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# Rearrangements in the furan series

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**REARRANGEMENTS IN THE FURAN SERIES**

**By**

**Raymond A. Franz**

4/15/36

**A Thesis Submitted to the Graduate Faculty  
for the Degree of**

**DOCTOR OF PHILOSOPHY**

**Major Subject Organic Chemistry**

**Approved:**

Signature was redacted for privacy.

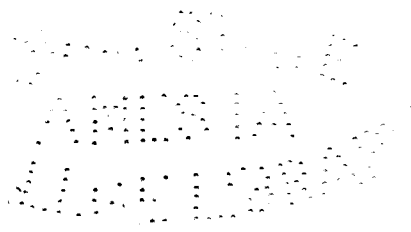
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**1936**

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## INTRODUCTION

For many years the instability of compounds in the furan series has been a challenging factor. Not only has this characteristic served to confound many investigators, but has seriously retarded this branch of organic chemistry. In recent years, however, a new and increasingly successful technique has been developing.

As an outgrowth of this phenomenon, the problem has naturally arisen as to the mechanism by which the decomposition has taken place and to the probable structure of the decomposition product. It is the purpose of this thesis to shed some light on this problem. In particular, investigations have been carried out on halogen substituted furylaryl carbinols and their subsequent decomposition products formed by the loss of halogen acids. Incidental to this, an additional proof of structure was developed for Hill's dibromo- and dichloro-furoic acids.

## HISTORICAL

Since the discovery of the Grignard reagent in 1900, the chemist has had access to one of the most useful tools of synthetic chemistry, especially in the preparation of secondary and tertiary furyl alcohols. Although the first compound of this nature was prepared by the action of diethylzinc on furfural (1), the earliest attempt using an alkylmagnesium halide was made by Victor Grignard (2) in synthesizing furylisoamylcarbinol.

Hale, McNally, and Pater (3) stated that furfural did not react with phenylmagnesium bromide nor benzylmagnesium chloride to give the expected secondary alcohols, but only the coupling products, diphenyl and dibenzyl. They found, however, that the Grignard reagent reacted smoothly with esters of furfuroic acid giving the tertiary alcohols in good yields. It was also noted that these carbinols were very sensitive to mineral acids, and even on standing for a short time diphenylfurylcarbinol gradually melted into a gummy mass, acquiring simultaneously a dark red color. Nothing further was done with these resinous substances.

(1) Pawlinoff and Wagner, Ber., 17, 1967 (1884).

(2) Grignard, Ann. de l'Univ. de Lyon., 6, 1 (1901). Chem. Zentr., 5, 622 (1901)/.

(3) Hale, McNally, and Pater, Am. Chem. J., 35, 68 (1906).

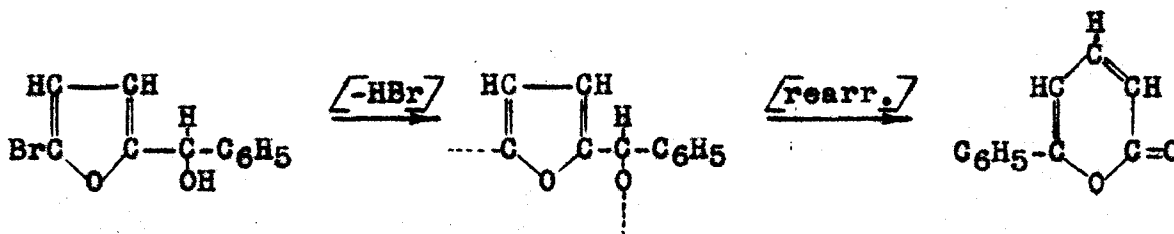
Since these early experiments, there have been reported several successful preparations of secondary and tertiary furylcarbinols by use of the Grignard reagent on corresponding derivatives of furan. Douris (4) prepared ethylfurylcarbinol from ethylmagnesium bromide and furfural. Other secondary furylcarbinols have been reported (5). Peters and Fischer (6) prepared 2-furylphenylcarbinol which Hale had failed to make. Maxim and Popesco (7) have recently prepared many tertiary furylcarbinols by the action of the Grignard reagent on aryl-furyl ketones. Paul (8) has given a few suggestions for increasing the yield of furylphenylcarbinol.

The reaction which serves as a basis for the work found in this thesis was discovered by Hewlett (9), who was attempting to prepare (5-chloro-2-furyl)phenylcarbinol and the corresponding bromo compound, by the action of phenylmagnesium bromide on 5-chloro-2-furfural and 5-bromo-2-furfural. The particular technique used in performing the experiment was directly re-

- (4) Douris, Compt. rend., 157, 722 (1913).  
(5) Pierce and Adams, J. Am. Chem. Soc., 47, 1098 (1925);  
Yavorski, Ber., 42, 435 (1909); Jolkver, Rec. trav. chim.,  
28, 439 (1909); Mahood and Jordan, Science, 60, 435 (1924).  
(6) Peters and Fischer, J. Am. Chem. Soc., 52, 2079 (1930).  
(7) Maxim and Popesco, Bul. soc. chim. Romania, 16, 89 (1934).  
C.A., 39, 4355 (1935).  
(8) Paul, Compt. rend., 202, 1444 (1936).  
(9) A. P. Hewlett, Thesis, "Furfural and some of its Derivatives", Iowa State College, p.83, (1930); Iowa State Coll. J. Sci., 6, 439 (1932).

sponsible for the results obtained. A discussion of these will be found later in this thesis. The two products which Hewlett isolated were both white solids with definite melting points, and were both called carbinols. The products contained halogens and were analyzed for them. The most unusual behavior of these two so-called carbinols was the loss of a halogen acid to form a new stable product. This substance, melting at  $86^{\circ}$ , was obtained as a decomposition product from both the chloro- and bromo-carbinols, being entirely devoid of halogens.

Several years later, Wright (10) repeated the work of Hewlett with identical results. His investigation of the decomposition material showed that it could not be 5-phenyl-2-furfural as a possibility of 1,4-addition, hence a further suggestion was offered that it might be an alpha-pyrone, thus

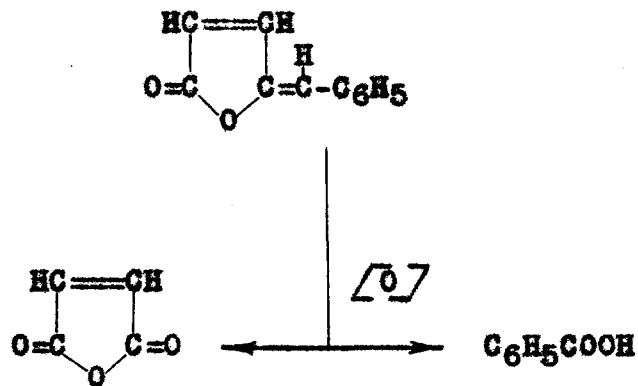


No proof of structure, however, was given at that time.

At a more recent date (10a) it was established in some unpub-

(10) G. F. Wright, Thesis, "Furfural and some of its Derivatives" Iowa State College, p. 62 (1932).  
(10a) Unpublished work, Iowa State College, 1936.

lished work of Wright's, that the final decomposition product, melting at  $86^{\circ}$ , on reduction with hydriodic acid in a sealed tube, yielded delta-phenyllevulinic acid, identified by its semicarbazone. It was also stated that the oxidation of the product melting at  $86^{\circ}$  with chromic oxide, gave benzoic acid and maleic anhydride. This work was not repeated by Wright and many attempts of the author to obtain maleic anhydride have failed. If correct, however, it would be excellent evidence for the following structure,



## DISCUSSION

In order to avoid confusion, the work will be discussed following the natural sequence in which it unfolded, each step apparently leading to a more promising development of the problem, until an assembly of facts warranted several theories as to the mechanisms involved.

The work of Hewlett was repeated in preparing the so-called (5-chloro-2-furyl)phenylcarbinol, care being centered on experimental details. The results were identical with his and those of Wright's. It was noticed, however, that the extreme instability of these products depended to a great extent on the absence of acids, moisture, or any reagent tending to bring about hydrolysis. If great care and speed were not exercised in crystallizing these materials, one frequently obtained the final, stable, and halogen-free decomposition product, m.p. 86°.

One of the details was the hydrolysis of the Grignard-complex with dilute acetic acid, followed by a steam distillation of the ether layer. The key to the whole problem depended on this step. After most of the ether had been distilled, there was a pronounced, yet slight darkening of the remaining oil, a fact which indicated that a distinct change had taken place. Some doubt then existed as to the validity of calling this unstable product, thus obtained, a carbinol. A Zerewitinoff analysis on this intermediate, m.p. 114.5°, soon proved that no



active hydrogen existed, thus confirming the suspicion that no carbinol had resulted.

In view of these facts it seemed advisable to run Zerewitinoff analyses on several furylcarbinols, such as furfuryl-alcohol, phenylfurylcarbinol and diphenylfurylcarbinol. All of these showed approximately one active hydrogen to be present. Also the product prepared by Hale and co-workers (3) from ethyl dehydromucate and phenylmagnesium bromide gave two equivalents of methane. The corresponding dicarbinol from methylmagnesium iodide was synthesized and likewise gave analyses for two active hydrogens. In every case, the normal carbinol was obtained as would have been expected. This led to the conclusion that either 5-chloro-2-furfural reacted normally, followed by some further reaction due to the steam distillation, or that it pursued an abnormal course with the Grignard reagent. The former being the simpler and more plausible explanation was further investigated.

Since the (5-chloro-2-furyl)phenylcarbinol, if first formed, would have been extremely sensitive toward heat, purification by vacuum distillation was entirely out of the question. Thus purification by any method having been eliminated, the only alternative left was direct preparation in *n*-butyl ether instead of the customary diethyl ether. After the phenylmagnesium bromide was prepared and the 5-chloro-2-furfural added to

it, the mixture was hydrolyzed with iced ammonium chloride solution. The n-butyl ether layer was dried with definite amounts of anhydrous sodium sulfate and sodium carbonate, aliquot portions being used for Zerewitinoff analysis. A blank was also run under identical conditions of temperature, moisture, drying agents, and time. It was thus found that after deducting the amount of methane produced in a blank and after figuring on 100% yield of carbinol from the aldehyde, which was highly unlikely, there was still evidence for 0.7 of an active hydrogen. In order to show the reliability of this method of analysis, a compound which had no active hydrogen, namely, benzophenone from benzonitrile and phenylmagnesium bromide was prepared in the same manner. The amount of methane produced from an aliquot sample was approximately the same as was given off by the blank, showing that the gas obtained above was due only to the active hydrogen from (5-chloro-2-furyl)phenylcarbinol. Further validity of this method was shown by the fact that 2-furylphenylcarbinol prepared in n-butyl ether solution gave almost the identical amount of methane as (5-chloro-2-furyl)phenylcarbinol, namely 49.1 cc. and 49.4 cc. respectively.

Since it was proved that the initial product from 5-chloro-2-furfural and the Grignard contained beyond a doubt an active hydrogen, it was deemed advisable to next show that this hydrogen came from a hydroxyl group. This was accomplished after

several attempts by oxidizing 2-furylphenylcarbinol in the cold with fuming nitric acid. Extreme care was taken that no acid fumes came in contact with the carbinol prior to its addition to the nitrating and oxidizing mixture. A product was finally obtained which was identical with Young's (11) 5-nitro-2-furylphenyl ketone. The carbonyl group proved not only the existence of an alcoholic hydroxyl group, but also its position, eliminating any suppositions that it might have rearranged.

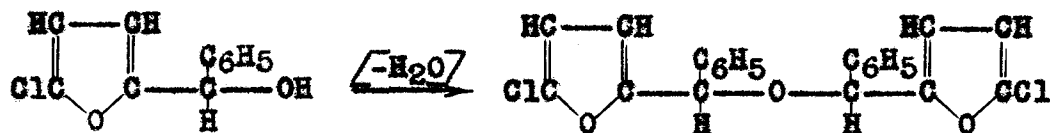
The reaction between 5-chloro-2-furfural and phenylmagnesium bromide having been shown to be a normal one, it was necessary to further investigate the unstable product, m.p. 114<sup>o</sup>, reported by Hewlett and Wright. Since the author has always felt that no acid should be used in the hydrolysis of any Grignard-complex involving the furan nucleus, all experiments were carried out in the above reaction using ammonium chloride for this purpose. It was found that the (5-chloro-2-furyl)phenylcarbinol prepared in n-butyl ether as above could be subjected to a vigorous steam distillation for fifteen minutes without the slightest signs of darkening or decomposition. A few drops of oil steam distilled very slowly and solidified when chilled in ice, but melted again after the cold bath was removed. Having been extracted with ether, dried, and evaporated in a stream

(11) Gilman and Young, J. Am. Chem. Soc., 56, 464 (1934).

of dry air, the product was stable for several days. When heated for a few minutes at 100°, darkening took place, moisture condensed on the flask, and after standing one hour the dark purple residue was recrystallized from alcohol giving the secondary reaction-product of Hewlett's, m.p. 114°.

The above experiment substantiates the supposition that the carbinol was obtained as the initial product of the reaction, and that its stability depended upon the absence of heat and acids. It was further strengthened by the following test; another sample of (5-chloro-2-furyl)phenylcarbinol was prepared in diethyl ether solution, ammonium chloride being used for hydrolysis, and dried with anhydrous potassium carbonate. The yellow oil left after removal of the solvent by evaporation with dry air was very soluble in alcohol, as would have been expected of a carbinol. It steam distilled very slowly without darkening. When, however, one drop of dilute acetic acid was added to this hot mixture, a sudden discoloration was noticed and upon completion of the run, Hewlett's unstable material was again obtained, m.p. 114°. This showed beyond a doubt that a trace of acid catalyzed the first step in the decomposition of (5-chloro-2-furyl)phenylcarbinol. Since moisture in considerable quantities was evolved upon heating a sample of the carbinol, it was concluded that water was one of the decomposition products from two molecules of the secondary alcohol,

giving in all probability an ether.



This hypothesis was substantiated by all the experimental data collected on this product. The molecular weight as determined both in camphor and in benzene showed a value approximately double that of the carbinol. Analyses for carbon and hydrogen and also chlorine, all agreed more closely with the ether structure.

Little or nothing has been said up to this time concerning the final, halogen-free compound, m.p.  $86^{\circ}$ . It is preferred to leave a discussion of its structure until later, since more light can be shed on the problem after considering the corresponding derivatives from tertiary carbinols.

