became
a catalyst which permitted only one of several possible
reactions to take place. In support of the claim of specificity,

Rosenmund showed the following reductions to be possible with the use of the palladium-barium sulfate catalyst. (1) Benzoyl chloride reduction was stopped at the aldehyde stage.[28] (2) Reduction of o-chlorobenzoyl chloride which according to previous experiments by Rosenmund and Zetzsche[29] might be expected to have nuclear halogen replaced by hydrogen, nevertheless gave seventy percent yields of o-chlorobenzaldehyde. (3) The reduction of p-nitrobenzoyl chloride gave better than ninety percent yields of the nitrobenzaldehyde, which in view of the fact that p-nitrobenzaldehyde is sensitive to reducing agents certainly demonstrates the selective action of the catalyst.

The palladium-barium sulfate catalyst is essentially that of Schmidt.[40] The catalyst poison which was finally recommended to be satisfactory for most reductions was a quinoline-sulfur regulator made by[28] heating six parts of quinoline with one part of sulfur under reflux for five to seven hours. The resulting dark brown mixture was finally diluted with xylene in such a manner that the amount of poison used could be easily determined.

In working out a theory for this reduction with or without regulators, Rosenmund and Zetzsche introduced the idea of a "Complex"[28]. It was their belief that the hydrogen was absorbed by or attached itself to the palladium and this Pd-H then reacted with the acid chloride.

$$Pd-H + RCOCl \longrightarrow Pd + HCl + RCHO$$

The palladium which is formed in this reaction can absorb more

hydrogen and the process can continue indefinitely. The
obstacle to this is that if such a system will reduce the acid
chloride then it ought to reduce the aldehyde as well. The
concept of a "complex" being formed it given as the reason why
this reduction fails to take place.

"In order for any two components to react it is necessary
to bring them close together and into a mutual sphere of
influence. If the process is affected by a catalyst it too
must come into the sphere of influence."[28] The arrangement
of these components with regard to their mutual positions
and the forces between them was called a "complex". This
"complex" was assumed to be labile and able to decompose as
soon as formed. The manner in which the decomposition occurred
was where the specific action of the catalyst found its
expression. If only molecules came together and the forces
were not great enough to cause a reaction then the complex
would decompose into the original substances. If, however,
the catalyst entered into the complex a rearrangement of
forces may occur and decomposition into new substances could
take place. The addition of foreign materials to a given
catalyst was assumed to produce an entirely new catalyst.
These added materials were assumed to combine with the catalyst,
to form a new catalyst with properties entirely different from
the original catalyst. This combination in turn was thought
to form a new complex with the reactants in such a manner
that the following effects might take place:

(1) Reaction might be hindered in one direction.

(2) Reaction might be favored in another direction.

(3) The effect of one catalyst might be increased.

(4) The effect of another catalyst might be poisoned.

This concept of the specific action of catalysts allows the possibility of being able to favor or bring about one reaction in the presence of a number of competing reactions, provided the proper regulating agent can be found.

This view has been objected to by Abel[1] who claimed that Rosenmund and Zetzsche overlooked previous work on the subject of specific acting catalysts. They have replied[37] to this objection with a defense for their theory of "Complexes" rather than for intermediate reactions in catalysis.

It is of interest to note how the postulates of Rosenmund compare with modern catalytic theory. Explanations of catalytic phenomena which were at one time made either on a purely physical or a purely chemical basis are now confined to the chemical point of view. The physical explanation which was based on the theory of adsorption has been changed by the fact that what was once thought to be purely a physical phenomena is now thought to be very closely akin to purely chemical phenomena.[44]

According to the modern theory of catalysts, a catalyst is a substance which will change the velocity of a reaction and remain chemically unchanged at the end of the reaction. The catalyst does[14] not change the position of equilibrium but merely hastens the attainment of equilibrium. According

to the theory of activated molecules, a molecule must first
be brought into an activated state before it can enter into
a chemical reaction. It is the high activation energy that
causes many reactions to reach equilibrium so slowly. The
role of a catalyst in a chemical reaction is to lower the
activation energy and thereby make it possible for more
molecules to attain the necessary energy and thereby allow
more molecules to react. The manner in which the catalyst
brings about the lowering of energy is thought to be due
to the formation of a "compound" between the catalyst and
the reacting molecules which has a lower activation energy
than the reacting molecules in the absence of the catalyst.

The difference between the energy required for activa-
tion of the reactants E_1 and the energy necessary to activate
the products E_2 is given in the following equation.

$$\frac{d(\ln K_1 - \ln K_2)}{dT} = \frac{E_1 - E_2}{RT^2}$$

The work of Langmuir[23] has shown that the adsorptive
force of catalysts is chemical in nature. This adsorptive
force determines the orientation of molecules at the inter-
face between the catalyst and the reacting molecules, and
it is the molecules at the contact surface that enter into
catalytic changes. Not every molecule which is adsorbed
enters into a chemical reaction; if the adsorptive force
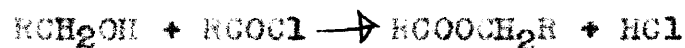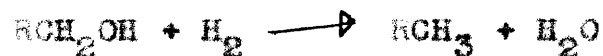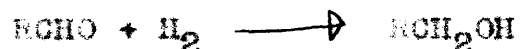at the interface between molecules is too great no reaction
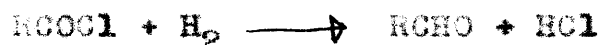will occur.

The effect of a poison is now agreed to be due to a

diminuition of the active catalyst surface by the poison. The poisoning may be permanent or temporary depending upon the force with which the foreign material is bound to the surface.

The particular portions of the catalyst covered by a poison will in effect determine the activity of the poisoned catalyst. The active portions of the residual surface on which no poison is adsorbed are responsible for further catalytic action of the poisoned catalyst. It is the change of adsorptive force of the catalyst caused by adsorption of poison which is responsible for the specific action of catalyst.

Modern theory is thus in complete agreement with the theory of Rosenmund.

Further studies on the reduction of acid chlorides were reported in 1921[30]. It was shown that four predominant reactions can take place in the catalytic reduction of acid chlorides.

$$RCOCl + H_2 \longrightarrow RCHO + HCl$$
$$RCHO + H_2 \longrightarrow RCH_2OH$$
$$RCH_2OH + H_2 \longrightarrow RCH_3 + H_2O$$
$$RCH_2OH + RCOCl \longrightarrow RCOOCH_2R + HCl$$
$$RCOOCH_2R + H_2 \longrightarrow RCOOH + RCH$$

The reduction of benzoyl chloride using pure materials yielded forty-five percent of high boiling hydrocarbons (principally dibenzyl) along with sixteen percent of benzoic acid and fifteen percent of benzylbenzoate. The presence of ester in

the mixture (formed by the union of acid chloride with alcohol) had an effect on the catalyst and a special investigation was undertaken to eliminate its formation. It was found that by reducing the partial pressure of the hydrogen that the yield of ester increased twenty-two to thirty-two percent and at the same time the yield of hydrocarbon fell twenty-two to twenty-three percent. A search for foreign substances which would affect the formation of ester was made and quinoline and xanthone were tried and found to have entirely different effects. Small amounts of quinoline in the benzoyl chloride reduction were found to completely eliminate the formation of hydrocarbon, ester and acid and in their place were formed principally benzyl alcohol along with small amounts of benzaldehyde and benzyl ether. The addition of xanthone to the reduction mixture increased the formation of ester (fifteen to twenty-four percent) and the acid (sixteen to twenty percent) while the amount of high boiling hydrocarbon dropped.

The appearance of a considerable amount of acid, which always occurs when ester was formed, led to the speculation that a relation existed between them.[30] Catalytic reduction of benzyl benzoate showed that benzoic acid and toluene were the only products. They were thought to be formed according to the following scheme:

$$RCOO \vdots CH_2R \longrightarrow RCOOH + RCH_3$$
$$H \vdots H$$
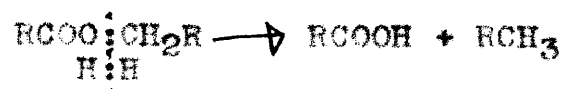
A summary of this work showed that (1) the reduction of acid chlorides with uninfluenced catalysts goes principally to hydrocarbons. (2) The addition of sulfur-nitrogen compounds stops the reduction at the aldehyde stage. (3) The addition of xanthone favors the formation of ester. (4) The addition of quinoline or toluene prevents the cleavage of ester in the catalytic reduction. (5) Reduction in a xanthone toluene mixture forms ester almost exclusively. (6) The addition of quinoline favors the formation of alcohol and prevents the formation of ester.

Further studies on the catalytic reduction of esters have been made by Rosenmund and Zetzsche[31] with the same conclusions.

The reduction was extended to the preparation of dialdehydes by Zetzsche in 1921.[33,34] Isophthaldialdehyde, $mC_6H_4(CHO)_2$, and terephthaldialdehyde, $p-C_6H_4(CHO)_2$, were prepared in eighty-three and eighty-one percent yields respectively from their corresponding acid chlorides. Octanedial (suberic dialdehyde) was prepared in seventy-six percent yield from suberyl chloride. The process failed in the case of $o-C_6H_4(COC)_2$. Zetzsche and Enderlin[33] were also successful in preparing sebacic dialdehyde in eighty percent yields from sebacyl chloride. Several unsuccessful attempts to prepare dialdehydes by catalytic reduction of acid chlorides have been reported.[47] These include $o-C_6H_4(CHO)_2$ benzyl, methyl benzyl and diethyl malonyl dialdehydes.

The method of Rosenmund has been further extended and

found to allow preparation of unsaturated aldehydes.[35]

The influence of the carrier on the activity of the catalyst has been studied.[36] The carriers investigated included blood charcoal, pure and technical kieselguhr, animal charcoal, barium sulfate, and pumice. The activity of the catalyst has been found to be dependent upon the carrier used.

A comprehensive study of the various solvents and the effect of the mode of purification with regard to their use as a solvent in the catalytic reduction of acid chlorides has been made by Zetzsche and Arnd.[48] They found that most commercial solvents contain impurities which may effect the reduction in one way or another. Catalytically inactive xylene was prepared by washing technical xylene with concentrated sulfuric acid or by treatment with phosphorus oxychloride or anhydrous aluminum chloride. One treatment with anhydrous aluminum chloride was found to be equal to twelve washings with sulfuric acid. Distillation or treatment with sodium amalgam, copper, picric acid, phosphoric acid, animal charcoal, or hydrogen chloride would not produce a catalytically inactive solvent.

A method of reduction of acid chlorides in the vapor phase has been proposed by Grignard[18] for the preparation of aldehydes. He showed that the reaction would occur, but the details and optimum conditions have yet to be worked out.