Thus far, the only reaction mentioned has been that involving the preparation and properties of secondary halogen-substituted carbinols of the furan series. The major portion of this thesis, however, deals with the attempted preparation of tertiary carbinols of the same type and their subsequent decomposition products. The study of these was undertaken because it was felt that the tertiary alcohols might be solids

and hence more stable. Some of the first attempts to prepare (5-chloro-2-furyl)diphenylcarbinol or the corresponding bromo compound proved very discouraging because the initial halogen esters were not sufficiently pure, even though they were purified by distillation in vacuum several times. The esters obtained from the chlorination of ethyl furoate and from the bromination of furoyl chloride were not sufficiently pure to give a clean-cut reaction product. They were both hydrolyzed, recrystallized, and then again esterified before they were satisfactory for use. Pure ethyl 5-chloro-2-furoate was prepared by Hill and Jackson (12) and ethyl 5-bromo-2-furoate by Hill and Sanger (13).

The tertiary carbinols were prepared in the usual manner by adding the halogen-substituted ester to the Grignard reagent. It might be pointed out here that a gummy, sticky, and insoluble precipitate formed at this stage of practically all experiments in which there was a Grignard-complex that had a furan ring as one of its components. This seems to be quite characteristic. For this reason all Grignard-complexes were hydrolyzed with ammonium chloride solution directly in the flask, cooling when necessary. The ether solution of the ter-

(12) Hill and Jackson, Am. Chem. J., 12, 30 (1890).

(13) Hill and Sanger, Proc. Am. Acad. Arts Sci., 21, 142 (1885).

tiary carbinol was evaporated by a stream of dry air, but just as soon as the last amount of solvent was removed, an immediate darkening commenced, accompanied by the copious evolution of the halogen acid. This decomposition sometimes gained such speed as to become violent. In order to avoid accidents, a small amount was first allowed to decompose, and then the remaining ether solution of the carbinol was added, the solvent being removed slowly with dry air. The same effect could have been brought about by removing the ether with steam, which would have been followed by a sudden darkening of the remaining oil. After all the halogen acid had been evolved, the brown to black colored, solid, residue was treated with norite in alcoholic solution and recrystallized several times, m.p.  $111^{\circ}$ . Its structure will be discussed later in detail.

As yet, no tertiary halogen-substituted carbinols have been isolated as such, because of their extreme instability. Hence it was believed that a tertiary furylcarbinol containing small groups in the place of phenyl residues might be slightly less inclined to decompose. (5-Chloro-2-furyl)dimethylcarbinol was prepared in the usual manner, and the pale yellow oil remaining after removal of the carefully dried solvent, ether, solidified in long glistening needles, one to two inches in length. It was extremely soluble in every organic solvent used, and all attempts to recrystallize it failed. A small

amount was pressed on a porous plate for five minutes and an immediate Zerewitinoff analysis showed one active hydrogen to be present. The melting point was  $42^{\circ}$ - $43^{\circ}$ . Decomposition slowly commenced and within thirty minutes a gummy sticky residue remained, hydrogen chloride having been lost. This compound represented the only solid tertiary halogen carbinol ever isolated long enough to take its melting point. No decomposition product could be found.

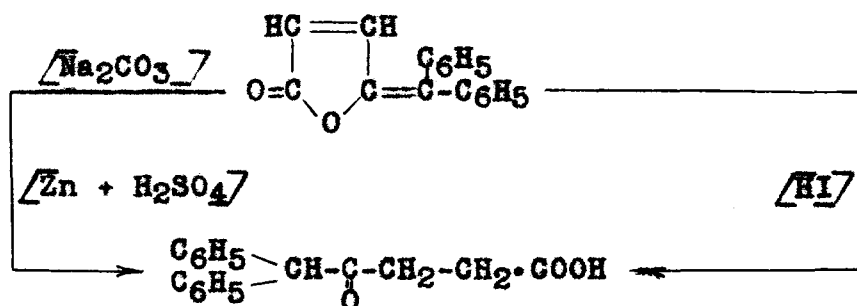
The next phase of the problem to be attacked was the structure of the residue, m.p.  $111^{\circ}$ , remaining after loss of hydrogen chloride or bromide from the corresponding (5-chloro-2-furyl)diphenylcarbinol or (5-bromo-2-furyl)diphenylcarbinol. After several unsuccessful attempts to synthesize it, the other method for proof of structure was followed, namely, degradation. Here several avenues of approach were used.

The first of these was the treatment with hydriodic acid in a sealed tube. The product isolated was an acid, postulated as a new diphenyllevulinic acid, m.p.  $107^{\circ}$ - $108^{\circ}$ . This compound had the peculiar property of oiling-out and remaining in this state sometimes for two weeks before solidification.

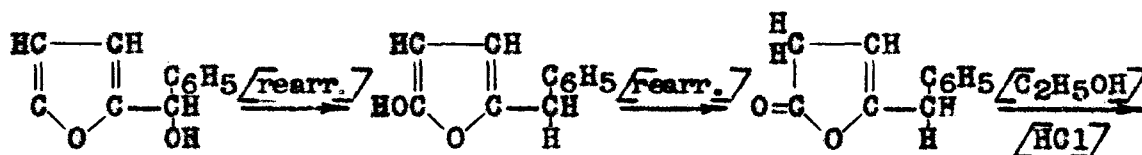
The second course was the hydrolysis with sodium carbonate followed by the reduction with zinc dust in acid solution. Since such a weak base as sodium carbonate hydrolyzed the compound, it was apparently a lactone, strong acids having little or no effect on it. For convenience, this product will be re-



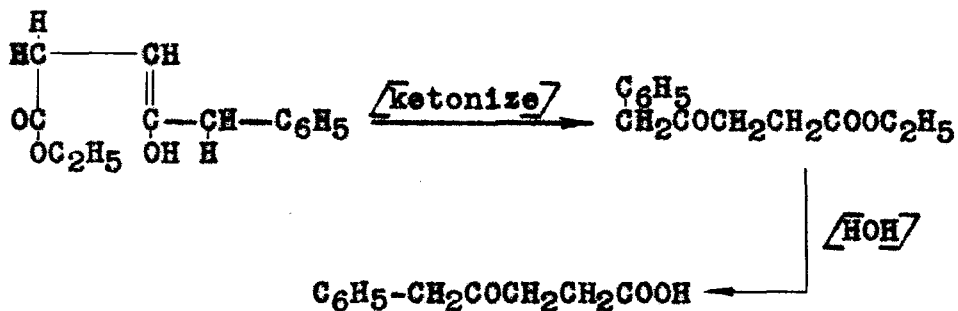
ferred to as a lactone, the formula of which is postulated below. It was found that the compound obtained in this experiment was also a diphenyllevulinic acid, identical with that resulting above.



In order that the preceding experiments shall have had any value, the structure of this acid was proved both by synthesis and degradation. A number of delta-substituted levulinic acids have been made by Chichibabin (14) by the catalytic scission of the furan ring in different primary or secondary carbinols. delta-Phenyllevulinic acid was prepared from furylphenylcarbinol in alcoholic solution using a trace of hydrogen chloride.

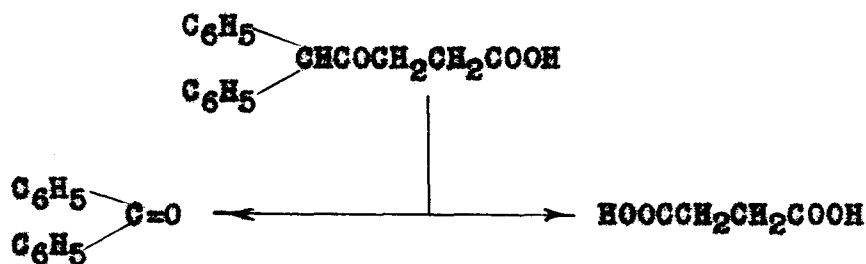


(14) Chichibabin, Chimie and industrie, 11, 563 (1931), Congres de Chimie.

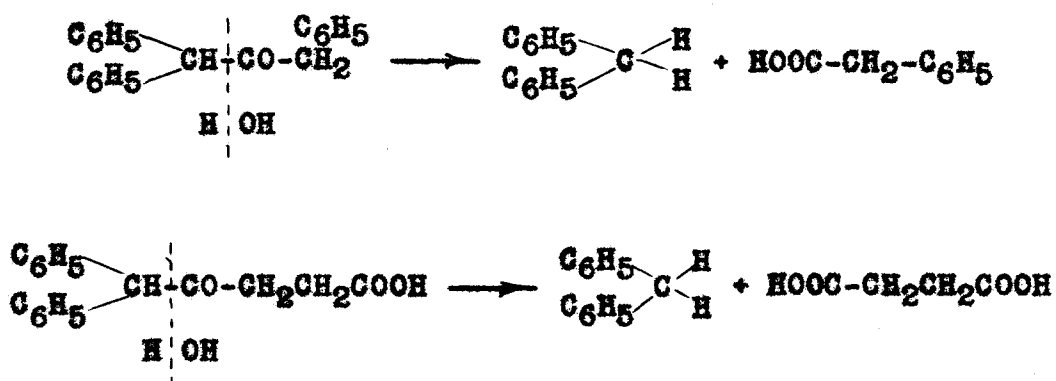


This same reaction was employed using diphenylfurylcarbinol. Although the ethyl ester of diphenyllevulinic acid was a very high boiling viscous liquid, it could be distilled in vacuum using small quantities. Hydrolysis with a base, however, as suggested by Chichibabin resulted in a total loss. Refluxing with 5% hydrochloric acid worked very well. The acid obtained was crystallized from petroleum ether (69°-70°) or in very small amounts from hot water. It showed slightly more than one active hydrogen in a Zerewitinoff analysis, a fact which might be explained as being due to slight enolization.

Two methods of degradation were followed, the first of which was oxidation. Upon treatment of an alkaline solution of diphenyllevulinic acid with potassium permanganate, two products were formed and identified by mixed melting points of appropriate derivatives with authentic samples. These were benzophenone and oxalic acid.



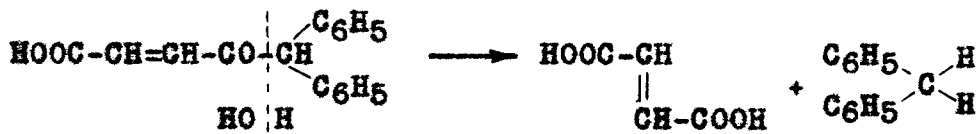
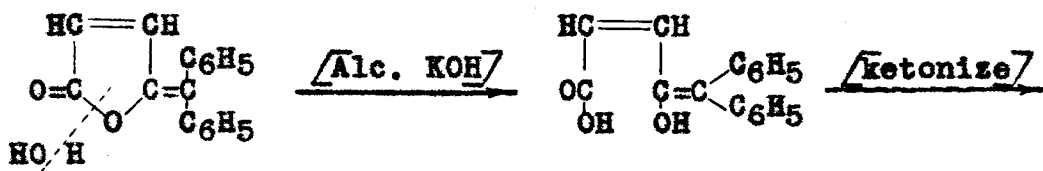
The second method used was the splitting with alcoholic potassium hydroxide. It has been shown by Orékhoff (15) that benzhydryl benzyl ketone gave diphenylmethane and phenylacetic acid when treated with alcoholic potassium hydroxide. Since the same type of linkage can be found in diphenyllevulinic acid, one would expect the similar cleavage-products, diphenylmethane and succinic acid. These were found and identified by appropriate derivatives.



Since the structure of diphenyllevulinic acid was shown to be as illustrated above, the third step in the proof of

(15) Orékhoff, Bull. soc. chim., 25, 109 (1919).

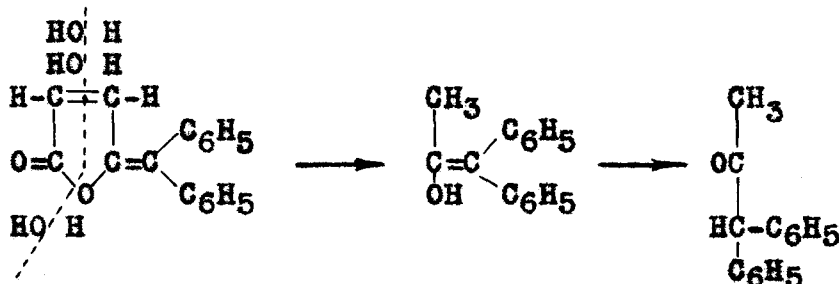
structure for the diphenyl lactone was the cleavage action of alcoholic potassium hydroxide. It was highly probable that hydrolysis was first brought about, followed by splitting. The products identified were diphenylmethane and fumaric acid.



In the fourth and last step, it was found that aqueous 5% sodium hydroxide slowly reacted upon the lactone giving an oil which could be steam distilled from the reaction flask in small amounts. After extraction, it suddenly solidified when scratched with a glass rod. It was recognized by its characteristic odor as asymm-diphenylacetone. There are two isotropic forms of this compound which was first synthesized by Stoermer (16). The lower melting unstable form, m.p. 46° was obtained only once, namely the first time it was prepared. This on

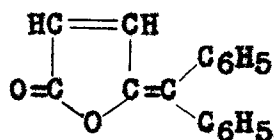
(16) Stoermer, Ber., 39, 2302 (1906).

standing changed into the higher melting form, m.p. 61°. Both forms gave the same oxime, m.p. 164°. The lower melting variety was obtained as the cleavage product of the lactone, the first time the reaction was performed, but all subsequent runs produced the higher melting substance. The ketone was identified as the oxime, and a mixed melting point was not lowered with an authentic sample synthesized according to Stoermer.

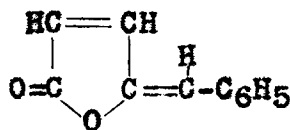


All attempts to isolate further products failed.

If the precursor to the lactone was a halogen-substituted tertiary carbinol, then it should have been possible to have prepared it also from the corresponding halogeno-ketone and the Grignard reagent. It was found that 5-bromo-2-furylphenyl ketone when treated with phenylmagnesium bromide gave the same oily product which lost hydrogen bromide in a vigorous manner. The same final halogen-free decomposition compound was formed as in the case of ethyl 5-bromo-2-furoate.



The structure of the stable halogen-free product obtained by Hewlett and Wright from 5-chloro-2-furfural and phenylmagnesium bromide is in all probability similar to that prepared above from the halogen furcic esters, the exception being, only one phenyl residue in the place of two. This is, of course, supported by all of the physical constants and data together with the results of Wright's work mentioned earlier in this thesis.



Since the only ester thus far treated with the Grignard reagent was a mono-halogen derivative, it was desired to investigate this same type of reaction with di- and tri-halogen compounds. Because of the apparently incorrect nomenclature given by Hill to some of his furcic acids, the following names will be used:

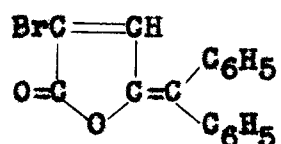
<u>Hill's name</u>	<u>Name used herein</u>
3,5-dibromofuroic acid (17)	4,5-dibromo-2-furoic acid
x-dichlorofuroic acid (18)	3,5-dichloro-2-furoic acid
3,5-dichlorofuroic acid (19)	4,5-dichloro-2-furoic acid

The reasons for this change will be discussed later in this thesis. In all cases in which the esters were liquids, purification by distillation was not alone sufficient. The free acid was first prepared in a pure form and then esterified. Solid esters, however, were recrystallized.