Due to the fact that the "Rosenmund Reduction" is often limited by the insolubility of the products or the reactants

in the hydrocarbon solvent which is used, Zetzsche and Enderlin[49] made a careful search for other solvents. Those studied were chloroform, carbon tetrachloride, pyridine, quinoline, 1,2 dichloroethane, tetralin, decalin, bromobenzene, chlorobenzene, amyl acetate, hexalin acetate, ethyl benzoate, diethyl phthalate, anisole, phenetole, acetic anhydride, turpentine and nitrobenzene. Only tetralin , decalin, anisole and turpentine showed any promise as a solvent for the reduction of acid chlorides to aldehydes.

While the presence of small amounts of phosphorus oxychloride was originally thought not to effect the reduction of acid chlorides to aldehydes,[26] its presence has been shown by Zetzsche[46] to greatly lower the yield of aldehyde formed. Since the time required for the reduction did not change when phosphorus oxychloride was present, this was taken to mean that phosphorus oxychloride did not poison the catalyst but rather directed the action of the catalyst.

Fröschl[13] has proposed a method for the preparation of aldehydes by the catalytic reduction of acid chlorides in the vapor phase. He used palladium on asbestos as a catalyst. He also found that Raney nickel was not applicable for the reduction and that sulfur and phosphorus compounds had to be absent in order to obtain aldehydes from acid chlorides by the use of the platinum catalyst.

Recently the "Rosenmund Reduction" has been used to

prepare acenaphthaldehyde,[11] and 2-naphthaldehyde.[8,11]
These aldehydes were obtained in seventy and eighty-four
percent yields respectively from their corresponding
acid chlorides.

INTRODUCTION

At the outset of this investigation it was desired to see whether o-aminobenzaldehyde could be prepared by the Rosenmund method for the preparation of aldehydes[26]. As a starting product o-aminobenzoyl chloride could be disregarded since there was question as to whether it even existed[2]. The use of this compound was further made impossible by the fact that o-aminobenzaldehyde has been shown to immediately condense with itself when in the presence of mineral acids[12]. The formation of hydrogen chloride in all acid chloride reductions would therefore rule out the catalytic reduction of acid chloride as the final step in the preparation of o-aminobenzaldehyde.

o-Nitrobenzoyl chloride seemed to be the logical starting product, for if a specific catalyst could be found which would selectively reduce the acid chloride and not the nitro group, then the o-nitrobenzaldehyde could be reduced to aminobenzaldehyde by the method of Kuggli and Schmid[38]. The fact that Rosenmund had been able to prepare p-nitrobenzaldehyde by catalytic reduction of the corresponding acid chloride tended to support the belief that the same reaction might be possible with the ortho isomer.

As a second method of attack, the reductions might be carried out on nitrogen substituted derivatives of anthranoyl chloride, which by subsequent hydrolysis of the reduction

product would yield the desired amino benzaldehyde. This method of attack was unsuccessful.

The work to be presented in this thesis covers the catalytic reduction of ortho, meta, and para nitrobenzoyl chlorides.

APPARATUS AND GENERAL PROCEDURE FOLLOWED IN THE
CATALYTIC REDUCTIONS

The apparatus used in all reductions of amounts of
material larger than 0.1 mol is shown in fig. 1. This
apparatus is essentially the same as that described for
the preparation of 2-naphthaldehyde in Organic Syntheses[8].
For the reduction of smaller amounts of material the tube
described by Rosenmund[28] and shown in fig. 2 was used. The
condenser and calcium chloride tube were attached to this
tube during the reductions.

The general procedure followed in all reductions was
as follows: Into the reaction vessel, which had been
brought to the desired temperature by means of an electrically
heated oil bath, was placed xylene, which had been dried by
refluxing it over night and distilling from sodium. A slow
stream of nitrogen was bubbled into the xylene and in the
following order the acid chloride, the catalyst and the
poison were introduced into the flask. The condenser was
then replaced and the gas from the outlet tube was bubbled
into two hundred ml. of water contained in an Erlenmeyer
flask. The nitrogen was then replaced by hydrogen and the
course of the reaction was followed by titrating the hydrogen
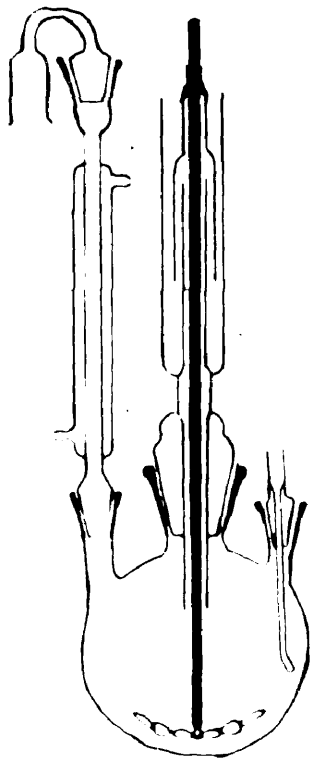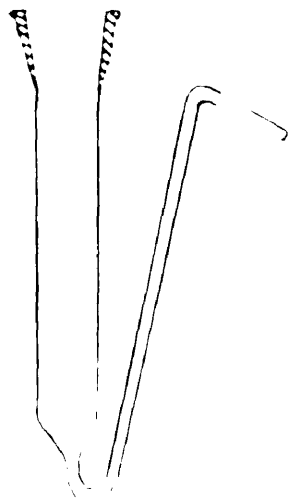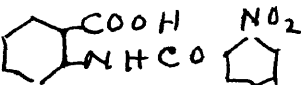chloride formed in the reduction with standard sodium
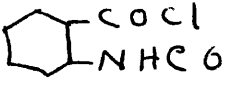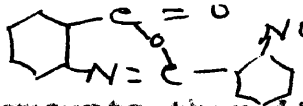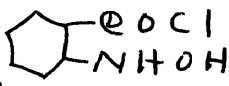hydroxide solution.

Fig 1.

Fig. 2
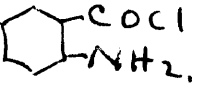
DISCUSSION

The work of Rosenmund and Zetzsche[28,30,31] had definitely shown that the reduction of acid chlorides could form products other than aldehydes if conditions were not carefully controlled. According to them, aldehydes were formed in the reduction of acid chlorides only when certain chance impurities were present in the solvents used or when a quinoline-sulfur regulator was used in conjunction with pure solvents.

The catalyst, poison, and solvent to be used in the catalytic reduction of the nitrobenzoyl chlorides were first tested in a preliminary reduction. The fact that they were capable of reducing benzoyl chloride to benzaldehyde was taken as proof that the reducing system to be used was capable of aldehyde production.

The first reduction of o-nitrobenzaldehyde which was carried out and in which large amounts of catalyst were used, resulted mainly in the formation of N- o-nitrobenzoyl anthranilic acid, (I). It was thereby evident that the nitro group in o-nitrobenzoyl chloride had been reduced in preference to the acid chloride group. The presence of (I) as the major product would seem to indicate that as soon as reduction to the amino group had taken place, the excess o-nitrobenzoyl chloride immediately reacted with it to form a nitrogen substituted acid chloride, which by hydrolysis gave the product (I) which was found. Whether the hydrolysis of the acid chloride actually occurs before

or after coupling takes place is difficult to say. If
N- o-nitrobenzoyl anthranoyl chloride, [structure: benzene ring with COCl, NHCO–benzene ring with NO₂] (II)
were formed at some stage of the reduction, then it would
seem that o-nitrobenzoyl anthranil [structure: C=O, N=C bridged bicyclic with NO₂ benzene] (III)
would be likely to occur in larger amounts than it does.
This behavior would be expected since treatment of (I) with
thionyl chloride forms the acyl anil (III) in preference to
the acid chloride (II).

The rate at which hydrogen chloride was formed in the
reduction would seem to indicate that the hydrolysis of the
acid chloride which formed or went on to eventually form the
acid (I) took place with a great deal of ease. Since
o-hydroxylaminobenzoyl chloride [structure: benzene ring with COCl, NHOH] (IV) or
o-aminobenzoyl chloride [structure: benzene ring with COCl, NH₂] (V) or o-nitrobenzoyl-
anthranilic acid chloride (II) are not known and thus the
ease with which they hydrolyze is not known, it is impossible
to say at which stage the hydrolysis took place, or at which
stage the coupling took place. If coupling took place after
(IV) or (V) were formed, products other than the acid (I)
would probably result. A possible mechanism for the formation
of the acid (I) is given below:

[reaction scheme: benzene-COCl/NO₂ → benzene-COCl/NHOH → benzene-COOH/NHOH → benzene-COO/NH₂]

[reaction scheme: benzene-COOH/NH₂ + benzene-COCl/NO₂ → benzene-COOH/NHCO-benzene-NO₂]
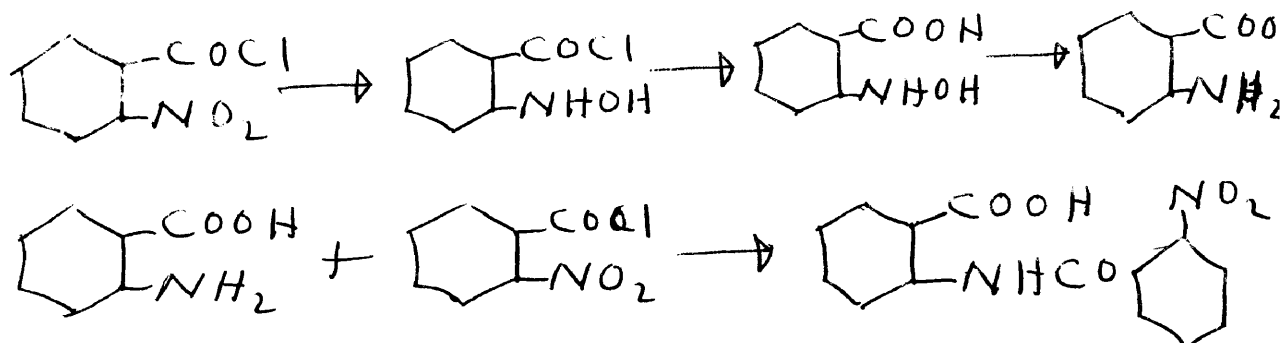
Further reductions which were carried out on o-nitro-benzoyl chloride showed that either with or without the quinoline-sulfur regulator, the reduction would not take place at room temperature. Successive experiments which were identical except for changes in temperature, showed that reduction did not become significant until a temperature of 120° was attained. Reductions were attempted at 27, 60, 80, 100, 130 and 150°. With other factors constant, the products of the reaction were not appreciably changed by raising the temperature above 120°. This is readily explained by the fact that the range between the temperature at which the reaction becomes significant and the boiling point of xylene was so small. In none of these reductions, whether actually carried to completion or not, were any traces of aldehyde found. Further reductions were carried out in which only the amount of poison used was varied. A summary of the important reductions that were carried out and the conditions of each experiment is given in Table I.