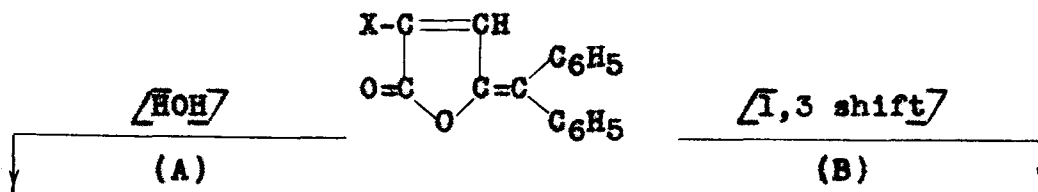
The first compound of this nature to be treated with the Grignard reagent was ethyl 4,5-dibromo-2-furoate, m.p. 58°, prepared by the bromination of furoyl chloride and followed by hydrolysis with ethyl alcohol. The (4,5-dibromo-2-furyl)diphenylcarbinol was, of course, never isolated because it lost hydrogen bromide more vigorously than the corresponding monobromo alcohol. It was so unstable that the ether solution sometimes turned purple around the sides of the flask. Cooling with ice was occasionally necessary when the decomposition gained speed, the reaction being exothermic.

- (17) Hill and Sanger, Proc. Am. Acad. Arts Sci., 21, 159 (1885-86).  
(18) Hill and Jackson, Am. Chem. J., 12, 128 (1890).  
(19) Hill and Jackson, Ibid., 12, 47 (1890).

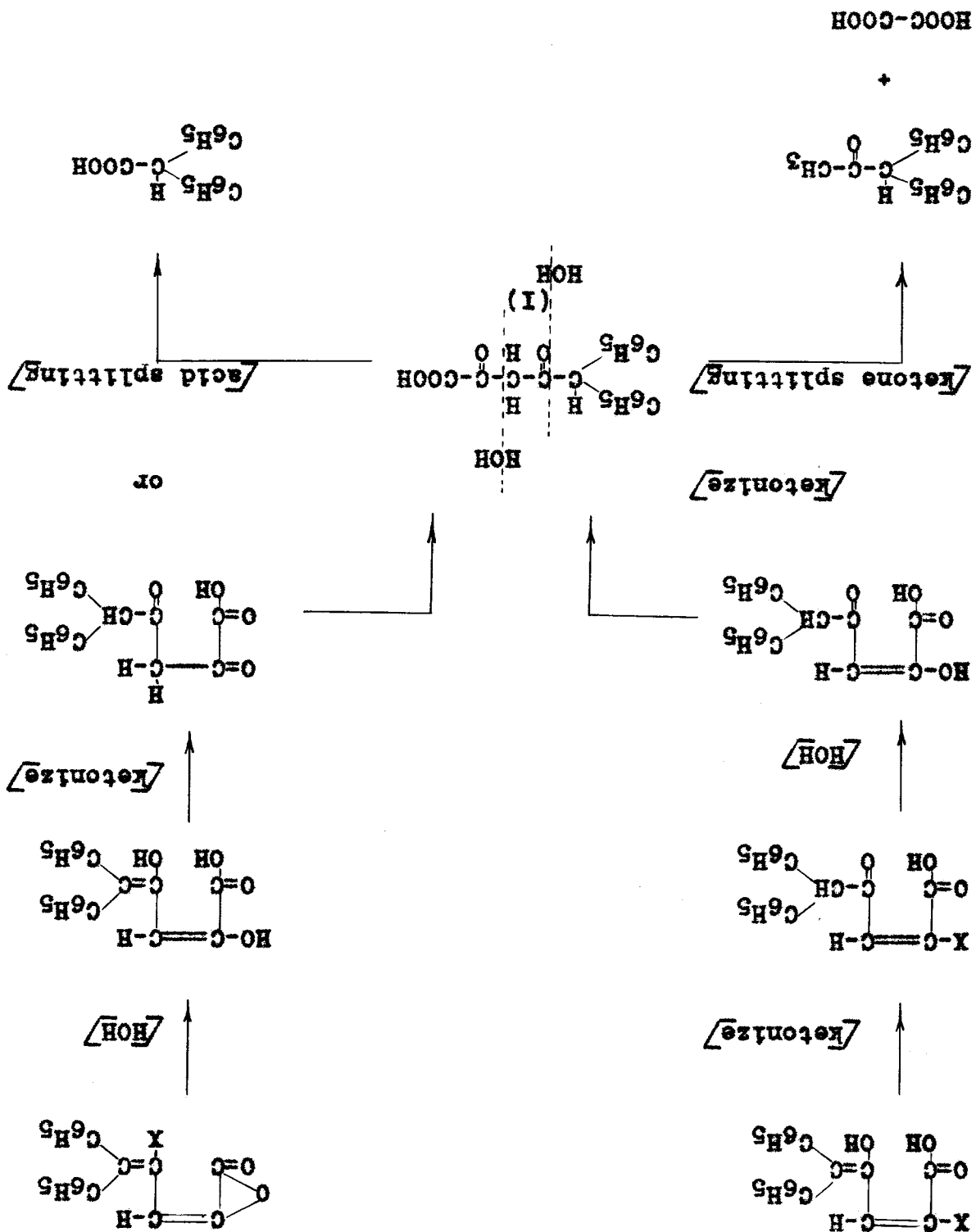
Upon crystallization from carbon tetrachloride, a light yellow colored lactone was obtained, m.p. 156°. Molecular weights both in benzene and in camphor, together with the analysis for carbon and hydrogen support the structure below.



Similarity of this structure to the above mentioned halogen-free lactone was supported by the fact that reduction with hydriodic acid gave the same product, namely diphenyllevulinic acid. Further evidence can be found in the scission products obtained by treatment with dilute sodium hydroxide. It will be recalled that the only material produced from the halogen-free diphenyl lactone was asymmetrical diphenylacetone. Here, however, in addition to this product two other compounds were isolated, namely, oxalic acid and diphenylacetic acid. These were identified by mixed melting points using oxal-p-toluidide and diphenylacetamide respectively. The mechanisms postulated for the formation of these compounds are as follows:

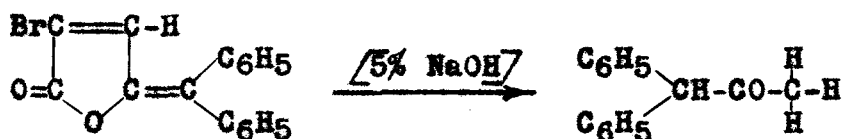
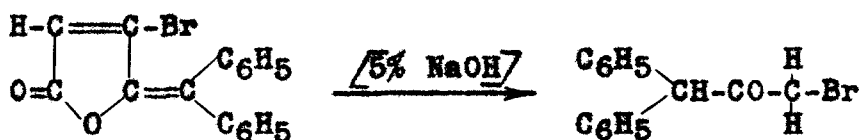




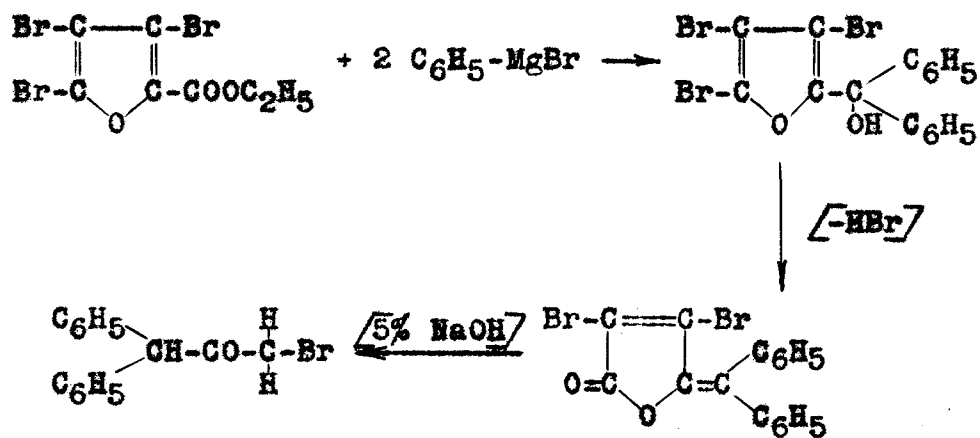


It will be noticed that identical groups are to be found in compound (I) as in acetoacetic ester, and hence the same type of cleavage might be expected. The only product lacking according to this scheme is pyruvic acid. Several attempts to isolate this compound failed.

The above series of reactions also helps to shed some light on the structure of Hill's dibromofuroic acid. Since asymm-diphenylacetone was obtained from the bromo-lactone produced by the action of phenylmagnesium bromide on ethyl dibromo-2-furoate, there is fairly good proof that the second halogen atom must have been in the 4-position of the furan ring, because no other plausible explanation can be given for the existence of the three hydrogen atoms of the methyl group in the ketone. If the second bromine atom had been in the 3-position as suggested by Hill, no asymm-diphenylacetone could have been obtained. Hence Hill's acid must have been 4,5-dibromo-2-furoic acid instead of 3,5-dibromo-2-furoic acid.



In order to further prove the validity of this reaction, 3,4,5-tribromo-2-furoic acid of Hill's (20) was made and the ester treated with the Grignard reagent in the usual manner. The decomposition product in this case contained two atoms of bromine as indicated.

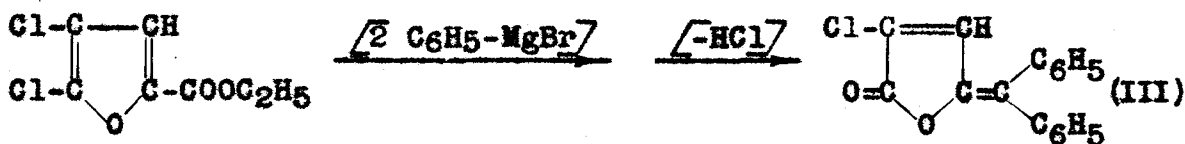
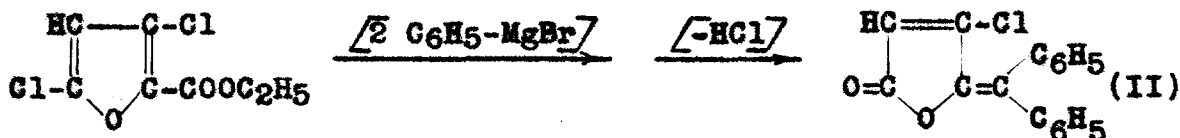


When this dibromo lactone was treated with dilute alkali as in previous experiments, no diphenylacetone could be detected. Only a wine-red color developed and no effort was made to isolate any other compound.

Because only one dibromofuroic acid is known having one of its halogens in the 5-position, the corresponding chloro derivatives were prepared, namely, 3,5-dichloro- and 4,5-dichloro-2-furoic acids. The esters of these compounds when treated with the Grignard reagent gave two isomeric chloro-

(20) Hill and Sanger, Proc. Am. Acad. Arts Sci., 21, 179 (1885-86).

lactones which had practically the same melting point. When mixed together, however, the melting point was lowered considerably.



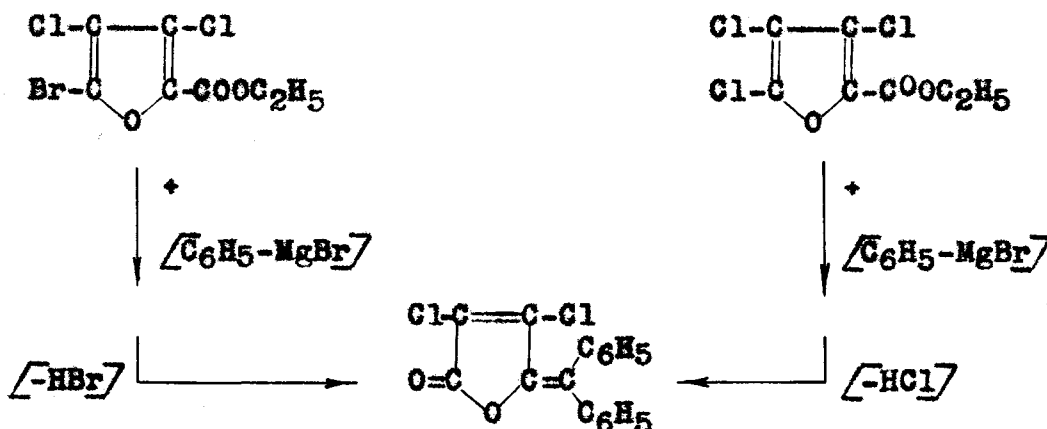
It was found that the chloro lactone (III) prepared from the 4,5-dichloro ester (called 3,5 by Hill) gave upon treatment with dilute alkali the same compounds as the corresponding bromo lactone, namely, diphenylacetone, diphenylacetic acid, and oxalic acid, as would have been predicted from its structure. The isomeric chloro-lactone (II), however, gave no diphenylacetone, the reaction being similar to the dibromo lactone above. These results would again indicate that Hill's two isomeric furoic acids were incorrectly named, thus reversing the positions of the halogens in them.

Before proceeding further it might be well to name these lactones. In a note from Dr. E. J. Crane, editor of Chemical Abstracts, it was stated that there was no particular objec-

tion to the name suggested by the author, alpha-bromo-gamma-diphenylmethylene-crotonolactone, but for purposes of indexing, preference was given to the lactone of alpha-bromo-gamma-hydroxy-delta,delta-diphenyl-alpha,gamma-pentadienoic acid. Further reference to these compounds will be made using the shorter and more convenient names as substituted crotonolactones.