Proof that the hydrolysis was caused by water formed in the reduction and not by water present in the system is shown by the fact that no hydrogen chloride was formed when no catalyst was present.

In all of these catalytic reductions of o-nitrobenzoyl chloride the reduction products were worked up in the same manner, and although the amounts of each product varied from one reduction to another, the same products were obtained

in all reductions. No aldehyde was ever obtained. In the xylene insoluble acid fraction, which was obtained by filtration from the xylene and extraction from the catalyst, o-nitrobenzoyl anthranilic acid was always found as the major constituent. By washing this acid with cold ethyl alcohol there was extracted along with small amounts of (I) another acid (VI), decomposed at 180°. This acid was never found in large amounts and was never obtained in pure condition. It has not been identified.

Three other products have been isolated from the reduction mixtures. After evaporation of the xylene, xylene-soluble compounds were left as a solid residue. A small amount of o-nitrobenzoic acid was always isolated by extraction of this mixture with dilute sodium hydroxide solution. From the residue which was insoluble in dilute alkali and which is referred to as the neutral material there were isolated two components, which were separated from each other by fractional crystallization in cellosolve. One of these compounds (m.p. 193-194) has been identified as o-nitrobenzoylanthranil (III). This compound was never obtained in large amounts. Difficulties in separation by fractional crystallization made it difficult if not impossible to determine the exact ratio of the two neutral components. The work done did show that the high melting neutral compound (III) was the minor constituent.

In Table I it is shown that as the amount of regulator was increased the time required for the reduction increased. Simultaneously with this increase in reaction time there was

a corresponding decrease in the amount of acidic material (I
and VI) formed. Accompanying this decrease of acidic material
there was an increase in the amount of neutral material formed.
Since large amounts of neutral material were formed when the
reaction time was long, it is possible that they were formed
in either one of two ways. They may have been formed from
intermediate reduction products which were formed and existed
for some length of time in the slow reductions; these inter-
mediate compounds were probably immediately reduced in the
fast reductions. It is also possible that these neutral
compounds could have been formed by secondary reductions, or
secondary reactions of partly reduced or completely reduced
primary or coupled compounds.

The small amount of o-nitrobenzoylanthranil (III) which
was formed seems to indicate that it was formed by the loss
of water from (I) rather than by the loss of hydrogen chloride
from (II).
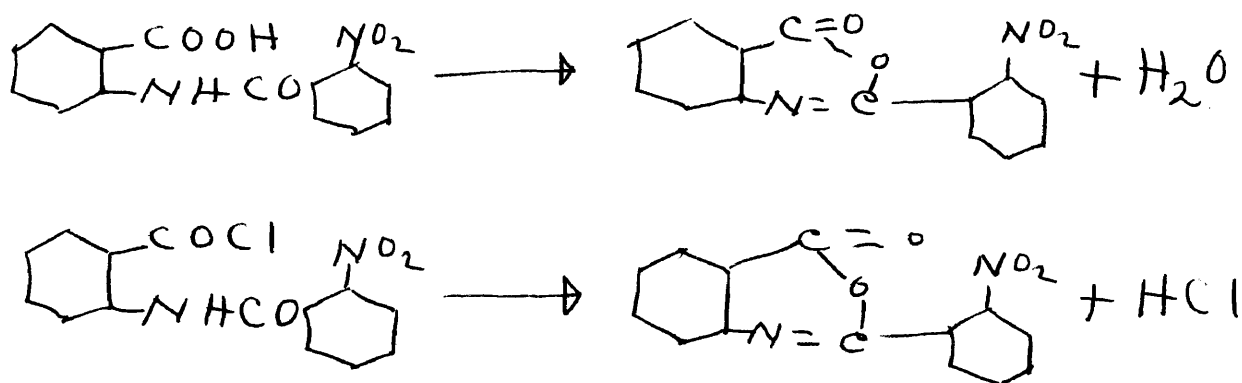
The first reaction would be slow and would require dehydrating
conditions (which are present). The second reaction would be
an instantaneous one.

The second neutral component (m.p. 157-157.5) has not yet been identified. The evidence that there is a relation between this neutral component (VII) and the acid (VI) is not too strong. Hydrolysis of (VII) by 0.3N sodium hydroxide formed an acid which was similar in properties to the acid (VI). It decomposed at 180°. The molecular weight (three hundred and fifty-five) which was determined for (VII) is not conclusive. This value corresponds in no way with the empirical formula indicated by the elementary analyses, i.e., $C_{21}H_{13}N_3O_7$ or $C_{14}H_8N_2O_5$. The acid VI was never obtained in pure enough form to make an elementary analysis worthwhile.

In an attempt to determine whether the unidentified neutral compound (VII) was formed by further reduction and coupling of the anil (III), o-nitrobenzoylanthranil (III) was subjected to reduction under conditions which were known to form large amounts of (VII). Since no further reduction took place it is more than likely that (VII) is formed from intermediate reduction products of o-nitrobenzoyl chloride.

On the assumption that (VII) was formed from intermediate reduction products, it was thought that (VII) might be the di-N-O-[o-nitrobenzoyl]derivative of p-amino phenol. Further studies on the hydrolysis of (VII) had shown that careful hydrolysis yielded an acidic material (VIII) (m.p. 85-86). Careful hydrolysis of the di[o-nitrobenzoyl] derivative of p-amino phenol could conceivably form N-[o-nitrobenzoyl]p-aminophenol which is acidic in nature.

Further hydrolysis or complete hydrolysis would form p-amino phenol (decomposes 180°). These reactions would agree with those of the neutral compound (VI). It had been assumed that p-aminophenol would result from the following series of reactions which are known to take place.[25]
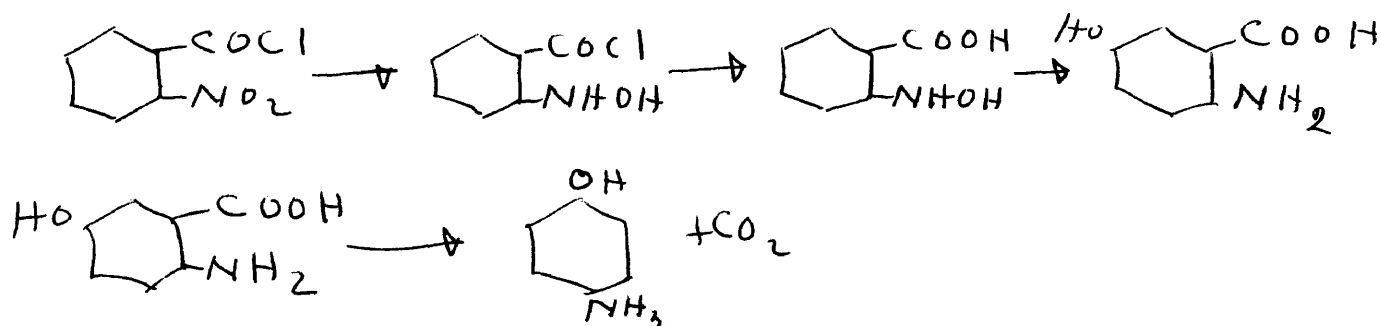
Since Rosenmund had used palladium on kieselguhr as the catalyst in the reduction of p-nitrobenzoyl chloride to p-nitrobenzaldehyde[28], it was thought that this combination might be specific for the preparation of nitroaldehydes from their acid chlorides. Two such catalysts were prepared, i.e. two percent palladium on Filter Del and two percent palladium on ninety-nine percent pure kieselguhr.[Note 1] Neither of these preparations would reduce o-nitrobenzoyl chloride.

In the catalytic reduction of p-nitrobenzoyl chloride it was found that with the solvent, catalyst and regulator used in the previous reductions, no reductions would take place. p-Nitrobenzoyl chloride (Eastman Kodak Co.) which had not been submitted to any kind of purification could not be reduced with or without catalyst regulator. This same acid chloride after having been recrystallized twice

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Kindly furnished by the United States Bureau of Mines.

from petroleum ether (b.p. 90-100°) was reduced to the
aldehyde. The addition of catalyst regulator stopped the
reduction. Reductions which were carried out on p-nitro-
benzoyl chloride which had been prepared in this laboratory
clearly showed that the success of the reduction was dependent
upon the state of purity of the acid chloride. p-Nitrobenzoyl
chloride prepared by treatment of p-nitrobenzoic acid with
excess thionyl chloride had to be distilled and fractionally
recrystallized before yields of aldehyde could be obtained
which would compare with those obtained by Rosenmund[28]. In
none of these reductions was it found necessary to use the
quinoline-sulfur regulator to obtain p-nitrobenzaldehyde; in
fact the use of the regulator stopped the reduction.

Whether the purity of the acid chloride was responsible
for the low yield of m-nitrobenzaldehyde obtained in the
reduction of the acid chloride was not determined. Redistilla-
tion or recrystallization of the acid chloride produced no
apparent change in the rate of reduction or in the yield of
aldehyde; the addition of the regulator completely stopped the
reduction. The results obtained do show that the reduction
of m-nitrobenzoyl chloride does yield aldehyde. Experimental
conditions which will increase the yield of m-nitrobenzaldehyde
have yet to be worked out.

All attempts to prepare nitrogen substituted anthranilic
acid chlorides met with no success. N-Benzenesulfonylanthra-
noyl chloride was prepared[42] but the catalytic reduction of

this substance produced no corresponding aldehyde. The
preparation of most acid chlorides of the type
except for a few cases, like the one mentioned above, is not
possible,for the anil   is formed in preference
to the acid chloride. Furthermore, substitution of the
second amino hydrogen in N-benzoylanthranilic acid by methyl
forms a substance (N-methyl-N-benzoylanthranilic acid) from
which no acid chloride could be obtained.

EXPERIMENTAL

PREPARATION OF o-NITROBENZOIC ACID

o-Nitrobenzoic acid was prepared by the oxidation of technical o-nitrotoluene with potassium permanganate, by the following method. In a twelve liter three-necked flask equipped with a Hershberg stirrer[19], a dropping funnel and a condenser, were placed two hundred grams of o-nitro-toluene (Eastman technical) and seven and one-half liters of distilled water. The stirrer was operated at such a rate that an emulsion was formed between the water and the nitrotoluene. The flask and its contents were heated by means of a steam bath to a temperature of 90-100°. To this hot emulsion was added, dropwise, a saturated solution of potassium permanganate containing four hundred and fifty grams of analytical potassium permanganate. When the violet color of the permanganate was gone the unoxidized o-nitrotoluene was removed by steam distillation. This removal was necessitated by the fact that the o-nitrobenzoic acid could not be made to crystallize in the presence of o-nitrotoluene. The manganese dioxide which was formed in the oxidation was filtered off, and the solution was made acid to congo red paper with hydrochloric acid and then cooled in an ice bath to precipitate the acid. After drying in air the acid weighed one hundred grams. By concentrating

the mother liquor an additional twenty-three grams of acid was recovered. The yield of o-nitrobenzoic acid (m.p. 146-147) based on the amount of the o-nitrotoluene used was seventy-nine percent.

PREPARATION OF o-NITROBENZOYL CHLORIDE

o-Nitrobenzoyl chloride was prepared by treating o-nitro-benzoic acid with an excess of thionyl chloride. The resulting mixture was warmed under gentle reflux for half an hour. At the end of this time the acid was completely converted into acid chloride and was left in the flask as a light yellow liquid. The acid chloride was carefully distilled through a fractionating column under partial vacuum after first distilling off the excess thionyl chloride at atmospheric pressure. The yield of acid chloride obtained was ninety-eight percent (b.p. 142-143°/8 mm.).

PREPARATION OF THE CATALYST AND CATALYST POISON

Two percent palladium-barium sulfate catalyst was prepared according to the procedure of Schmidt[40]. The 0.1 percent quinoline-sulfur regulator was prepared according to the directions on page 4 .

In order to make certain of the activity of the catalyst and of the ability of the poison to stop the reduction at the aldehyde stage, a preliminary reduction was carried out on freshly distilled benzoyl chloride. Fourteen grams (0.1 mol) of benzoyl chloride, six grams of

catalyst and 0.6 ml. of the regulator were used. The reaction was complete in one hour. The fact that the resulting solution showed a positive test with Schiff's reagent and that it formed a voluminous precipitate on addition of a solution of 2,4-dinitrophenylhydrazone in alcohol was taken as sufficient evidence that the catalyst-regulator system was capable of reducing an acid chloride to an aldehyde.

PRELIMINARY REDUCTION OF o-NITROBENZOYL CHLORIDE

Thirteen grams of o-nitrobenzoyl chloride, six grams of two percent palladium-barium sulfate catalyst, 0.06 gram of quinoline-sulfur regulator and two hundred ml. of xylene were used in this reduction. The temperature of the bath was 150°. The reduction was complete at the end of one hour. The mixture was allowed to stand over night. The catalyst, along with an acidic material which had precipitated on standing, was filtered from the xylene solution. The xylene solution gave a negative test for aldehydes with both Schiff's reagent and with 2,4-dinitrophenylhydrazine. The acidic material was separated from the catalyst by extracting the catalyst with 0.3N sodium hydroxide solution. The acid was purified by recrystallization from hot ethyl alcohol (m.p. 233-235°). This acid (I) when mixed with synthetic o-nitrobenzoylanthranilic acid (m.p. 233-235°) produced no depression in its melting point. The acid (I) was synthesized by treating anthranilic acid with o-nitrobenzoyl chloride. The acid (I) was further identified by its conversion to

o-nitrobenzoylanthranil (III). This preparation is described
in a later experiment.

SYSTEMATIC REDUCTIONS OF o-NITROBENZOYL CHLORIDE

In this series of reductions, the apparatus shown in
fig. 2 was used throughout. Five and six-tenths grams of
o-nitrobenzoyl chloride, thirty ml. of xylene and 0.88 gram
of catalyst were used in each reduction. The course of the
reduction was followed by titrating the hydrogen chloride
with one normal sodium hydroxide solution. (Made by making
up a solution of twenty grams of analytical sodium hydroxide
to exactly five hundred ml.). The effect of the temperature,
the effect of quantity of catalyst and the effect of the
amount of poison on the reduction of o-nitrobenzoyl chloride
has been summarized in Table I.

These reduction mixtures were all worked up in the
following manner. At the end of the reduction the mixture
was allowed to cool in an atmosphere of nitrogen. The xylene
solution was tested for the presence of aldehyde and then
allowed to stand over night. High molecular weight acidic
material precipitated during this standing and was filtered
off from the xylene solution along with the catalyst. The
light yellow colored xylene solution which remained after
filtration of the catalyst was distilled in a partial
vacuum in an atmosphere of nitrogen at a temperature of
80-100°/20 mm. In every case a solid residue was left after
all of the xylene had been evaporated. This light yellow

colored residue was thoroughly extracted with 0.3N sodium hydroxide solution. In this manner there were separated the following products. (1) a high molecular weight, xylene insoluble acidic fraction, (2) a xylene soluble acidic fraction, (3) a xylene soluble, sodium hydroxide insoluble fraction (Neutral Fraction).

TABLE I

REDUCTION OF o-NITROBENZOYL CHLORIDE

Run	Bath temperature	Extent of reaction*	Time of reaction	Grams poison	Gms. o-nitrobenzoic acid	Gms. o-nitrobenzoyl-anthranilic acid	Grams neutral material
1	room temperature to 120°	0	1 hour				
2	120°	99%	1 hour	0	0.4	3.3	0.5-1.0
3	130-140°	99%	1½-2 hours	0.0175	0.65	1.85	1.1-1.7
4	125-130°	95%	2½ hours	0.0225	-	0.8	3.25
5	126°	95%	3¼ hours	0.0275	0.56	0.2	3.40
6	125°	66%	5⅛ hours	0.0325	0.5	-	3.7
7	120-150°	0	1 hour	0.035	-	-	-
8	120-165°	0	4 hours	0.0875	-	-	-
9	120-160°	0	1 hour	no poison no catalyst	-	-	-

* based on hydrogen chloride evolved.

INVESTIGATION OF THE XYLENE INSOLUBLE ACIDIC FRACTION

The material was recrystallized from hot alcohol (m.p. 234-235°). The melting point of this acid and the fact that when mixed with synthetic o-nitrobenzoylanthranilic acid (I) (m.p. 233-235°) it produced no change in melting point showed it to be identical with (I).

A more careful examination of the acidic fraction showed that if the acid fraction were first extracted with cold alcohol a small amount of impure acid could be obtained. This acid (VI) was not identical with the acid (I). After two recrystallizations from alcohol and water the acid (VI) decomposed around 180°. Due to the fact that it was contaminated with (I) and because a satisfactory solvent was not found, the acid (VI) was never obtained pure; it never occurred in large amounts. (VI) was insoluble in benzene, water, petroleum ether, ethyl acetate, xylene and chloroform. (VI) was soluble in amyl alcohol, ethyl alcohol, cellosolve, acetic acid and acetone. (VI) gave a negative phenol test with ferric chloride solution.

INVESTIGATION OF THE XYLENE SOLUBLE ACIDIC FRACTION

A small amount of acid was always obtained by acidifying the alkaline extract of the xylene soluble residue. This acid was recrystallized from hot water. Its melting point (145-146°) showed it to be o-nitrobenzoic acid.

EXAMINATION OF THE NEUTRAL MATERIAL

Preliminary work showed that this material could be recrystallized from cellosolve. Fractional crystallization yielded three fractions. (A) a high melting fraction (m.p. 180-190°), (B) a fraction melting at 150-155°, (C) a low melting fraction (M.P. 125-145°).

Fraction (A) after two recrystallizations from cellosolve yielded a light yellow colored crystalline material (m.p. 193-194°). Fraction (B) was difficult to purify. After three to five recrystallizations from cellosolve it was obtained in a pure condition (m.p.157-157.5°). All attempts to isolate a low melting component from fraction (C) failed. This low melting fraction was submitted to an exhaustive series of fractional crystallizations; purification of any fraction yielded a product melting at 157° or at 194°. At every stage of the crystallization of fraction (C) mixed melting points were taken to determine the identity of these components with the two pure components found in fractions A and B. It was concluded that the neutral fraction contained a mixture of two compounds; compound (IX) (m.p. 193-194°) and compound (X) (m.p. 157-157.5°). Although it was not expedient to determine the exact ratio of these two compounds, it was shown that the neutral fraction consisted mainly of compound (X).

IDENTIFICATION OF THE NEUTRAL COMPOUND (IX)

This light yellow colored compound, on slow recrystallization from ninety-five percent ethyl alcohol formed long needle like crystals. It was insoluble in cold water, cold ten percent sodium hydroxide, and boiling 0.3N hydrochloric acid. It was slightly soluble in cold ethyl alcohol and cellosolve. When (IX) was warmed on the steam bath with 0.3N sodium hydroxide solution, it dissolved in the course of one hour. When this product dissolved, the solution became light yellow in color. Acidification of the yellow solution formed a white precipitate which after recrystallization from ninety-five percent alcohol melted at 233-235°. This white acid when mixed with synthetic (I) did not lower its melting point.

When the high melting acid (I) obtained synthetically or from the reductions was treated with an excess of thionyl chloride and the resulting mixture heated on the steam bath until the excess thionyl chloride evaporated there was left a light colored residue. This residue was recrystallized from cellosolve, (m.p. 193-194°) and has been shown by Schroeter[43] to be o-nitrobenzoylanthranil (III). Mixtures of (IX) and (III) were found to melt at 193-194°.

Combustion analyses were carried out on (IX).

Weight sample: 5.665 mg.   weight H_2O 1.625 mg. weight CO_2 12.917 mg.

3.969 mg.   weight H_2O 1.130 mg. weight CO_2 0.144 mg.

Calculated for $C_{14}H_8N_2O_4$ C. 62.7; H. 2.99. Found C. 62.2; H. 3.16

C. 62.8; H. 3.16

PRELIMINARY IDENTIFICATION OF THE LOW MELTING NEUTRAL
        COMPOUND (X)

This light yellow colored compound formed long needle-
like crystals from hot cellosolve. It was insoluble in water
and cold ten percent sodium hydroxide solution. When (X) was
heated with 0.3 N hydrochloric acid, concentrated hydrochloric
acid or with alcoholic hydrochloric acid it could be recovered
from the acetyl chloride unchanged.

A small portion of (X) when treated with 0.3 N sodium
hydroxide solution and carefully warmed on the steam bath was
found to go into solution. The resulting solution varied from
light brown to deep red in color depending upon the care used
in heating. Acidification of the solution and subsequent
cooling caused precipitation of an acid from the solution.
The solubility and appearance of this acid (XI) were in every
way identical with the acid (VI). The acid (XI) decomposed
around 180°.