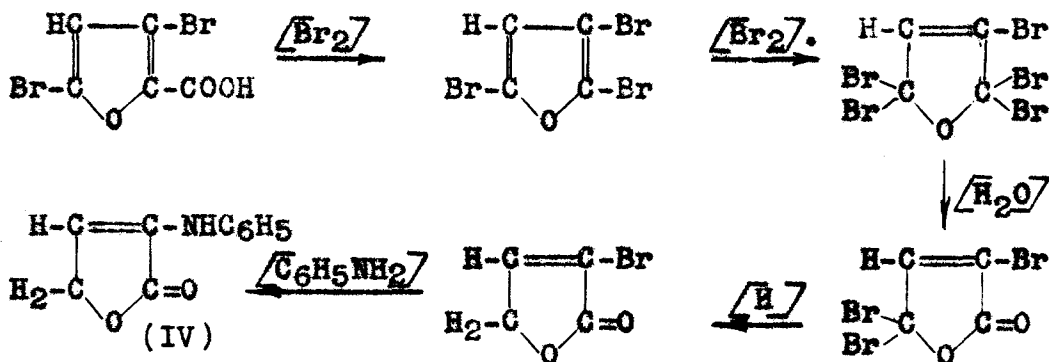
In order to eliminate the possibility of migration of the bromine atom in the 5-position, and in order to prove that it was this atom which was lost rather than any other halogen, the ester of 3,4-dichloro-5-bromo-2-furoic acid (21) was treated with phenylmagnesium bromide. The product isolated should have been alpha,beta-dichloro-gamma-diphenylmethylene-crotonolactone, provided the acid lost was hydrogen bromide. This compound was then synthesized from ethyl 3,4,5-trichloro-2-furoate in the usual way. A mixed melting point showed no depression, thus proving the identity of these two substances and establishing the fact that no rearrangement of the halogen atom in the 5-position had taken place.

(21) Hill and Jackson, Am. Chem. J., 12, 125 (1890).



At this stage of the problem it was desired to add another bit of evidence for the proof of structure of Hill's dihalogenofuroic acids. A long and detailed discussion of Hill's work may be found in the doctoral thesis of R. J. VanderWal (22), where proof is presented for the structure of 4,5-dibromo-2-furoic acid and the corresponding dichloro acid showing Hill to be wrong. Several phases of the problem were left unfinished, first, the synthesis of Hill's so-called alpha-anilido-crotonolactone, second, the preparation of the same compound by another method, and third, the proof of their identities by means of a mixed melting point. A brief review of Hill's work should be pertinent at this point, using the structures as he proposed them.

(22) R. J. VanderWal, Thesis, "Furan Mercurials and Derived Types", Iowa State College, 1936.

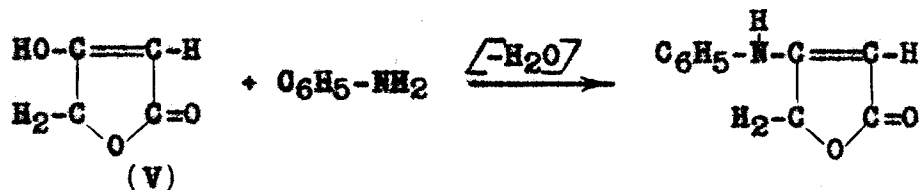


Starting with 3,5-dibromo-2-furoic acid, Hill prepared by the above series of reactions what he called an alpha-anilido-crotonolactone (IV), m.p. 217°-218°. He assigned the alpha-position because he believed the second halogen in furoic acid was attached to the ring in the 3-position. If, however, the bromine atom was located in the 4-position of the furan ring, then Hill's derivative should in reality be beta-anilido-crotonolactone. Since the only reference in the literature to a compound of this type was a beta-substituted lactone, it was synthesized and compared to Hill's product.

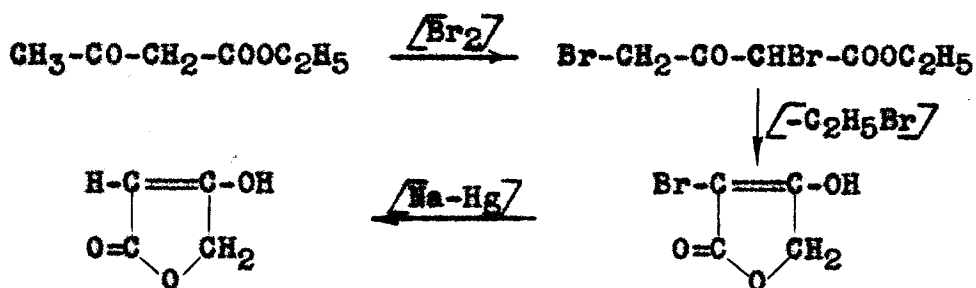
Wolff and Schimpff (23) found that tetronic acid (V) reacted very easily with aniline to give a beta-anilido-crotonolactone (VI), because the structure of tetronic acid demands that the compound be a beta-substituted derivative. The melting point was reported at 220°-221°, which was so close to that

(23) Wolff and Schimpff, Ann., 315, 156 (1901).

given by Hill as to be considered identical.



There are only two methods in the literature for the preparation of tetrone acid, the first of which having been given by Wolff and Schwabe (24) according to the following scheme.



Tetrone acid

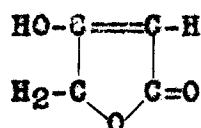
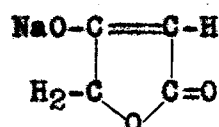
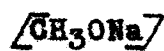
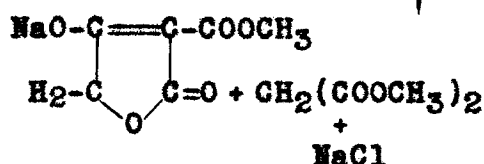
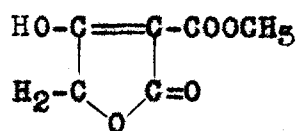
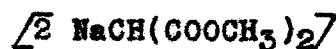
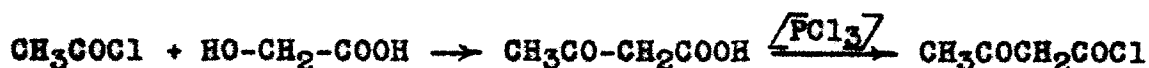
Bromotetrone acid

The other method of preparation was given by Anschütz and Bertram (25) whose synthesis was rather long and involved.

(24) Wolff and Schwabe, Ann., 291, 231 (1896). Wolff, ibid., 291, 234 (1896).

(25) Anschütz and Bertram, Ber., 36, 466 (1903); ibid., 36, 469 (1903).





Tetronic acid

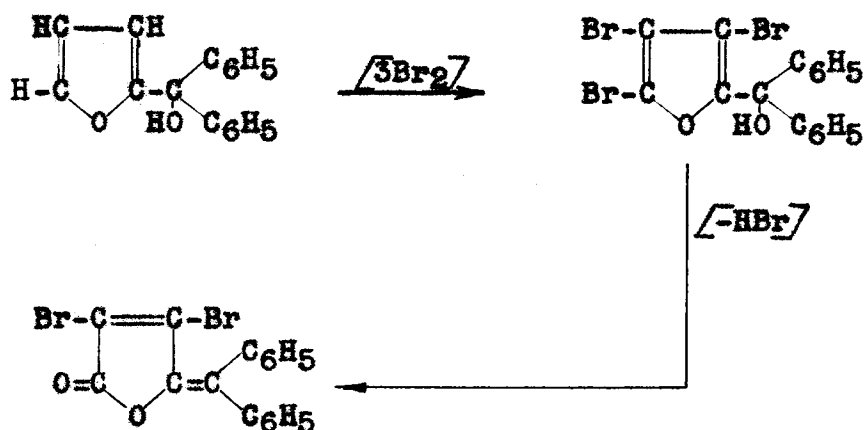
The tetronic acid prepared by both of the above methods was converted to the anilido derivative in each case. A mixed melting point of these with Hill's so-called alpha-anilido-crotonolactone showed no depression. This proves again that Hill had a beta-substituted bromocrotonolactone, and consequently a 4,5- instead of a 3,5-dibromo-2-furoic acid as a starting material.

In view of the fact that both 5-bromo and 5-chloro-2-furoic acid esters gave the same crotonolactone when treated with the Grignard reagent, it was desired to know if methyl 5-iodo-2-furoate followed the same path of decomposition. When the solvent was evaporated from the (5-iodo-2-furyl)diphenyl-

carbinol, a light tan solid remained which was stable for a few minutes and then slowly turned purple. A small amount was pressed on a porous plate, leaving a white solid that melted at 75°-76°. Any attempt to crystallize it failed, as decomposition began whenever moderate heat was used. The remaining dark-colored solid was warmed on a steam bath and a vacuum applied for a few minutes. On standing over night the black oil solidified, and after extraction with petroleum ether yielded a very small amount of a compound, m.p. 85°-86°. This was not the gamma-diphenylmethylene-crotonolactone, m.p. 111°. The new substance contained iodine as evidenced by a micro test. It is not surprising, however, that this carbinol did not follow the usual path of decomposition, since the hydrogen iodide liberated has such different properties from hydrogen chloride or bromide. Because of the extremely small amounts available, nothing further was done toward the structure of this new compound.

Since (5-bromo-2-furyl)diphenylcarbinol was never isolated for more than a few seconds, the proof that it was a true carbinol was still lacking. Hence diphenylfurylcarbinol was prepared and then brominated in carbon tetrachloride, keeping the mixture cool. The solution turned purple and evolved hydrogen bromide. The black oil obtained partially solidified on standing, giving off more hydrogen bromide when heated. A small amount of alpha,beta-dibromo-gamma-diphenylmethylene-

crotonolactone together with considerable quantities of the mono-bromolactone were isolated. This would tend to show again that it was the carbinol which was first formed, and that the Grignard reagent acted normally as would have been predicted. Incidentally, this experiment also lends support to the theory (26) that the furan ring possesses superaromatic properties by virtue of the fact that it not only brominated twice, but even three times in preference to two benzene nuclei.



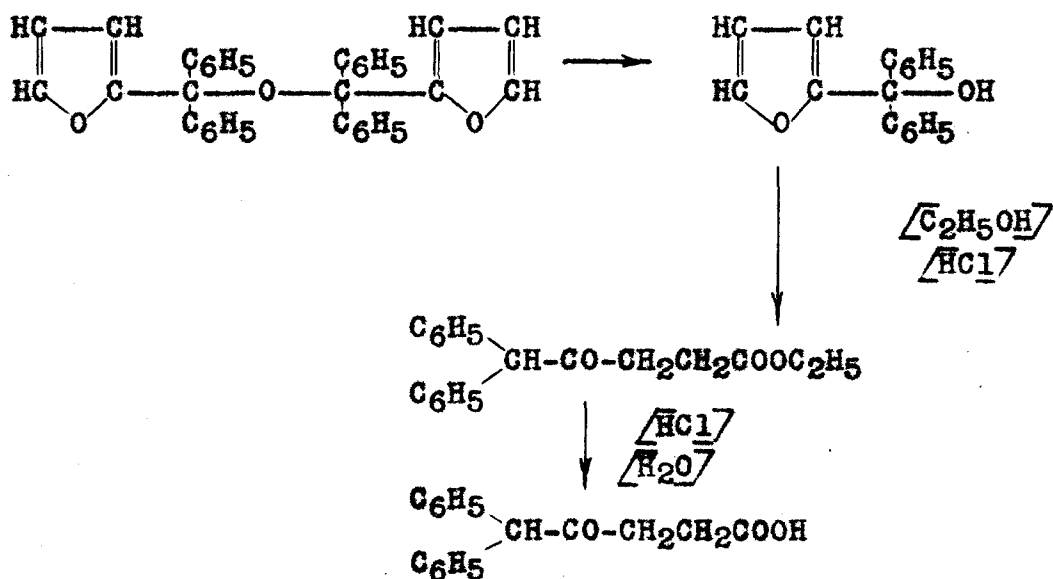
It was mentioned in the early part of this thesis (27) that diphenylfurylcarbinol on standing for several months or more slowly reverted to a reddish-brown resinous substance.

- (26) Gilman and Towne, *Rec. trav. chim.*, 51, 1054 (1932).  
 Gilman and Calloway, *J. Am. Chem. Soc.*, 55, 4197 (1933).  
 Gilman and Young, *ibid.*, 56, 464 (1934).  
 (27) This Thesis, page 8.

When this material was triturated with acetone, there separated a very finely divided solid which upon being filtered and washed gave a practically white crystalline residue. This material was almost insoluble in all common solvents, but could be recrystallized from benzene using a Soxhlet extractor. The melting point of this compound varied, but usually was found to be  $215^{\circ}$  (decomposition). This property is not uncommon to this type of structure, as Gomberg (28) found that the melting point of bis(triphenylmethyl) ether varied as much as ten degrees. There was a remarkable resemblance between the properties of this new material and those of Gomberg's ether. It was quite susceptible to the hydrolyzing action of acids, but not of bases. All physical data indicated that the product was bis(diphenylfurylmethyl) ether. Since a compound of this type should give the corresponding carbinol upon hydrolysis, several attempts were made to obtain the tertiary alcohol. Because of the instability of such furyl carbinols toward acids, complete decomposition resulted. Since it was assumed, however, that before decomposition had begun, diphenylfurylcarbinol had first been formed, then it should have been possible to control this secondary action by splitting the furan ring to a known product according to the reaction of Chichibabin (14). This hydrolysis and cleavage was accomplished by the use of

(28) Gomberg, J. Am. Chem. Soc., 35, 208 (1913).

alcohol to which a trace of dry hydrogen chloride had been added. There resulted the ethyl ester of diphenyllevulinic acid which in turn gave the free acid in yields of 65% based on an ether structure for the initial material. Since more than a 50% yield was obtained, the identity of both residues in the ether was explained.

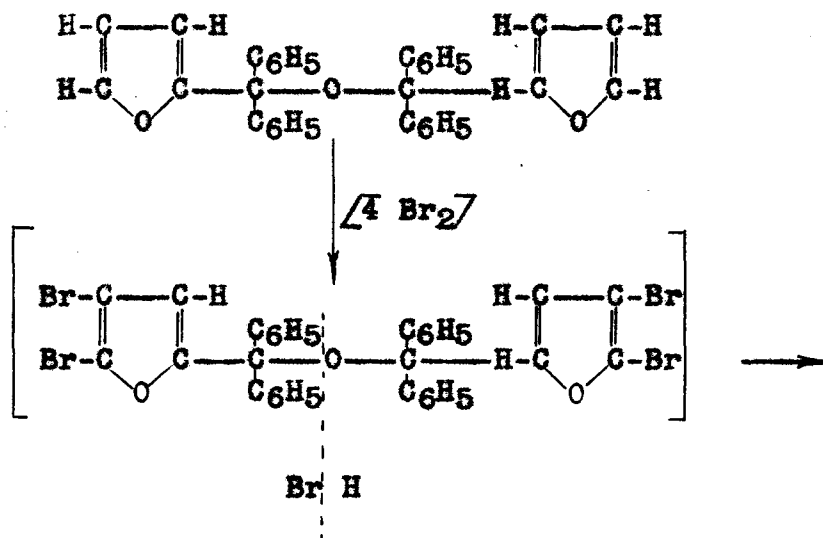


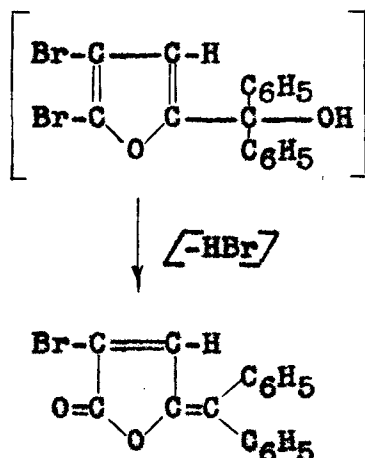
Several attempts were made to synthesize this ether by the same methods used in making Gomberg's triphenylmethyl oxide, but all reagents were too drastic for diphenylfurylcarbinol. Earlier in this thesis (29) it was postulated that an unstable ether was first formed when (5-chloro-2-furyl)phenyl-

(29) This Thesis, page 17.

carbinol started its series of decompositions in the presence of dilute acetic acid. Hence it was desired to know if this acid would have a similar effect on diphenylfurylcarbinol when heated on a water bath. To be sure, the decomposition was accomplished in seventeen hours, the product being identical with that extracted from the resinous material which formed when the carbinol was left standing for several months.