Further work of the hydrolysis of (X) showed that the
acid (XI) was not the only hydrolysis product. A small amount
of (X) was added to a cold solution of one gram of analytical
potassium hydroxide dissolved in ten ml. of diethylene glycol.
The material (X) rapidly dissolved and the color of the

solution became dark red. This color disappeared in the course of a half hour. The clear solution was made acid to Congo red paper with dilute sulfuric acid. The added water was then evaporated in partial vacuum by heating on the steam bath. The material was protected from the air by surrounding the capillary with nitrogen. After evaporation of the water the diethylene glycol solution was extracted with several portions of ether. On evaporation of the ether in a stream of nitrogen a white crystalline material remained. This material decomposed when heated with water in the presence of air. A small sample was washed with water, carefully dried and melted at 85-86° (XII. (XII turns a dark red color at its melting point. It also turns to a dark red resinous material on standing in air.

Combustion analyses were carried out on (X) after the sample had been first recrystallized several times from cello-solve, then dissolved in ethyl alcohol and decolorized with Norite and then recrystallized twice from ethyl alcohol.

Nitrogen:

   (1) Temperature 27.3° Pressure 763 mm.

   Weight sample 3.774 mg. Volume of nitrogen 0.333 ml.

   (2) Temperature 26.8° Pressure 762 mm.

   Weight sample 3.788 mg. Volume of nitrogen 0.333 ml.

Calculated for $C_{21}H_{13}N_3O_7$ 10.02 found 10.07; 10.03.

Carbon-hydrogen:

Weight sample 4.461 mg. weight H_2O 1.229 mg. weight CO_2 9.813mg.

Weight sample 4.013 mg. weight H_2O 1.097 mg. weight CO_2 8.768mg.

Calculated for $C_{21}H_{13}N_3O_7$ H 3.10; C 60.1, found H 3.06; C 60.0

H 3.04; C 59.6

Molecular weight:

Constant was 40. The melting point of the camphor was 176.9°.

(1) Weight sample 0.387 mg. Weight camphor 5.363 mg.

M.P. lowering 8.1°.

(2) Weight sample 0.370 mg. Weight camphor 6.361 mg.

M.P. lowering 6.6°.

Calculated for $C_{21}H_{13}N_3O_7$ 419   found 356; 353.

An attempt to relate the acid (VI) with the neutral component
(X) was made.   The acid (VI) was treated with an excess of
thionyl chloride and the excess was removed by heating on the
steam bath, and the residue was boiled with dilute hydrochloric
acid, filtered and recrystallized from alcohol. The small
amount of material recovered after this treatment prevented
complete purification. The recrystallized material (m.p. 140-
144°) was not soluble in dilute alkali.

ATTEMPTED REDUCTION OF o-NITROBENZOYLANTHRANIL (IX)

3.35 grams of (IX), one hundred ml. of xylene, 0.88 gram
of two percent palladium-barium sulfate catalyst and 0.0175
gram of the quinoline-sulfur regulator were placed in the small
reducing flask. A stream of hydrogen was passed through the

flask for four hours. The temperature of the oil bath was 150°. No reduction of the compound (IX) took place for all of it was recovered.

PREPARATION OF DI-N-O-[o-NITROBENZOYL]p-AMINOPHENOL

p-Aminophenol (decomposed at 180°) was dissolved in an excess of ten percent sodium hydroxide solution and then treated with two equivalents of o-nitrobenzoyl chloride. A precipitate formed which was filtered, washed thoroughly with water, then ten percent sodium hydroxide solution and finally with concentrated hydrochloric acid. After recrystallization from cellosolve this material was obtained as a white crystalline solid (m.p. 189-190.5°).

PREPARATION OF m-NITROBENZOYL CHLORIDE

Twenty-seven grams of m-nitrobenzoic acid, contained in a two hundred ml. round-bottomed flask, was treated with an excess of thionyl chloride. An efficient condenser carrying a calcium chloride tube was attached to the flask and the mixture was gently heated on the steam bath for two hours. At the end of this time the acid was completely converted into the acid chloride which was left as a light yellow liquid. The condenser was replaced by an efficient distilling column and after removing the excess thionyl chloride by heating at atmospheric pressure, the m-nitrobenzoyl chloride was distilled in partial vacuum in an atmosphere of nitrogen. The flask was heated by means of an electrically heated oil bath and the

temperature of the oil bath was not allowed to go above 200°.
A water trap and a calcium chloride tower were placed between
the pump and the system during the distillation. The yield
was twenty-nine grams and represented ninety-eight percent of
the theoretical yield (b.p. 155°/10 mm.). For use in subsequent
reductions, this acid chloride was carefully redistilled and a
five gram forerun was discarded. The last five grams in the
flask was not included.

PREPARATION OF p-NITROBENZOYL CHLORIDE

p-Nitrobenzoic acid which had been prepared by the
oxidation of p-nitrotoluene according to the directions in
Organic Syntheses[15] was treated with an excess of thionyl
chloride and the acid chloride prepared and distilled in the
same manner as the corresponding meta compound. The p-nitro-
benzoyl chloride was obtained as a lemon yellow colored
solid (b.p. 152°/17 mm.). The yield obtained was ninety-two
percent.

p-Nitrobenzoyl chloride was also made by treating the
acid with phosphorus pentachloride according to the method
of Organic Syntheses[16]. The yield obtained was ninety-one
percent. The first portion of the distillate which contained
some phosphorus oxychloride was discarded.

REDUCTION OF p-NITROBENZOYL CHLORIDE TO p-NITROBENZALDEHYDE

For use in catalytic reduction the p-nitrobenzoyl
chloride, prepared by using thionyl chloride, was redistilled

and twice recrystallized from petroleum ether. The acid chloride was then dried in a vacuum at the temperature of boiling ether until there was no further loss in weight.

Five and six-tenths grams of this purified p-nitrobenzoyl chloride, 0.88 gm. of two percent palladium-barium sulfate catalyst and thirty ml. of xylene were placed in the small reducing flask. The temperature of the oil bath was 150°. Eighty-seven percent of the calculated amount of hydrogen chloride was collected in three hours. The resulting mixture was cooled in an atmosphere of nitrogen and after filtering from the catalyst the xylene was tested for the presence of aldehyde. The solution gave a positive test for aldehydes with Schiff's reagent and with 2,4-dinitrophenylhydrazine. The xylene was evaporated in the usual manner and after evaporation a light yellow colored solid residue was obtained. This solid was washed with a small amount of cold ether and then it was dried in air. The crude material (m.p. 105°) which weighed 3.6-3.75 grams represented seventy-nine to eighty-two percent of the theoretical amount. The crude material could be recrystallized from hot water (m.p. 106°).

Reduction of the acid chloride which had not been recrystallized gave only sixty-seven percent yields. Reduction under the same conditions as above on p-nitrobenzoyl chloride prepared by the use of phosphorus pentachloride would not proceed at all, in spite of the fact that no poison was

used and that fresh catalyst was used. p-Nitrobenzoyl chloride (Eastman Kodak Co.) which had not been further purified would not reduce under the same conditions. This same acid chloride, if recrystallized twice from petroleum ether could be reduced to ninety percent completion in three hours.

PREPARATION OF m-NITROBENZALDEHYDE

5.6 grams of m-nitrobenzoyl chloride, 0.88 gram of palladium-barium sulfate catalyst, thirty ml. of xylene were placed in the small reduction flask. The temperature of the bath was 150°. The reduction required four to five hours. At the end of two hours an additional 0.88 gram of catalyst was added; eighty-five to ninety percent of the theoretical amount of hydrogen chloride was collected in three to five hours. The mixture was cooled in an atmosphere of nitrogen and the xylene evaporated in the same way it was evaporated in the preparation of p-nitrobenzaldehyde. A liquid residue which solidified when cooled in an ice bath was obtained by evaporation of the xylene. The m-nitrobenzaldehyde contained in this residue was obtained in a crude form by recrystallization of the residue from ether. The weight of the crude product (m.p. 50-53°) was three grams. This amount represents sixty-six percent of the theoretical amount.

In another reduction under conditions identical with those described above, the entire residue obtained from the xylene evaporation was treated with an excess of 2,4 dinitrophenylhydrazine according to the method described in Schriner

and Fuson[41]. The weight of the 2,4 dinitrophenylhydrazone formed was six grams. This represents a sixty-six percent yield of m-nitrobenzaldehyde. The 2,4 dinitrophenylhydrazone decomposed at 293°. This corresponds to the value given in Schriner and Fuson[41]. Less recent books list the decomposition temperature as 168°. This value was further confirmed by preparing the 2,4 dinitrophenylhydrazone of known (Eastman Kodak Co.) m-nitrobenzaldehyde (decomposed at 293°).

The phenylhydrazones of the aldehyde formed in the reduction of m-nitrobenzoyl chloride and known m-nitrobenzaldehyde were made. Both melted at $125-126^{o}$. This value is not in agreement with the value (m.p. 120°) found in most books.

All attempts to increase the yield of m-nitrobenzaldehyde by fractional crystallization or redistillation of the m-nitrobenzoyl chloride, by the use of fresh catalyst or by the use of xylene which had been washed six times with concentrated sulfuric acid failed.

UNSUCCESSFUL ATTEMPTS TO PREPARE N-SUBSTITUTED ANTHRANOYL CHLORIDES

(I) N-benzoylanthranilic acid was prepared by dissolving 27.4 grams (0.2 mol.) of anthranilic acid in one hundred ml. of twenty percent sodium hydroxide solution, and adding 28.1 grams of benzoyl chloride dropwise. The solution was mechanically stirred until the odor of benzoyl chloride could

no longer be noticed. The mixture was made acid to Congo red paper with hydrochloric acid and the acid which was precipitated was recrystallized from alcohol and water. Treatment of the N-benzoylanthranilic acid with thionyl chloride gave a quantitative yield of benzoyl anthranil (m.p. 122°). No acid chloride was obtained.

(II) N-methyl-N-benzoylanthranoyl chloride

Ten grams of N-methylanthranilic acid (prepared by the addition of dimethyl sulfate to a sodium carbonate solution of anthranilic acid) was dissolved in fifty ml. of fifteen percent sodium hydroxide solution. While being stirred mechanically the mixture was treated with 9.3 grams of benzoyl chloride. Acidification produced a light yellow colored viscous liquid. Only after complete drying did this substance become solid. It was then recrystallized from dry benzene (m.p. 161°). All attempts to prepare the acid chloride of this acid by treatment with an excess of thionyl chloride led to the formation of an amorphous compound which could not be recrystallized. No acid chloride was obtained.

SUMMARY

1)   Catalytic reductions have been carried out on ortho, meta and para nitrobenzoyl chlorides.

2)   The catalytic reduction of o-nitrobenzoyl chloride selectively reduces the nitro group in preference to the acid chloride group. o-Nitrobenzoylanthranilic acid (I) and o-nitrobenzoylanthranil (III) have been identified as products of this reduction. Two other products of the reduction(1) an acid which decomposes at 180° (VI) and (2) a neutral compound (X) (m.p. 157-157.5) have been related but not yet identified.

3)   N-o-nitrobenzoyl-O-o-nitrobenzoyl-p-aminophenol has been prepared (m.p. 189-190.5°) and has been shown not to be identical to the unidentified neutral compound (X).

4)   p-Nitrobenzaldehyde has been prepared in eighty percent yields by reduction of the acid chloride using the palladium-barium sulfate catalyst in the absence of quinoline-sulfur regulator.

5)   It has been shown that m-nitrobenzaldehyde can be prepared by the catalytic reduction of m-nitrobenzoyl chloride, using two percent palladium-barium catalyst in the absence of quinoline-sulfur regulator.
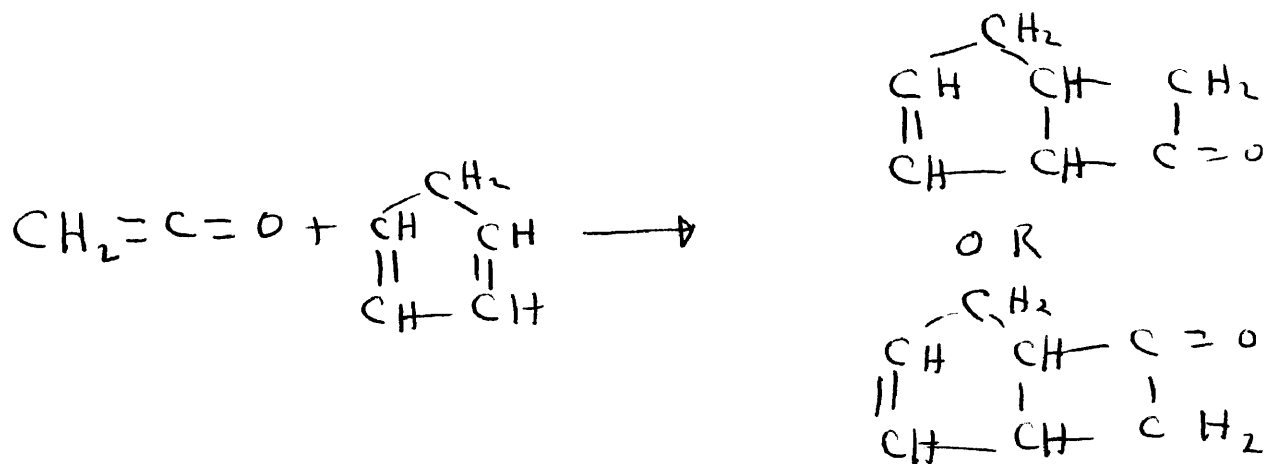
PART II

INTRODUCTION

The so-called "Diels Alder" reaction or "Diene Synthesis" was first discovered by Diels in 1928, when he found that cyclopentadiene would undergo addition to quinone[7]. The reaction consists essentially of the 1,4-addition of a system containing two conjugated double bonds. The addition of butadiene to maleic anhydride is a good example.
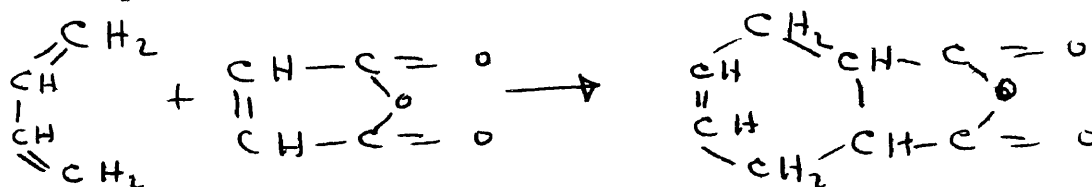
Ketene written $CH_2=C=O$ belongs to the 1,2 dienoid system $X=Y=Z$[17]. In the active form of ketene the oxygen tends to withdraw an electron pair between the link $C=O$, thereby making the center carbon atom in $CH_2=C=O$ an acceptor center and the oxygen a donor center. Thus the addition of most substances takes place on the 1,2 positions. However, it is conceivable that 2,3 addition according to the following scheme[17].
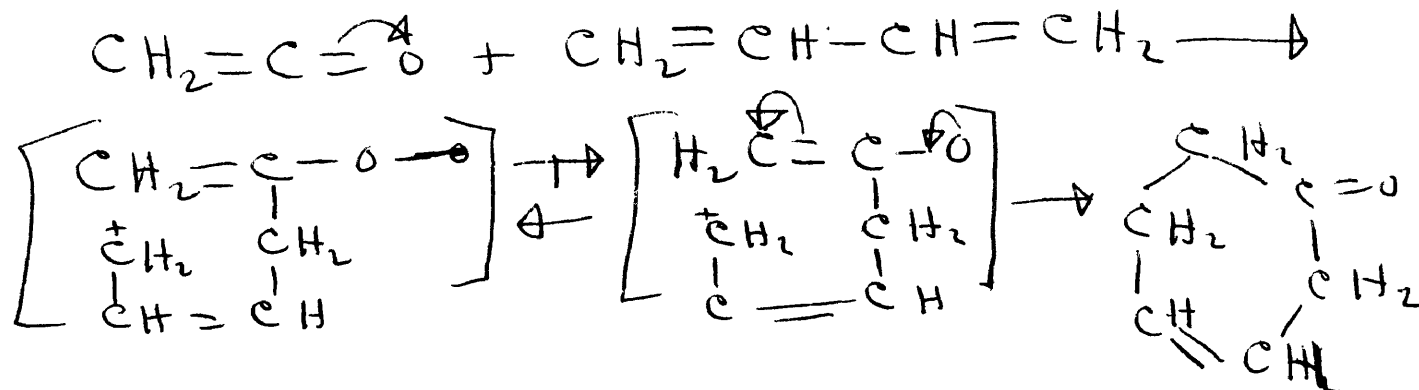
Several attempts have been made to make the carbon to carbon double bond in ketene undergo 1,4-addition to a system of conjugated double bonds. Only recently has ketene been induced to react with double bond systems. The reaction was carried out by dissolving ketene and cyclopentadiene in toluene and heating to 100° under pressure for one hour[4]. The expected 1,4-addition to the diene did not take place but in its place 1,2-addition to the double bond resulted.

$$CH_2 = C = O \ + \ \begin{array}{c} CH_2 \\ CH \quad CH \\ \| \quad \| \\ CH - CH \end{array} \longrightarrow$$

$$\begin{array}{c} CH_2 \\ CH \quad CH - CH_2 \\ \| \quad | \quad | \\ CH - CH - C = O \end{array}$$

$$OR$$

$$\begin{array}{c} CH_2 \\ CH \quad CH - C = O \\ \| \quad | \quad | \\ CH - CH - CH_2 \end{array}$$

The object of this investigation was to see if ketene could be made to undergo 1,4-addition to a system of two conjugated double bonds by reacting in the gaseous phase with or without the aid of a catalyst.

DESCRIPTION OF APPARATUS

The apparatus which was finally worked out to test the
reaction between ketene and butadiene is shown in fig. 3.
The ketene was prepared in a generator described by Williams[45].
It was first passed through trap #1 which was cooled to a
temperature of -30°. by means of a dry-ice alcohol bath.
The three way stopcock #4 made it possible to direct the
ketene either into the system or into the traps #2. These
traps each held 200 ml. of water and were used to determine
the rate of flow of ketene by titration of the acetic acid
formed. While the ketene was being introduced into the
standardization traps #2 the rate of flow of butadiene
through the flowmeter #6 was brought to a desired rate.
Butadiene was allowed to pass into the air by means of the
three way stopcock #5. When the standardization was
complete, cocks #4 and #5 were simultaneously turned so
that both ketene and butadiene were brought into the
mixing chamber #3. At this moment timing was begun. The
mixed gases passed from the mixing chamber into the furnace.
If any reaction products formed they were caught in the
trap #8. This trap was cooled in an ice bath. The
unreacted gases then passed through traps #9, each of which
contained 200 ml. of water and served to absorb the un-
reacted ketene. The butadiene was caught in the trap #10.
This trap was surrounded by a thermos bottle containing

alcohol cooled to -78° by dry ice.

After the gases had been allowed to flow for ten minutes they were cut off and the entire apparatus was swept for fifteen minutes with nitrogen. It has previously been determined that this time was sufficient to purge the apparatus of reagents or reaction products.

The unreacted ketene was determined by titration of the acetic acid formed using standard alkali. The amount of butadiene which passed through the system was determined in an indirect way. Since butadiene is a gas at ordinary temperatures it was possible to determine the weight of gas passing through the flowmeter by calibration of the difference in level in terms of the volume passed per unit of time. The butadiene was then passed through the meter and through the system under conditions identical to those during an actual run except for the temperature of the furnace. At the end of ten minutes the flow was stopped and the system was swept with nitrogen for fifteen minutes. At the end of this time the volume of liquid butadiene (at -78°) in trap #10 was quickly read. This procedure was repeated at several different rates of flow and by this procedure the rate of butadiene flow was found in terms of the volume of liquid butadiene collected in the trap.