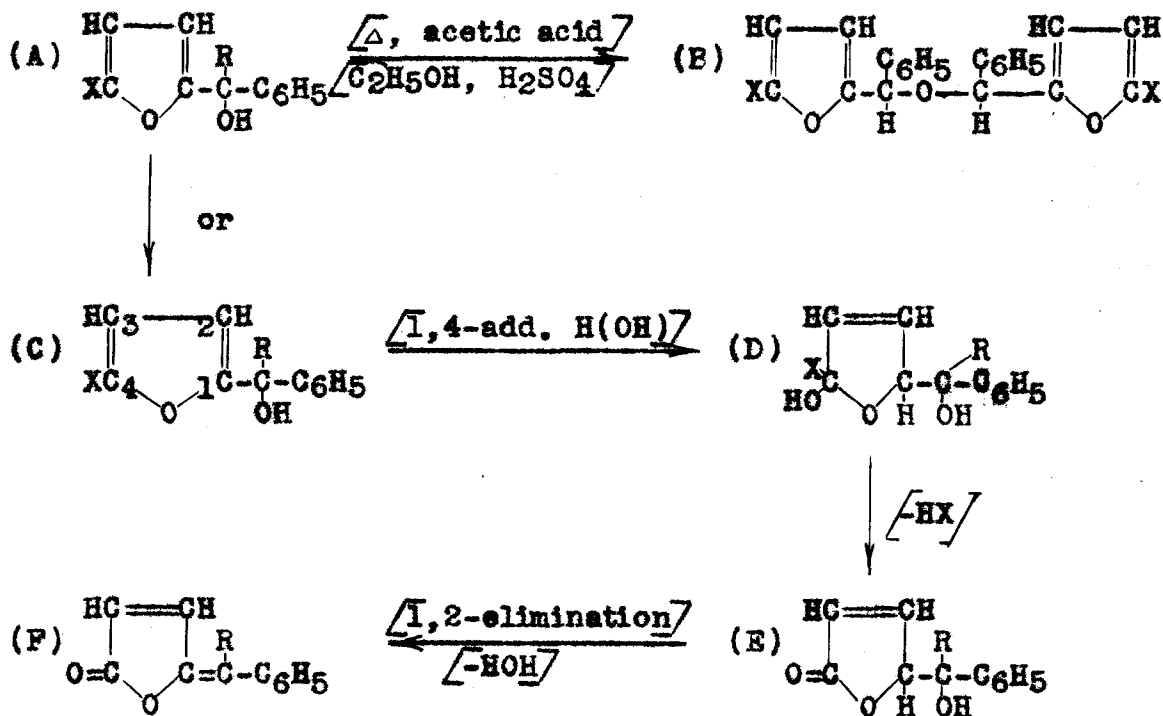
Further evidence for this type of structure given to Hewlett's unstable halogen-substituted ether which he called (5-bromo-2-furyl)phenylcarbinol may be added to that already presented, from the fact that the diphenylfurylmethyl oxide obtained above could be brominated. A bromo-ether, however, was not isolated because such a compound would probably be highly unstable. Instead, a decomposition product was found which was identical with that formed by the action of phenylmagnesium bromide on ethyl 4,5-dibromo-2-furoate.





Although there are a number of mechanisms which might be formulated to interpret the results of the work presented in this thesis, it seems that the most convincing evidence at the present points toward 1,4-addition to the furan ring. It appears altogether reasonable that on this basis the following series of reactions is most plausible (30).

(30) Note: This system may be used for either secondary or tertiary carbinols except in the step (A) to (B) which is, of course, valid for only the former type.



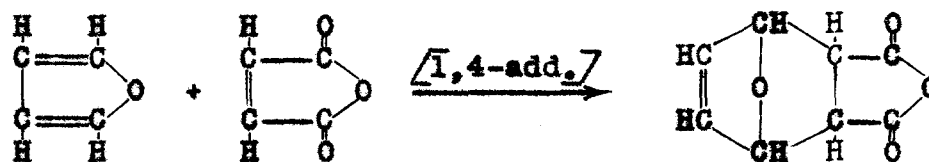
The formation of the ether (B) may be considered as being reversible depending wholly upon the conditions to which the compound is subjected. Although this halogeno-ether was reported by Hewlett and Wright as being very unstable, if it is stored in a dry atmosphere and not in a small confined space, it may be kept without appreciable decomposition. A small sample has been stored in an open-mouthed bottle contained in a desiccator over concentrated sulfuric acid for more than two years. There was of course some discoloration, and the melting point was low,  $97^\circ$ , but after one crystallization it melted sharply at  $114^\circ$ . Another small sample which was sealed in a test tube



with an atmosphere of dry nitrogen decomposed to a black solid within twenty-four hours. This would tend to show that the ether is quite susceptible to hydrolysis. As stated before, an experimenter is quite likely to miss the ether wholly, because he did not use precisely the correct conditions for its formation. The synthesis of the ether (B) from the carbinol (A) is supported experimentally by the appearance of moisture when the true carbinol is warmed on a water-bath.

Since the furan nucleus contains a conjugated system, it is quite logical to postulate certain mechanisms as taking place through the well known 1,4-addition. A few of the outstanding examples in the furan series will be reviewed.

Diels and Alder (31) having found that maleic anhydride added to a conjugated system as in isoprene showed that furan also followed the same reaction by adding in the 1,4-position.

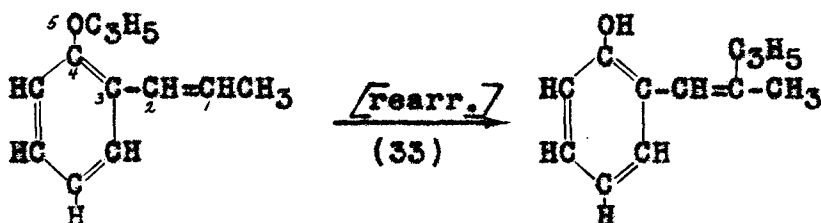
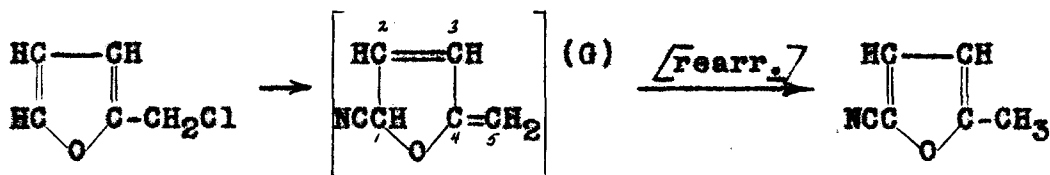


In the reaction between furfuryl chloride and potassium cyanide, Reichstein (32) obtained a mixture of products, the

(31) Diels and Alder, *Ber.*, 62B, 554 (1929).

(32) Reichstein, *ibid.*, 63, 749 (1930).

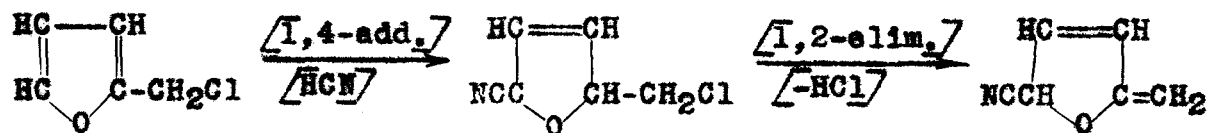
major portion of which was found to be 5-methyl-2-furoic acid caused by some type of rearrangement. It was partially explained on the basis of an intermediate compound (G) whose conjugation behaved like an allyl double bond as is characteristic of allyl phenolic ethers.



Scott and Johnson (34), however, explain the presence of such a compound as (G) on the basis of 1,4-addition followed by 1,2-elimination.

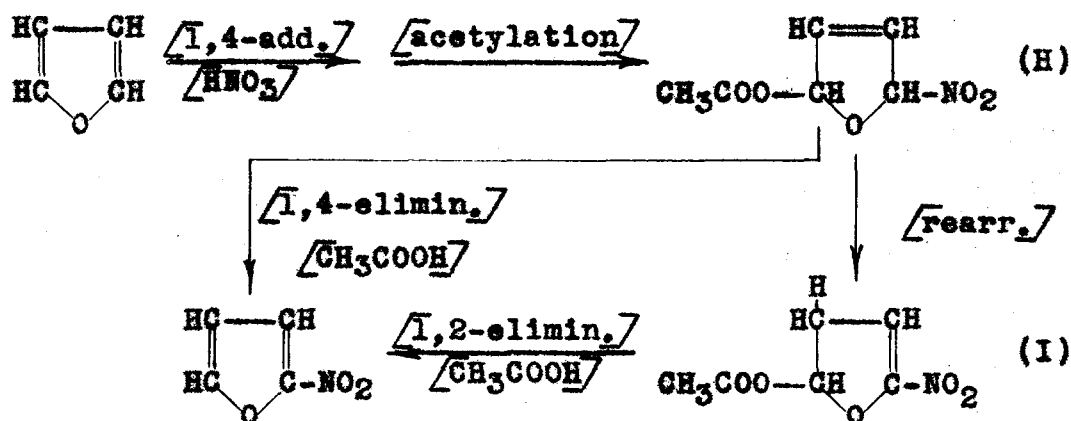
(33) Claisen, Ann., 449, 81 (1926); Ber., 59, 2344 (1926).

(34) Scott and Johnson, J. Am. Chem. Soc., 54, 2551 (1932).



Support for this mechanism may be found in the fact that 5-methyl-2-furfuryl chloride gives the normal product, 5-methyl-2-furonitrile and no rearranged material.

Freure and Johnson (35) have observed that in the nitration of furan, which was effected in the presence of acetic anhydride, there was formed an intermediate nitroacetate. It seemed reasonable to assign to this compound a ring structure (H), which would be produced by 1,4-addition of nitric acid and subsequent acetylation.



The transformation of the intermediate (H) into 2-nitrofuran

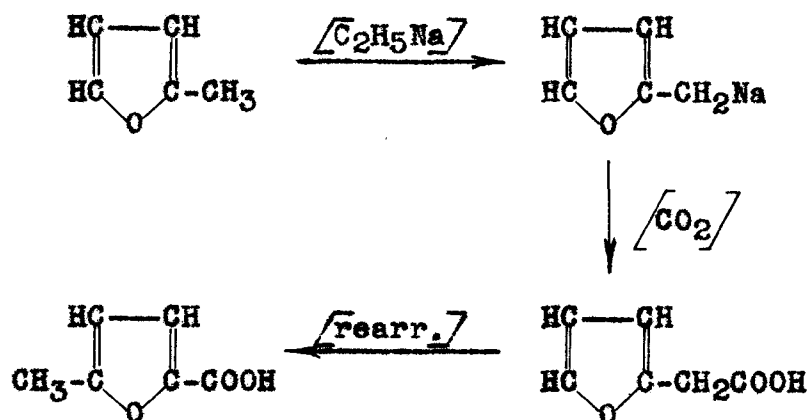
(35) Freure and Johnson, J. Am. Chem. Soc., 53, 1142 (1931).

by the action of pyridine was explained by 1,4-elimination of acetic acid or by the preliminary rearrangement into an isomeric nitroacetate (I) followed by 1,2-elimination of acetic acid. This type of rearrangement may be expected to occur readily since this shift of the double bond brings it into conjugation with the double bond of the nitro group. This reaction is analogous to the migration of the double bond from the beta,gamma- to the alpha,beta-positions in unsaturated carboxylic acids.

In the bromination of ethyl furylacrylate to get ethyl 5-bromofurylacrylate, Gilman and Wright (36) have favored 1,4-addition partly because the second molecule of bromine apparently added laterally; because no ethyl 3- or 5-bromofurylacrylate was isolated, and finally because polynuclear substitution took place with great difficulty when the hydrogens attached to carbon atoms 2 and 5 were replaced.

Gilman and Breuer (37) also have explained the formation of 5-methyl-2-furoic acid from 5-methylfuran and RNa compounds followed by carbonation, as being due to an allylic rearrangement so characteristic of furfuryl systems.

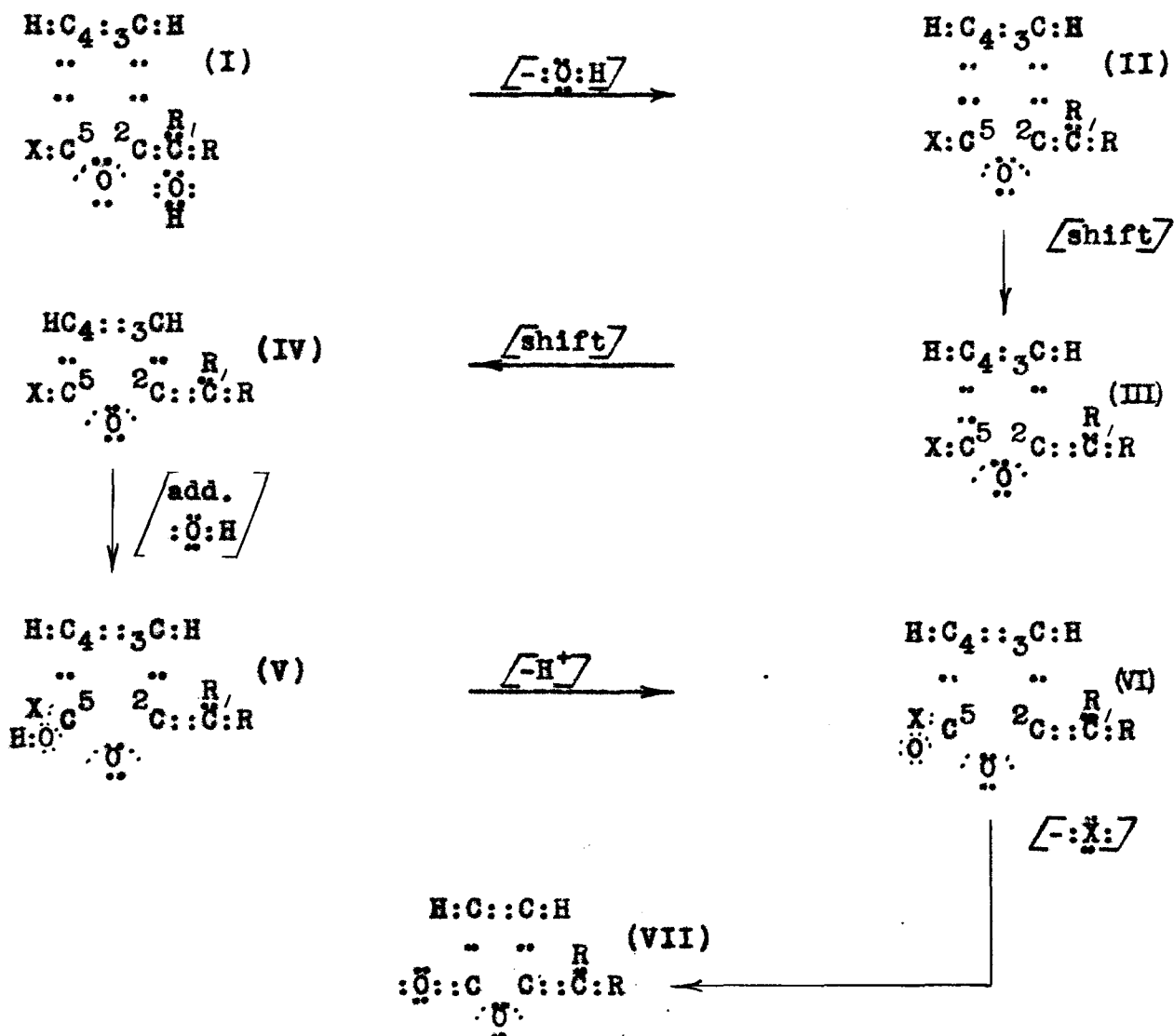
(36) Gilman and Wright, J. Am. Chem. Soc., 52, 3351 (1930).  
(37) Gilman and Breuer, ibid., 56, 1124 (1934).



In view of the fact that most of our evidence points toward 1,4-addition in the furan ring, the mechanism presented above for the loss of a halogen acid from secondary or tertiary arylfurylcarbinols appears to be most convincing. It will be noted that one molecule of water could accomplish the complete decomposition of an infinite number of carbinol molecules.

In the last step of the mechanism proposed, the 1,2-elimination of water forms a compound having a series of conjugated systems both of the running and crossed types. The latter arises by virtue of the presence of two benzene nuclei when the scheme is applied to tertiary carbinols. This might find support as pointed out above by the tendency of the double bond to migrate from the beta,gamma- to the alpha,beta- position in unsaturated carboxylic acids, thus forming a conjugated system.

An electronic interpretation for the decomposition may be given on the basis of the explanation suggested by Whitmore (38) for molecular rearrangements.



In the original carbinol (I), each atom has a completed octet

(38) Whitmore, J. Am. Chem. Soc., 54, 3274 (1932).

and the linking is due to the shared electrons. Such a system remains quite stable until something disturbs the equilibrium. If a hydroxyl group is lost, together with its complete octet, then carbon atom 1 in structure (II) finds itself deficient in electrons. It is believed that the electronegative hydroxyl group is removed first, because of the nature of the environment which surrounds it. Experimental evidence has shown that a tertiary alcohol possesses an extremely labile hydroxyl group. On this basis it might be predicted that a tertiary carbinol having two negative phenyl residues would impart a greater tendency for the elimination of the hydroxyl group, than a similar secondary carbinol, having only one phenyl radical. This fact is born out by the experimental evidence that the tertiary halogeno-arylfurylcarbinols are much more violent in their process of decomposition than the corresponding secondary alcohols. The deficiency of electrons in the open sextet on carbon 1 is made up by a shift which leaves carbon 2 momentarily unstable. This deficiency is in turn satisfied by a second shift of electrons, leaving carbon 5 in structure (IV) with an open sextet. In this reactive condition, carbon 5 completes its octet by the addition of the hydroxyl ion which was lost earlier in the reaction. Since such a compound as (V) is unstable due to the presence of a halogen and a hydroxyl group attached to the same carbon atom, a further loss of HX may be considered as

taking place in two steps: first, the loss of a proton, and second, the loss of the highly negative halogen with its complete octet. This elimination gives rise to a perfectly stable lactone (VII).

This mechanism may or may not have any merit for one reason, namely, that the same type of electronic interpretation can be used to explain practically any rearrangement, hence it may be too general in its application to be of any specific value.



EXPERIMENTAL

Reaction between 5-Chloro-2-furfural and Phenylmagnesium Bromide.

The directions of Hewlett and Wright (39) in the preparation of what they called (5-chloro-2-furyl)phenylcarbinol were carefully followed, and identical results were obtained. The following experiment illustrates the general technique used throughout the course of this problem. A stock solution of the Grignard reagent was titrated in the customary manner (40) and aliquot samples were used for all reactions. Experiments were conducted in a three-necked, round-bottomed flask equipped with a mechanically driven mercury-sealed stirrer, dropping funnel, and a reflux condenser. The apparatus was filled with dry nitrogen.

To 0.09 mole of phenylmagnesium bromide in 100 cc. of dry ether, there was added, dropwise, and with stirring, 10 g. (0.076 mole) of 5-chloro-2-furfural (41) in 40 cc. of dry ether. When approximately half of the aldehyde had been added, a characteristic precipitate formed, which, in this case, was a white solid. In all other runs the Grignard-complex was a gummy, sticky, mass, the physical state of which made it impossible to

(39) This Thesis, page 9.

(40) Gilman and Meyers, *Rec. trav. chim.*, 45, 314 (1926).

(41) Gilman and Wright, *Ibid.*, 50, 833 (1931).

transfer prior to hydrolysis. For this reason, the mixture was hydrolyzed by the addition of a saturated solution of ammonium chloride, through the dropping funnel, cooling when necessary. Prior to hydrolysis, the mixture was stirred for one hour and then a color test made (42). The result was often positive because an excess of Grignard reagent was generally used. Stirring greatly shortened the time of hydrolysis and consequently lessened the possibility of further side reactions. The ether layer was separated, dried over anhydrous potassium carbonate, and used in the following experiments.

In this particular run, the ether solution was placed in a distilling flask and steam passed into it to remove the solvent. The residue, a light yellow oil, remained unchanged throughout an additional fifteen-minute heating period. At the end of this time one drop of dilute acetic acid was introduced and an immediate darkening occurred. After cooling the mixture, the oily material was extracted with ether. When this solution was dried and evaporated, it left a dark purple solid, which was washed with alcohol and recrystallized from petroleum ether (69 - 70°). The white needles thereby obtained melted at 114°. The yield of bis(5-chloro-2-furylphenylmethyl) ether was 28.2% of the theoretical amount. If the solvent from a small portion of the

(42) Gilman and Schulze, J. Am. Chem. Soc., 47, 2002 (1925).

Carefully dried ether solution of (5-chloro-2-furyl)phenylcarbinol was removed by a stream of dry air, there remained a clear light yellow oil which was stable for several hours. When heated on a water bath for a few minutes, darkening occurred, and the appearance of moisture in considerable quantities on the sides of the flask was noted. No test was made to prove that this moisture was water. After standing a short time, the dark oil solidified, and upon recrystallization, gave the same chloro-ether as above, m.p.  $114^{\circ}$ .

Another sample of the ether solution was subjected to prolonged steam distillation without decomposition. A few drops of yellow oil in the distillate solidified in an ice bath, but melted again at room temperature. They were dissolved in ether, and the solution carefully dried with anhydrous sodium sulfate. Upon removal of the solvent, the oil which remained was quite stable for several days. When heated on a water bath, as above, the same result was obtained, namely, the formation of bis(5-chloro-2-furylphenylmethyl) ether. This would indicate that the carbinol, formed as the initial product of the Grignard reaction, lost water upon heating, thus producing the chloro-ether.

Properties of Bis(5-chloro-2-furylphenylmethyl) Ether.

When pure, this compound is a white solid in the form of

needles, melting at  $114^{\circ}$ . After being stored in a desiccator containing concentrated sulfuric acid for two years, it did not decompose but merely discolored. After one recrystallization it was again pure. A small amount which was sealed in a test tube under dry nitrogen, decomposed the following day. This apparent difference in behavior was due to the fact that in the latter case, if any hydrogen chloride was evolved, it would have no chance to escape as in the case of the desiccator, but would bring about complete decomposition.

Anal. Calcd. for  $C_{22}H_{16}O_3Cl_2$ : C, 66.2; H, 4.04; Cl, 17.77; mol. wt., 399. Found: C, 66.25; H, 4.42; Cl, 17.87; mol. wt. by micro Rast (43) method, 391.5; by cryoscopic method in benzene, 364, 365. Zerewitinoff analysis: No active hydrogen.

Reaction between 5-Bromo-2-furfural (44) and Phenylmagnesium Bromide.

This reaction was carried out in the same manner as 5-chloro-2-furfural and phenylmagnesium bromide. The (5-bromo-2-furyl)phenylcarbinol was stable when subjected to steam distillation, but darkened immediately upon the addition of a drop of dilute acetic acid. The bis(5-bromo-2-furylphenylmethyl)

(43)Houben, "Die Methoden der Organischen Chemie", Leipzig, 1925, Vol. I, p.933.

(44)Gilman and Wright, J. Am. Chem. Soc., 52, 1170 (1930).

ether was more sensitive to decomposition than the corresponding chloro-ether, and hence required more care in preparation. The yield was 23.5% of the theoretical amount.

Properties of Bis(5-bromo-2-furylphenylmethyl) Ether.

When pure, this compound is a white solid, melting at 127 - 128°. It is less soluble in alcohol than the corresponding chloro-compound.

Anal. Calcd. for  $C_{22}H_{16}O_3Br_2$ : C, 54.15; H, 3.31; mol. wt. 448. Found: C, 53.56, 53.6; H, 3.46, 3.56; mol. wt. by cryoscopic method in benzene, 458, 472.

Zerewitinoff Analyses of Furyl Carbinols.

Furfuryl alcohol, water soluble, 0.91 active hydrogen, (45).

Furfuryl alcohol, water insoluble, 0.85 active hydrogen, (45).

Furylphenylcarbinol, 0.93 active hydrogen.

Diphenylfurylcarbinol, 0.91 active hydrogen.

Tetraphenyl-2,5-furyldicarbinol, 1.89 active hydrogen.

Tetramethyl-2,5-furyldicarbinol, 1.84 active hydrogen.

Tetramethyl-2,5-furyldicarbinol was prepared in the usual manner from methylmagnesium iodide and ethyl dehydromucate,

(45) Note: This sample was furnished by Dr. Willard E. Catlin.

with a yield of 26.5% of the theoretical amount. After recrystallization from petroleum ether (69 - 70°), the melting point of the white solid was 66 - 67°. The compound became greenish-yellow in color when left standing for a short time. This reaction has not been reported in the literature.

Preparation of Furylphenylcarbinol in n-Butyl Ether and Subsequent Zerewitinoff Analysis.

The purpose of this experiment was to establish a method for the identification of an active hydrogen in a carbinol, without preliminary isolation and purification. Such a run was necessary since (5-chloro-2-furyl)phenylcarbinol could not be purified without decomposition.

Phenylmagnesium bromide was prepared in the usual manner from 12.5 g. (0.08 mole) bromobenzene, except that the n-butyl ether was used in place of the diethyl ether. All excess magnesium was removed by filtration. To this solution was slowly added 5.76 g. (0.06 mole) of furfural, dissolved in 25 cc. of n-butyl ether. A negative color test showed that all the Grignard reagent had reacted. The hydrolysis with ammonium chloride required two hours. The ether layer was separated and the water layer extracted with 5 cc. of n-butyl ether. The combined ether solutions were dried in a 100 cc. volumetric flask with 4 g. of anhydrous sodium sulfate and 1 g. of sodium carbonate. After standing in an ice box for two days, enough

sodium-dried n-butyl ether was added to bring the volume to 100 cc. at 25°. A 5 cc. portion was used for a Zerewitinoff analysis, correction being made for the volume occupied by the drying agents.

Theoretical volume of methane, 67.5 cc.

Volume of methane found, 59.5 cc.

Volume of methane from blank, 10.4 cc.

Volume of methane found due to furylphenylcarbinol, 49.1 cc.

These results show that the method used is suitable for the analysis of unstable carbinols of this type and that 72% active hydrogen was present after the volume of the gas from a blank was deducted.

Preparation of (5-Chloro-2-furyl)phenylcarbinol in n-Butyl Ether and Subsequent Zerewitinoff Analysis.

To an excess of phenylmagnesium bromide there was added 8 g. (0.06 mole) of 5-chloro-2-furfural in 20 cc. of n-butyl ether. The experimental details were as nearly identical with those in the above preparation as possible. Thus the amount of methane produced should have approximated the volume obtained from an equal sample of furylphenylcarbinol. This quantity was 49.4 cc. for (5-chloro-2-furyl)phenylcarbinol as compared with 49.1 cc. from furylphenylcarbinol. This shows that an active hydrogen exists, and that the reaction between 5-chloro-

2-furfural and the Grignard reagent is perfectly normal.

Preparation of Benzophenone from Benzonitrile and Phenylmagnesium Bromide.

Six and two-tenths grams (0.06 mole) of benzonitrile were added to an excess of phenylmagnesium bromide in the same manner as above, except that the hydrolysis was accomplished by heating with 5% hydrochloric acid. The remaining manipulation was identical. Since no active hydrogen exists in benzophenone, only a small amount of methane was obtained, namely, 13.4 cc. This was comparable to that produced by the blank, and further substantiates the validity of the method used.

Oxidation and Nitration of Furylphenylcarbinol.