The furnace tube was removable and consisted of a length of 20 mm. pyrex tubing. It was attached to the system by means of standard taper ground glass joints.
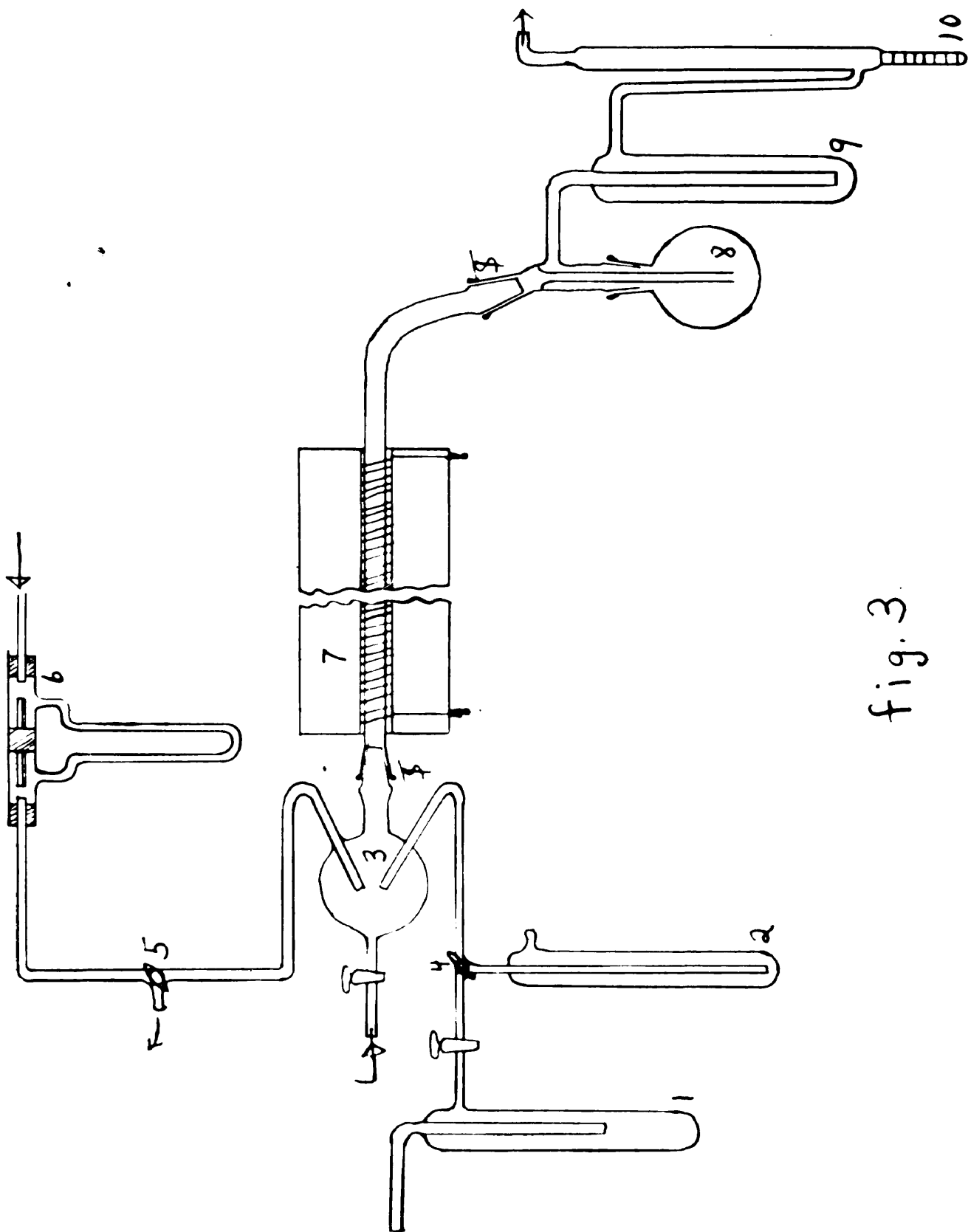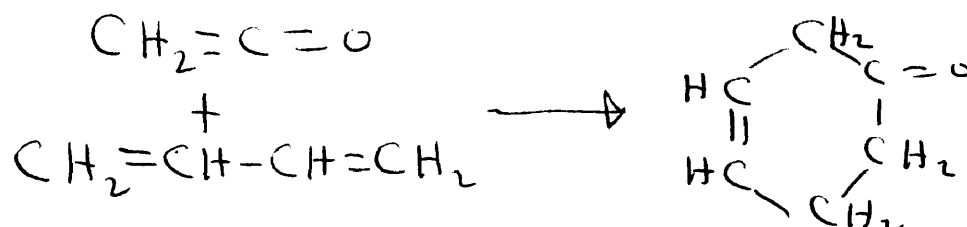
fig. 3

DISCUSSION

Since 1,3 butadiene is a gas at ordinary temperatures
and yet is easily liquified it was chosen as the conjugated
diene to be used in this study. A tank of this gas was
very kindly furnished to the author by the Carbide and
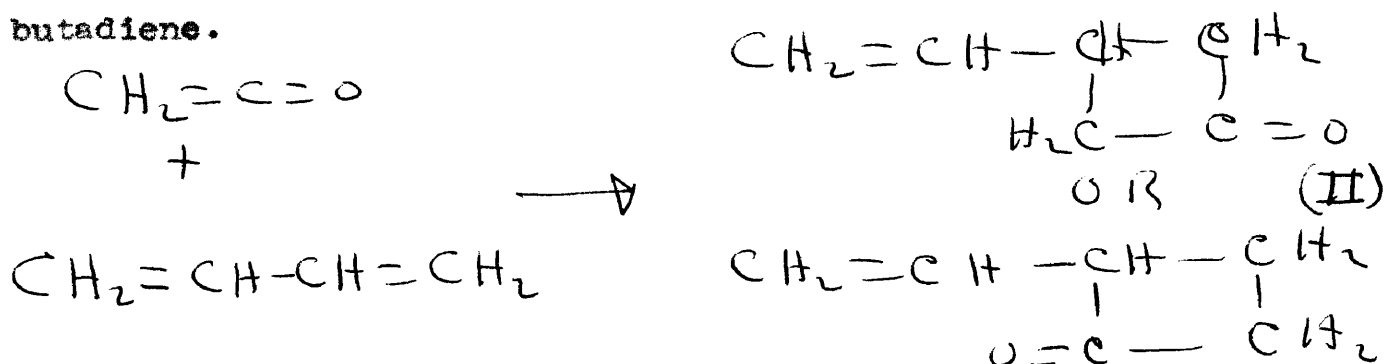Carbon Chemicals Corporation.

The difficulties, technical and otherwise, encountered
in this investigation of ketene were manifold. The problem
resolved itself into (1) the preparation and maintenance of
a steady flow of ketene, (2) the determination of the rate
of flow of ketene, (3) the simultaneous introduction of
known amounts of butadiene and ketene into the reaction
furnace whose temperature was known, (4) the separation
and analysis of possible reaction products and unreacted
ketene and butadiene.

Due to variations in temperature and voltage, etc.,
the rate of flow of ketene was never exactly constant;
however, the fluctuation was brought within a range that
would allow a fairly accurate determination of the ketene
being produced.

If ketene were to react with butadiene in a Diels
Alder addition cyclohexene-3-one (I) would result

$$CH_2=C=O$$
$$+$$
$$CH_2=CH-CH=CH_2 \longrightarrow$$

$$\begin{array}{c} HC \overset{CH_2}{\diagup} \diagdown \\ \quad \quad \quad C=O \\ HC \qquad CH_2 \\ \diagdown CH_2 \diagup \end{array}$$

No such product was ever found in any of the reactions.
Neither was any compound of the type (II) found. Such
a substance would result from 1,2 addition of ketene to
butadiene.

$$CH_2=C=O$$
$$+$$
$$CH_2=CH-CH=CH_2$$

$$\longrightarrow$$

$$CH_2=CH-CH-CH_2$$
$$H_2C-C=O$$
$$OR \qquad (II)$$

$$CH_2=CH-CH-CH_2$$
$$O=C-CH_2$$

It should be clearly pointed out that the possibilities
of this reaction have by no means been exhausted. It can
only be said that the results of experiments that were
carried out indicated that no addition had taken place when
ketene and butadiene were heated together in the presence
of pyrex glass, clay plate, Filtros, reduced copper on clay
plate or Filtros, or copper chromite on clay plate.

The greatest criticism of this work is that not enough
catalysts were tried nor was the amounts of material employed
sufficiently large. The small quantities of materials which
were allowed to come into mutual contact was made necessary
by the size and construction of the apparatus as well as
the limit of the quantity of starting material. Qualitative
runs were made in which the reaction time was at least an
hour. In none of these runs were any reactants of the
desired type ever found.

The structure of diketene has long been a subject of investigation. The most recent evidence has been submitted by Calvin, Magel and Hurd[5]. The evidence which they present favors the -crotonolactone formula with the condition of easy transformation into acetyl ketene.

$$CH_3-\overset{|}{\underset{O\text{————}}{C}} = CH - C = O \longrightarrow CH_3\overset{\overset{O}{\parallel}}{C} - CH = C = O$$
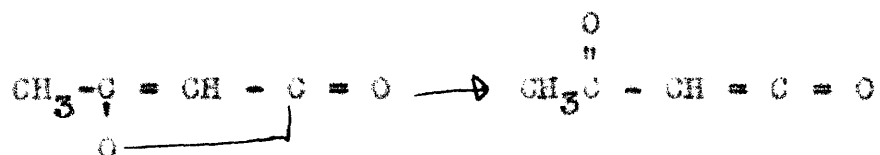
It was hoped that some light might be thrown upon the structure of diketene if it could be made to undergo a 1,4 addition to a conjugated diene. The diene chosen for the reaction was 2,3 dimethylbutadiene 1,3. A sealed tube reaction between these two components failed to produce any addition compound.

Ketene acetal has been shown by McIlvain to undergo a Diels Alder type of reaction with maleic anhydride[6]; two products are produced.
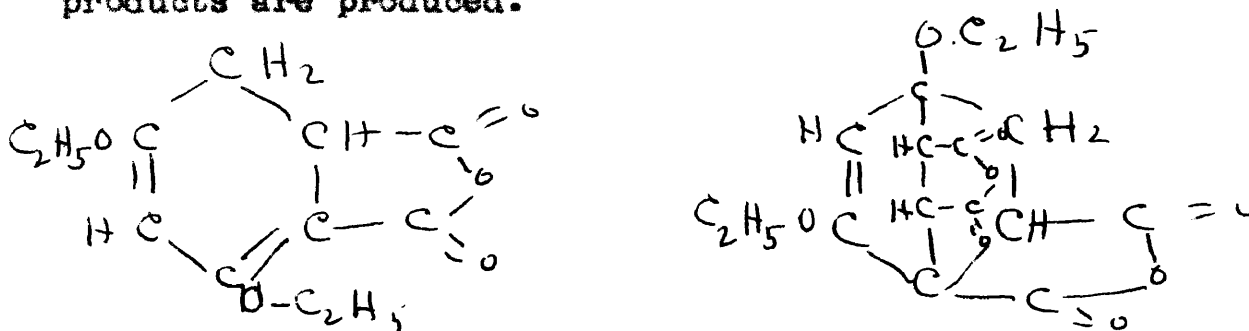
In forming these compounds two molecules of ketene acetal have come together to make up the conjugated diene system. In the light of this information one would not expect a conjugated system of two double bonds to add to the double bond of ketene acetal. This expectation was borne out by the failure of ketene acetal to react with 2,3-dimethyl-1, 3 butadiene.

EXPERIMENTAL

Attempted reaction of butadiene (2,3) and ketene

In this series of experiments the tube was filled with 1 cm. lengths of 4 mm. pyrex glass rod. The results are summarized in Table 2.

I. Attempted reaction of ketene with butadiene, using various tube filings.

    1) Alumina

        This series of experiments was identical with those above except that the furnace tube was filled with 8 mesh activated alumina. No reaction products were obtained. At all temperatures from room temperature to 400° ketene was quantitatively decomposed by the alumina. None was recovered as acetic acid. At temperatures around 400° butadiene was partially polymerized by alumina to a liquid hydrocarbon. At all other temperatures it was quantitatively recovered.