To 46.5 g. (0.454 mole) of acetic anhydride contained in a 200 cc. three-necked flask provided with a thermometer, a mercury-sealed stirrer, and a dropping funnel, and cooled to  $-5^{\circ}$ , there was added slowly 20.3 g. (0.316 mole) of fuming nitric acid (sp.gr., 1.5), so that the temperature did not exceed  $0^{\circ}$ . The temperature was then reduced to  $-15^{\circ}$ , and 11 g. (0.0632 mole) of furylphenylcarbinol dissolved in 20 g. of acetic anhydride was slowly added, keeping the temperature below  $-12^{\circ}$ . Care must be exercised by using another clean, dry, dropping funnel for the carbinol. No acid fumes should be al-



lowed to come in contact with the alcohol. Stirring was continued at  $-15^{\circ}$  for two hours. The mixture was poured on cracked ice and partially neutralized with 10% sodium hydroxide, followed by an excess of sodium carbonate. The brown oil which separated was extracted with ether. To this solution there was added 11 g. of pyridine. After standing fifteen minutes, the ether was removed under reduced pressure, and the residue poured on cracked ice. The mixture was extracted with ether and the solution dried with anhydrous sodium sulfate. Upon evaporation of the solvent, the brown semi-solid residue was treated with 25 cc. of methyl alcohol, allowed to stand in the cold, and filtered. The solid was recrystallized from methyl alcohol, using norite. The cream-colored 5-nitro-2-furyl phenyl ketone melted at  $112^{\circ}$ . A mixed melting point with an authentic sample was not lowered. The yield was 1.57 g., or 11.45% of the theoretical amount.

Decomposition of Bis(5-chloro-2-furylphenylmethyl) Ether to gamma-Benzalcrotonolactone.

This procedure has already been given by Wright (46). The hydrolysis was accomplished in good yields by merely refluxing either the chloro- or bromo-ether in an alcoholic solution for

(46) G. F. Wright, Doctoral Thesis, "Furfural and Some of its Derivatives". Iowa State College, 1932, page 63.

one hour, and then cooling to obtain crystals of the lactone, m.p. 85°.

In order to show that it was not the heat alone which brought about the reaction, a small amount of the bromo-ether was refluxed for six hours in a benzene solution. The compound was recovered unchanged, mp. 127°.

Preparation of gamma-Diphenylmethylene-crotonolactone from Ethyl 5-Chloro-2-furcoate and Phenylmagnesium Bromide.

To 0.52 mole of phenylmagnesium bromide there was added in the usual manner 43.6 g. (0.25 mole) of ethyl 5-chloro-2-furcoate in 200 cc. of ether. When the ether from the solution of the carbinol was evaporated, a pale yellow oil remained for approximately one minute. At the end of this time, decomposition began and hydrogen chloride was evolved. The reaction became so vigorous that a small amount of the product was lost in the mild explosion which accompanied the formation of the gas. An improved method for controlling this reaction was accomplished by first allowing a small sample of the oil to decompose, and then adding to it the ether solution. Upon removal of the ether by a stream of dry air the liberation of hydrogen chloride was apparently smooth and controlled. The dark purple residue was recrystallized from alcohol, using norite to remove the color. The yellow crystalline lactone melted at 111°, and was obtained

in a yield of 48.4% of the theoretical amount.

Anal. Calcd. for  $C_{17}H_{12}O_2$ : C, 82.25; H, 4.84. Found:  
C, 81.8; H, 5.28.

Preparation of Ethyl 5-Chloro-2-furoate.

5-Chloro-2-furoic acid was prepared according to Hill and Jackson (47) by the chlorination of ethyl furoate followed by fractional distillation in vacuum. Although certain fractions boiled over small ranges of temperature, they were still too impure to use with the Grignard reagent. The fraction boiling at  $98-110^{\circ}/19$  mm. was hydrolyzed with alcoholic sodium hydroxide. The sodium salt was dissolved in a small amount of hot water and the free acid precipitated by pouring upon iced hydrochloric acid. Upon recrystallization from hot water, the acid melted at  $176-177^{\circ}$ .

The pure ester was prepared by refluxing gently for 12 hours a mixture of 7.2 g. of 5-chloro-2-furoic acid, 12 g. of absolute ethyl alcohol, and 7 g. of concentrated sulfuric acid. The solution was then poured into ice water, and the oil extracted with ether. The mixture was washed with a sodium bicarbonate solution and dried with anhydrous sodium sulfate. After removal of the solvent, the ester was distilled in vacuum;

(47) This Thesis, page 18.

b.p. 95-96°/17 mm.;  $n_D^{25}$  1.4982;  $d_4^{25}$  1.2387.

Preparation of gamma-Diphenylmethylenecrotonolactone from Ethyl 5-Bromo-2-furoate and Phenylmagnesium Bromide.

(5-Bromo-2-furyl)diphenylcarbinol was prepared in the same way as the corresponding chloro-derivative from 21.9 g. (0.1 mole) of pure ethyl 5-bromo-2-furoate and 0.224 mole of phenylmagnesium bromide. The carbinol obtained began to decompose as soon as the ether was removed, becoming a reddish-purple in color. Hydrogen bromide was evolved and the reaction became violent. Within ten minutes a dark solid remained. Upon recrystallization from alcohol, the yellow crystalline product melted at 111°. A mixed melting point with the above crotonolactone from ethyl 5-chloro-2-furoate was not lowered. The yield was 56.5% of the theoretical amount. It might be pointed out here, that the addition of one drop of pyridine to the ether solution of (5-bromo-2-furyl)diphenylcarbinol stabilized the compound after the removal of the solvent, even upon heating at 100° for thirty minutes. When the pyridine was removed by washing with water, the remaining yellow oil decomposed quickly. This experiment was not repeated.

Preparation of Ethyl 5-Bromo-2-furoate.

The most convenient method for the preparation of 5-bromo-

2-furoic acid is given by Whittaker (48), who brominated furoic acid in a carbon tetrachloride solution. The acid, m.p. 183-184°, was purified by recrystallization from hot water. Of the various methods for esterification, the Fischer-Speier method, using dry hydrogen chloride, gave the best yield. Seventy-six grams (0.39 mole) of pure 5-bromo-2-furoic acid was dissolved in 150 cc. of absolute ethyl alcohol. After saturation with hydrogen chloride, the solution was allowed to stand over night and then poured on cracked ice. The oil was extracted with ether and the solution washed, first with water, then with dilute sodium carbonate. After drying with anhydrous sodium sulfate, and removing the solvent, the residue was distilled in vacuum, b.p. 117-118°/20 mm. The yield was 86.6% of the theoretical amount.

Preparation of (5-Chloro-2-furyl)dimethylcarbinol and its Properties.

The compound was prepared in the usual manner from 13.5 g. (0.0775 mole) of ethyl 5-chloro-2-furoate and a ten per cent excess of methylmagnesium bromide. After hydrolysis, the solvent was removed from the ether by gentle heat. The residual oil was steam distilled. About 6 cc. of oil was found in the distillate, and extracted with ether. The solution was dried

(48) Whittaker, Rec. trav. chim., 52, 352 (1933).

with anhydrous sodium sulfate and the ether evaporated. The clear yellow oil which remained, solidified on standing. The needles which formed were sometimes two inches in length. The compound was extremely soluble in all common organic solvents and would not crystallize from any of them. A small sample was dried on a porous plate for five minutes and the white solid residue was found to melt at 42-43°. A Zerewitinoff analysis of this material showed 0.84 of an active hydrogen. Within thirty minutes the compound started to decompose. It slowly lost hydrogen chloride, leaving a dark oil from which no further product was isolated.

Preparation of Methyl 5-Iodo-2-furoate.

2,5-Dichloromercurifuran was prepared by the mercuriation of furan described by Gilman and Wright (49). Iodination of this material gave mostly, 2,5-diiodofuran, which was purified first by steam distillation, and second by distillation under vacuum, b.p. 115-116°/12 mm.; m.p. 47°. This compound was immediately used for the preparation of the Grignard reagent. It has been reported (50) that an activated magnesium alloy is necessary for the preparation of 5-iodo-2-furylmagnesium iodide.

(49) Gilman and Wright, J. Am. Chem. Soc., 55, 3306 (1933).

(50) Gilman and Wright, Iowa State Coll. J. Sci., 5, 85 (1931).

It was found, however, that the reaction between the iodide and magnesium turnings began after being refluxed in dry ether for ten to fifteen minutes, if a crystal of iodine and a few drops of ethylmagnesium bromide were added. In fact, a very positive color test was obtained when the ethylmagnesium bromide was omitted. It was found advantageous to start the reaction with a small amount of magnesium turnings, and then to add the remaining required amount in the form of large pieces, in order that they might be removed prior to hydrolysis. If considerable quantities of magnesium were present during hydrolysis of the carbonated 5-iodo-2-furylmagnesium iodide, reduction occurred and furoic acid was obtained.

To 3.5 g. of magnesium turnings and 2 g. of lump magnesium, there was added a crystal of iodine and a few drops of ethylmagnesium iodide in 10 cc. of dry ether. Fifty-five and eight-tenths grams (0.17 mole) of freshly distilled 2,5-diiodofuran dissolved in 100 cc. of dry ether was placed in a dropping funnel. After adding approximately 10 cc. of this halide, the mixture was refluxed. In ten to fifteen minutes the reaction started and continued to reflux when the remainder of the diiodofuran was dropped into the flask. After all the halide had been added, the mixture was refluxed for fifteen minutes more. A very deep green color test was obtained. When the mixture

was carbonated (51) in the usual manner, a dark brown precipitate formed. The product was hydrolyzed quickly with dilute acetic acid, so that the excess of magnesium could be filtered to prevent reduction. Hydrolysis with ammonium chloride was not used because it was too slow in its action. The ether solution was extracted three times with 5% sodium hydroxide. The combined basic extractions were acidified with hydrochloric acid and the black precipitate was recrystallized from hot water. The light tan 5-iodo-2-furoic acid melted at 195°. A mixed melting point was taken with an authentic sample. The yield was 3.3 g., or 7.96% of the theoretical amount.

Four grams (0.017 mole) of 5-iodo-2-furoic acid was dissolved in 10 cc. of absolute methyl alcohol, and saturated with hydrogen chloride. The mixture was poured slowly into a cold sodium carbonate solution and the solid ester was filtered. It was recrystallized to a constant melting point of 85°. Methyl-5-iodo-2-furoate crystallized from the solution in shining plates, and was obtained in a yield of 40.5% of the theoretical amount. One and two-tenths grams of acid, however, was recovered from the basic solution.

Reaction of Methyl 5-Iodo-2-furoate and Phenylmagnesium Bromide.

To an excess of phenylmagnesium bromide in 10 cc. of ether,

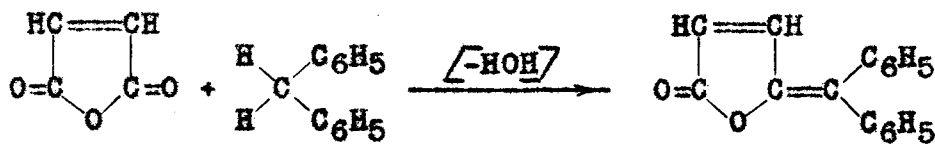
(51) Gilman and Parker, J. Am. Chem. Soc., 46, 2816 (1924).



there was added 0.5 g. (0.0004 mole) of methyl 5-iodo-2-furoate in 10 cc. of ether. A characteristic gummy precipitate formed. After refluxing for fifteen minutes, the mixture was hydrolyzed by the addition of an ammonium chloride solution. A fleeting but delicate lavender color developed for a few seconds, and then disappeared when more of the hydrolyzing solution was added. The ether layer was dried, and upon evaporation of the solvent, there remained a light-colored solid. This was stable for a few minutes, but gradually turned purple. A small amount was quickly pressed on a porous plate, leaving a white solid, m.p. 75-76°. All attempts to recrystallize the compound failed, since decomposition took place as soon as any heat was applied to aid solution. Within one-half hour the color of the material had changed to dark purple. Further decomposition was accomplished by heating on a steam bath in a vacuum. The remaining black oil solidified after standing over night. This was recrystallized from hot petroleum ether (77-115°). The light tan precipitate melted at 85-86° and gave a positive micro test for iodine. The yield was approximately 0.01 g. A mixed melting point with gamma-diphenylmethylene-crotonolactone was 60°, showing that this reaction was entirely different from the corresponding chloro- and bromo-esters.

An Attempt to Synthesize  $\gamma$ -Diphenylmethylene-crotonolactone.

Using a synthesis somewhat similar to that given by Thiele (52), a mixture of 9.8 g. (0.1 mole) of maleic anhydride and 16.8 g. (0.1 mole) of diphenylmethane was heated to 150°, and 16 cc. of acetic anhydride was added, dropwise, with stirring, over a half-hour period. It was hoped that the two hydrogen atoms in diphenylmethane would be sufficiently active to remove one of the oxygen atoms of the carbonyl group in maleic anhydride, thus forming a double bond.



Upon removal of the diphenylmethane by steam distillation, only approximately 0.1 g. of gummy residue remained. This did not yield any solid material upon extraction with petroleum ether. (69-70°).

Reduction of  $\gamma$ -Diphenylmethylene-crotonolactone to Diphenyllevulinic Acid.

One gram of the lactone was refluxed for five hours with 5 cc. 47% hydriodic acid. Since the reaction started immediate-

(52) Thiele, Ann., 306, 242 (1899).

ly, this time could have been shortened. The mixture was then made basic with sodium hydroxide and extracted with ether to remove any foreign material. The alkaline layer was then acidified with hydrochloric acid and extracted three times with small portions of ether to remove the diphenyllevulinic acid. Upon drying, and evaporating the ether solution, an oil was obtained which was recrystallized from petroleum ether (69-70°). Five-tenths grams of white crystalline acid was isolated, m.p. 107°. A mixed melting point with known diphenyllevulinic acid prepared from diphenylfurylcarbinol was not lowered.

Hydrolysis of  $\gamma$ -Diphenylmethylene-crotonolactone followed by Reduction to Diphenyllevulinic Acid.

A mixture of 0.5 g. of this lactone, 7 cc. of alcohol, and 10 cc. of saturated sodium carbonate (53) was heated on a steam bath for one hour, allowing most of the alcohol to evaporate. A 10 cc. portion of water was added, thus obtaining a clear solution. The odor of asymm-diphenylacetone was quite noticeable. The basic solution was extracted with ether and the ether solution discarded. After acidification with hydrochloric acid, the aqueous layer was again extracted to remove the acidic compounds. This ether solution was evaporated and the

(53) Thiele, Ann., 306, 149 (1899).

oily residue dissolved in 10 cc. of 10% sodium hydroxide. To this there was added 3 g. of zinc dust, and the mixture was heated for fifteen minutes at the boiling point. After filtering, the solution was extracted twice as indicated above. The ether solution containing the acidic compounds was evaporated to dryness, leaving a yellow oil. This was extracted with boiling water and the solution hurriedly filtered. Upon standing for several hours, a white solid precipitated. After recrystallization from petroleum ether (69-70°), the white solid, diphenyllevulinic acid, melted at 107-108°. A mixed melting point with diphenyllevulinic acid prepared from diphenylfurylcarbinol was not lowered. The low yield of approximately 0.05 g. was probably due to cleavage of the lactone as well as hydrolysis, since asymm-diphenylacetone was recognized by its odor.