TABLE II

Run	Mol.of Ketene In	Mol. of Ketene Out	Mol. of Butadiene		Temp. Furnace	Result
			In	Out		
1	.035	.030	.034	.035	100	-
2	.033	.028	.034	.034	100	-
3	.038	.029	.036	.044	200	-
4	.037	.031	.034	.034	200	-
5	.038	.033	.034	.035	200	-
6	.040	.038	.033	.033-	315	-
7	.041	.031	.033	.033-	425	-
8	Not calculated				above 500	-

2) Filtros and Clay plate

In an attempt to find a carrier which would not decompose the ketene or the butadiene, clay plate and Filtros were investigated. When either one was used as a filler for the furnace the butadiene could be quantitatively recovered except at temperatures above 400°. Both of these materials brought about considerable decomposition of the ketene at temperatures above 100°.

3) Copper on filtros, copper on clay plate, nickel chromite on clay plate

In an attempt to catalyze the reaction between butadiene and ketene the furnace tube was filled with various catalysts. The following were used: reduced copper on filtros and reduced copper on clay plate, nickel chromite on clay plate. None of these brought about any reaction. The recovery of the butadiene in every case was quantitative. Considerable ketene was lost because of decomposition.

II. Attempted reaction of diketene and 2,3 dimethylbuta-
diene (1,3)

A quantity of pinacol hydrate prepared according to Organic Synthesis[24] was dehydrated by azeotropic distillation using benzene. The anhydrous pinacol was distilled and converted into 2,3 dimethylbutadiene by catalytic dehydration

using activated alumina according to the method of Fieser[10]. The diene was obtained in eighty percent yields; its boiling point was 69-70°.

Diketene was prepared according to the method of Organic Syntheses[9].

Experiment 1

Equimolar amounts of diketene and 2,3 dimethylbutadiene were placed in a flask equipped with a condenser. The mixture was heated on the steam bath under gentle reflux for two days. The solution turned reddish colored due to the further polymerization of diketene. The diene was recovered unreacted.

Experiment 2

Equimolar amounts of diketene and 2,3 dimethylbutadiene were placed in a pyrex tube. The tube was sealed and heated at 170-200° for ten hours. At the end of this time the tube was opened and the contents examined. Considerable decomposition had taken place. The mixture was black in color and very viscous. This viscous mixture was distilled and the following products were identified. (1) Dehydro-acetic acid (m.p. 108-109°; (2) the dimer of 2,3 dimethyl-1, 3 butadiene. The boiling point found in the literature for this compound was listed as 95° at seventeen mm. of mercury. The boiling point found was 87-89° at seventeen mm. pressure. The refractive index corresponded more closely to the value

in the literature, n_D^{20} 1.4815. The value found was n_D^{20} 1.4814; (3) a small amount of butadiene polymer (b.p. 58°/3 mm.).

ATTEMPTED REACTION BETWEEN KETENE DIETHYLACETAL AND 2,3 DI-ETHYL-1,3 BUTADIENE

Ketene diethylacetal was prepared from bromoacetal by treating it with potassium tertiary butoxide. The bromo-acetal was prepared by treating vinyl acetate with bromine in the presence of absolute ethyl alcohol. These preparations have been described by McIlvain[21].

Equimolar amounts of ketene diethylacetal and 2,3 dimethylbutadiene were placed in a pyrex tube. The tube was sealed and then heated at 170-200° for six hours. Ketene diethylacetal, polymers of ketene diethylacetal and the dimer of 2,3 dimethylbutadiene were identified in the reaction mixture. No addition products were found.

SUMMARY

1) Ketene and butadiene will not react in the gaseous phase at temperatures between 100-500°.

2) Filtros, clay plate, nickel chromite on clay plate, or reduced copper on filtros or clay plate will not catalyze a reaction between ketene and butadiene.

3) Activated alumina will quantitatively decompose ketene at all temperatures between 25-400°.

4) Equimolar amounts of diketene and 2,3 dimethylbutadiene heated in a sealed tube were not found to undergo a Diels-Alder addition.

5) Equimolar amounts of ketene diethylacetal and 2,3 dimethylbutadiene heated in a sealed tube for six hours at 170-200° were not found to undergo a Diels-Alder addition.

BIBLIOGRAPHY

1. Abel, E. Catalysis and specifically acting catalyzers. Remarks on the work of Rosenmund and Zetzsche. Ber. 54, 28685-8 (1921).

2. Anschutz, R. and H. Boedeker. Is the chloride of anthranilic acid capable of existence? Ber. 62, 826-30 (1929).

3. Bamberger, E. and J. Lagutt. The reaction of phenylhydroxy-lamines with alcoholic sulfuric acid. Ber. 31, 1500-8 (1898).

4. Brooks, B. T. and G. Gilbert. The reaction of cyclopenta-diene and ketene. J. Am. Chem. Soc. 63, 870 (1941).

5. Calvin, M., T. Magel and C. Hurd. The structure of diketene from spectroscopic evidence. J. Am. Chem. Soc. 63, 2174-77 (1941).

6. Cohen, H. and S. M. McElvain. The reaction of ketene acetal with maleic anhydride. Abstract of papers presented to the American Chemical Society, St. Louis, April, 1941.

7. Diels, O. and K. Alder. Syntheses in the hydroaromatic series. Ann. der Chemie 460, 98-122 (1928).

8. Drake, N. L. Organic Syntheses. (John Wiley and Sons, Inc. New York, 1941), vol. 21 p. 84.

9. Ibid, p. 64.

10. Fieser, L. F., Unpublished work. Harvard University.

11. Fieser, L. F. and E. Hershberg. Use of hydrogen fluoride in acylations and cyclizations. J. Am. Chem. Soc. 62, 49-53 (1940).

12. Friedlander, P. About o-aminobenzaldehyde. Ber. 15, 2572-5 (1882).

13. Fröschl, N. Catalytic reduction of acid chlorides in vapor phase at atmospheric pressure. J. Prakt. Chem. 144, 217-24 (1936).

14. Getman, F. and F. Daniels. Outlines of theoretical chemistry. (John Wiley and Sons, Inc. New York, 1937) p. 344.

15. Gilman, Henry. Organic Syntheses. (John Wiley and Sons, Inc., New York 1941) Coll. vol. p. 392.

16. Ibid, p. 394.

17. Gilman, Henry. Organic Chemistry (John Wiley & Sons, Inc. New York 1939) Vol. II p. 1681.

18. Grignard, V. Reduction of acid chlorides under pressure. Method for preparing aldehydes. Compt. rend. 185, 1173-6 (1927).

19. Hershberg, E. A new type of stirrer. Ind. Eng. Chem. Anal. Ed. 8, 313 (1936).

20. Houben, J. and W. Brassert. Alkylation and arylation of anthranilic acid. Ber. 39, 3233 (1906).

21. Johnson, P., H. Barnes and S. M. McIlvain. Ketene acetals. IV Polymers of ketene diethylacetal. J. Am. Chem. Soc. 62, 964-72 (1940).

22. Kelber, C. The catalytic hydrogenation of organic compounds with non-noble metals at room temperature. Ber. 50, 305-10 (1917).

23. Langmuir, I. J. Am. Chem. Soc. 38, 222 (1916); 39, 1848 (1917); 40, 1361 (1918).

24. Marvel, C. S. Organic Syntheses. (John Wiley and Sons, Inc. New York 1925) Vol. V, p. 87.

25. Pawlewski, Br. The stability of anthranilic acid. Ber. 37, 592-6 (1904).

26. Rosenmund, K. W. A new method for the preparation of aldehydes. Ber. 51, 585-93 (1918).

27. Rosenmund, K. W. and F. Zetzsche. A new method for the preparation of aldehydes. II Synthesis of gallaldehyde. Ber. 51, 594-602 (1918).

28. _____ _____ Catalytic influence and specific acting catalysts. Ber. 54, 425-37 (1921).

29. _____ _____ Catalytic reduction of organic halogen compounds. Ber. 51, 578-85 (1918).

30. _____ F. Reise. The influence on the activity of catalysts. II The reduction of acid chlorides to alcohol and esters. Ber. 54, 638-47 (1921).

31. _____ and F. Zetzsche. The influence of the activity of catalysts V. The catalytic reduction of esters and aldehydes. Ber. 54, 2038-42 (1921).

32. _____ Reply to Schliewiensky. Z. angew. Chem.
      35, 483 (1922).

33. _____ The preparation of aldehydes from acid
      chlorides. V. F. Zetzsche and F. Engerlin. Dialdehydes
      II. The synthesis of Decandials. Ber. 55, 609-12 (1922).

34. _____ The preparation of aldehydes from acid
      chlorides. I dialdehydes. Ber 54, 2888-93 (1921).

35. _____ The catalytic reduction of acid chlorides VI.
      The preparation of unsaturated aldehydes. Ber. 56,
      1481-87 (1923).

36. _____ and G. Langer. The influence of carriers on
      the activity of catalysts. Ber. 56, 2262-64 (1923).

37. Rosenmund, K. W. and F. Zetzsche. The influence of
      catalysts and catalysts with specific action. Reply
      to E. Abel. Ber. 54, 2885-8 (1921).

38. Ruggli, P. and O. Schmid. Indoles and isatogens.
      Helvetica chim. Acta. 18, 1215-28 (1935).

39. Schliewiensky, H. Reductions of acid chlorides to
      aldehydes by nickel catalysts. Z. angew. Chem. 35, 483.

40. Schmidt, E. On the constitution of tetranitromethane.
      Ber. 52, 409 (1919).

41. Schriner, R. and R. Fuson. The systematic identification
      of organic compounds. (John Wiley and Sons, Inc. New
      York, 1940) p. 143.

42. Schroeter, G. Di-molecular anhydrides of anthranilic
      acid. Ber. 40, 1610-21 (1907).

43. _____ and O. Eisleb. Di-molecular anhydrides of
      anthranilic acid. Ann. 367, 101-68.

44. Taylor, H. A treatise on physical chemistry. (D. Van
      Nostrand Co., Inc. New York 1936) p. 1986.

45. Williams, J. and C. D. Hurd. Apparatus for the
      preparation of ketene and butadiene. J. Org. Chem. 5,
      122-5 (1940).

46. Zetzsche, F. and O. Arnd. Influence of phosphorus
      oxychloride on the catalytic reduction of acid chlorides.
      Helvetica Chim. Acta. 8, 591-6 (1925).

47. _____ . The catalytic reduction of several acid
      chlorides. Helvetica Chim. Acta. 9, 182-5 (1926).