Action of Aqueous Sodium Hydroxide on  $\gamma$ -Diphenylmethylenecrotonolactone.

A mixture of 1 g. of the lactone and 100 cc. of 5% sodium hydroxide was subjected to steam distillation. The volume of liquid was kept constant by the application of more heat when necessary. An oil slowly collected in the distillate. When approximately 800 cc. of distillate had been collected, it was extracted with ether. After drying with anhydrous sodium sulfate the solution was evaporated, leaving an oil with a char-

acteristic sweet odor. After cooling and scratching with a glass rod, it solidified. Recrystallization from petroleum ether (69-70°) gave a white solid, m.p. 46°. This was the lower melting form of asymm-diphenylacetone, which slowly reverted to the higher melting variety, m.p. 61°. Both forms, however, gave the same oxime, m.p. 163°. A mixed melting point with the oxime of known asymm-diphenylacetone showed no lowering. The yield was 77.2% of the theoretical amount.

Further investigation of the aqueous solution remaining in the distilling flask, revealed no oxalic acid in contrast to that obtained from alpha-bromo-gamma-diphenylmethylene-crotonolactone (54).

Action of Alcoholic Potassium Hydroxide on gamma-Diphenylmethylene-crotonolactone.

One gram of this lactone was refluxed for six hours with methyl alcoholic potassium hydroxide prepared by dissolving 10 g. of alkali in 25 cc. of absolute methyl alcohol. A solid potassium salt was filtered, washed with a small amount of alcohol, and dissolved in 10 cc. of water. After being acidified with hydrochloric acid and cooled, 0.19 g. of white solid precipitated. This was identified as fumaric acid by esterification, using methyl alcohol and dry hydrogen chloride. The

(54) This Thesis, page 83.

methyl fumarate was recrystallized from "Skelly D" (77—115°) and melted at 102-103°. A mixed melting point with an authentic sample was not lowered. The yield of fumaric acid was 40.6% of the theoretical amount. The alcoholic filtrate from the potassium fumarate was poured into 50 cc. of water and the oil extracted with ether. After drying with calcium chloride and evaporating the solvent, the residue was nitrated with 3 cc. of fuming nitric acid in an ice bath. The product was diluted with cold water, filtered, and washed with hot alcohol. This dinitrodiphenylmethane, melting at 183°, was obtained in a yield of 67.3% of the theoretical amount. A mixed melting point with an authentic sample was not lowered.

An Attempt to Synthesize Diphenyllevulinic Acid from the Monoethyl Ester of Succinyl Chloride and Benzohydrylmagnesium Chloride.

It was hoped that the acid chloride group, being more active according to Enteman and Johnson (55) than the carboethoxy group, would react in the major portion of this synthesis. This would have produced ethyl diphenyllevulinate.

To 3.84 g. (0.023 mole) of the monoethyl ester of succinyl chloride (56) dissolved in 100 cc. of ether, was added with the

(55) Enteman and Johnson, J. Am. Chem. Soc., 55, 2900 (1933).

(56) Michaels and Hermens, Ber., 25, 2747 (1892).

usual precautions, 0.022 mole of benzhydrylmagnesium chloride (57). When each drop of Grignard reagent hit the solution, there developed a fleeting orange color which disappeared in a fraction of a second. After the addition of the Grignard reagent, a positive color test was obtained, which may or may not have had any significance (58) since acid chlorides give positive tests also. The mixture was hydrolyzed with an ammonium chloride solution and the ether layer was dried with anhydrous sodium sulphate. Upon evaporation of the solvent, an oil was obtained along with a small amount of solid tetraphenylethane, m.p. 214-216°. No mixed melting point was taken. The oil was extracted with alcohol, and the solution was then evaporated. One-half the residue was distilled in vacuum, but the boiling point was considerably lower than that of ethyl diphenyllevulinate. The other half was refluxed for six hours with 5% hydrochloric acid. After this treatment the insoluble oil was collected with ether. The ether solution was extracted with 5% sodium hydroxide to remove any diphenyllevulinic acid, but nothing precipitated when the basic solution was acidified.

Preparation of Diphenyllevulinic Acid from Diphenylfurylcarbinol.

The reaction used by Chichibabin (14) was slightly modi-

- (57) Gilman and Zoellner, J. Am. Chem. Soc., 52, 3984 (1930).  
(58) Gilman and Heck, ibid., 52, 4949 (1930).

fied to suit the conditions. Twenty-two and eight-tenths grams (0.0912 mole) of freshly prepared diphenylfurylcarbinol was dissolved in 45 g. of absolute ethyl alcohol. Dry hydrogen chloride was passed into the solution until a slight warming was noted. The mixture was then refluxed for four hours and poured into 250 cc. of 5% sodium carbonate. The oil which precipitated was extracted with ether and dried with anhydrous sodium sulfate. After removal of the solvent, the residue was distilled in vacuum, b.p. 226-227°/7 mm.;  $n_D^{25}$  1.552;  $d_4^{25}$  1.159. The yield of ethyl diphenyllevulinate was 12.9 g. or 47.7% of the theoretical amount.

Hydrolysis of this ester was first attempted with alkaline reagents, but only a very poor yield of diphenyllevulinic acid was obtained. It was found, however, that prolonged refluxing with ten parts of 5% hydrochloric acid gave a 72.2% yield of the theoretical amount. The product was extracted from the reaction mixture with ether, which in turn was extracted with 5% sodium hydroxide. This basic solution was acidified and again extracted with ether. After being dried with anhydrous sodium sulfate, the solvent was evaporated. The residue occasionally was an oil which required several weeks to solidify. This oil crystallized from an ether-ligroin (69-70°) mixture in the form of a white needle-like solid, m.p. 107-108°.

Anal. Calcd. for  $C_{17}H_{16}O_3$ : C, 76.2; H, 5.97; mol.wt.,



268; active hydrogen, 1.0. Found: C, 76.0; H, 6.59; mol.wt. by Rast method, 270; active hydrogen, 1.1.

Oxidation of Diphenyllevulinic Acid.

To 1 g. of this acid dissolved in 50 cc. of 5% sodium hydroxide there was slowly added 1 g. of potassium permanganate in 65 cc. of water. After thirty minutes the mixture was filtered, and the clear solution extracted with ether. The ether solution, having been dried and evaporated, left an oil which, when treated with hydroxylamine, gave 0.26 g. of benzophenone oxime. This was identified by a mixed melting point with an authentic sample. The yield was 74% of the theoretical amount.

The alkaline filtrate was acidified and carefully evaporated to dryness on a sand bath. The residue was pulverized and extracted three times with small portions of hot alcohol. These extracts were evaporated, leaving a white residue which was slightly sticky. After refluxing for one hour with 25 cc. of ether, and filtering while hot, the solution was evaporated to 5 cc. The supernatant liquid was decanted and the crystals remaining were dissolved in 0.5 cc. of alcohol. Upon evaporation to two drops, crystals formed. These melted at 183-184°. A mixed melting point with known succinic acid was 185-6°. The yield was approximately 0.02 g.

Cleavage of Diphenyllevulinic Acid with Alcoholic Potassium Hydroxide.

Five-tenths grams of this acid was refluxed for six hours with 10 cc. of concentrated methyl alcoholic potassium hydroxide. The potassium salt which separated, was filtered and washed with a small quantity of methyl alcohol. The filtrate was diluted with several times its volume of water, and then extracted with ether. The ether solution was dried with calcium chloride and evaporated. The residue was nitrated in an ice bath with 2 cc. of fuming nitric acid and poured into cold water. The solid, m.p. 182-183°, was filtered and recrystallized from benzene. A mixed melting point with known dinitrodiphenylmethane was not lowered. The yield was 70.8% of the theoretical amount.

The solid potassium salt was dissolved in a 5 cc. of water, filtered, acidified with hydrochloric acid, and evaporated to dryness on a sand bath. The residue was pulverized and extracted three times with 5 cc. portions of hot alcohol. These were evaporated to dryness and washed with small amounts of ether. The succinic acid obtained weighed 0.2 g. and represented a 91% yield. Its p-toluidide was prepared and a mixed melting point with an authentic sample of succin-p-toluidide, m.p. 263°, was not lowered.

Preparation of  $\gamma$ -Diphenylmethylene-crotonolactone from 5-Bromo-2-furyl Phenyl Ketone and Phenylmagnesium Bromide.

To an excess of phenylmagnesium bromide there was added 6 g. (0.0239 mole) of 5-bromo-2-furyl phenyl ketone, obtained from J. M. Straley (59), who prepared it by the bromination of furyl phenyl ketone. A white crystalline precipitate formed and the mixture was refluxed for fifteen minutes. A positive color test indicated an excess of Grignard reagent. After hydrolysis with a cold ammonium chloride solution, the ether layer was dried with anhydrous sodium sulfate. It was noticed that the (5-bromo-2-furyl)diphenylcarbinol, thus prepared, was extremely unstable as evidenced by the decomposition which took place around the edges of the flask containing the ether solution. The solvent was removed by a stream of dry air, and the dark purple residue continued to evolve hydrogen bromide. The decomposition was then hastened by heating on a water bath and by applying a vacuum. The black oil solidified on standing a few hours. This was recrystallized from alcohol, giving tan crystals which melted at 110-111°. The yield was 55.7% of the theoretical amount. A mixed melting point with  $\gamma$ -diphenylmethylene-crotonolactone, prepared from ethyl 5-bromo-2-furoate and the Grignard reagent, showed no lowering.

(59) J. M. Straley, Doctoral Thesis, page 31, Iowa State College, 1936.

Preparation of Ethyl 4,5-Dibromo-2-furoate.

Furoyl chloride was first prepared according to the method given by Baum (60) using furoic acid and thionyl chloride. The yield by this procedure was very good. To 180 g. (1.276 mole) of furoyl chloride there was slowly added, at room temperature, 600 g. (7.5 mole) of bromine, through a reflux condenser. After the addition was completed, the mixture was refluxed in an oil bath for four hours. At the end of this time the pressure was reduced and a vacuum applied for ten hours, until the excess bromine was removed along with hydrogen bromide. To this mixture was added 460 g. (10 mole) of ethyl alcohol, taking care that the reaction did not become too violent. After refluxing again for four hours, the ester was poured into ice water, with stirring, and the oil collected with ether, dried, and distilled in vacuum. A modified Claisen flask was very helpful in separating the monobromo-ester from the dibromo-ester. The fraction boiling at  $131^{\circ}/16$  mm. contained only a small amount (25 g.) of dibromo-ester, which was recovered by another distillation. The fraction boiling at  $131-145^{\circ}/16$  mm. contained practically pure dibromo-compound and solidified upon cooling. It was recrystallized from methyl alcohol, giving a pure product, m.p.

(60) Baum, Ber., 37, 2951 (1904).

57-58° (61). The yield based upon the furoyl chloride was 44.2% of the theoretical amount.

Preparation of alpha-Bromo-gamma-diphenylmethylenecrotonolactone from Ethyl 4,5-Dibromo-2-furoate and Phenylmagnesium Bromide.

To 0.056 mole of phenylmagnesium bromide in 74 cc. of ether there was slowly added 7.94 g. (0.0278 mole) of the ester dissolved in 35 cc. of dry ether. A dark viscous oil separated. An abnormal length of time was required to hydrolyze the Grignard-complex with an ammonium chloride solution. The ether layer was dried and the solvent evaporated with air. Decomposition began before all the ether was removed. The dark purple residue was washed with a little ether and then with ligroin (69-70°). There remained a tan colored solid which, after being recrystallized from carbon tetrachloride and decolorized with norite, gave sparkling yellow crystals, m.p. 158°. The yield was 52.8% of the theoretical amount.

Anal. Calcd. for  $C_{17}H_{11}O_2Br$ : C, 62.35; H, 3.36; mol.wt., 327. Found: C, 62.3; H, 3.74; mol.wt. by cryoscopic method, 312, by Rast method, 332.

(61) Hill and Sanger, Proc. Am. Acad. Arts Sci., 21, 164 (1885-1886).

Reduction of alpha-Bromo-gamma-diphenylmethylene-crotonolactone to Diphenyllevulinic Acid.

One gram of the lactone was refluxed with 5 cc. of 47% hydriodic acid for five hours. The same technique was used in isolating diphenyllevulinic acid as was followed in the experiment concerning the reduction of the corresponding halogen-free lactone (62). The acid which was obtained required ten days to solidify, and was then crystallized from petroleum ether (77-115°), m.p. 105-106°. A mixed melting point with diphenyllevulinic acid prepared from diphenylfurylcarbinol was 107-108°. The yield was 54.8% of the theoretical amount.

Action of Aqueous Sodium Hydroxide on alpha-Bromo-gamma-diphenylmethylene-crotonolactone.

Two grams of the lactone was placed in a 100 cc. distilling flask equipped with a condenser, and 28 cc. of 5% sodium hydroxide was added. Steam was passed through the mixture, the level of the liquid being kept approximately constant by the application of more heat. When no more oil was visible in the distillate, the reaction was stopped. The volatile oil was collected with ether, and the solvent evaporated. The remaining product was treated with hydroxylamine, giving 41 g. of the oxime of asymm-diphenylacetone, or a yield of 33.6%.

(62) This Thesis, page 70.

When the above basic solution was acidified, a precipitate formed. After being filtered and dried, the compound weighed 0.81 g., which represented a yield of 62.4%. It melted at 143-144° and a mixed melting point with diphenylacetic acid was not lowered. In order to be absolutely positive, diphenylacetamide was prepared according to Japp and Knox (63) by way of the acid chloride. It melted at 167° and a mixed melting point with an authentic sample was not lowered.

The acidic filtrate from diphenylacetic acid was made basic with sodium hydroxide and extracted with ether to remove undesirable material. The aqueous layer was acidified and carefully evaporated to dryness. The residue, after being pulverized, was extracted twice with small amounts of hot alcohol to remove any oxalic acid. These alcoholic extracts were combined and evaporated. The remaining acid was used to prepare a derivative with p-toluidine. The oxal-p-toluidide melted at 268° and a mixed melting point with an authentic sample was 269°. The yield was 8% of the theoretical amount.

Preparation of  $\alpha$ ,  $\beta$ -Dibromo- $\gamma$ -diphenylmethylene-erotenolactone from Ethyl 3,4,5-Tribromo-2-furoate and Phenylmagnesium bromide.

To 0.07 mole of phenylmagnesium bromide in 50 cc. of ether

(63) Japp and Knox, J. Chem. Soc., 87, 685 (1905).

there was slowly added 11.3 g. (0.03 mole) of the above ester dissolved in 200 cc. of ether. After hydrolysis, the ether layer was dried and evaporated in a stream of air. The light brown oil remaining seemed to be quite stable for a short time, even when heated for five minutes on a water bath. To start decomposition, a trace of hydrogen chloride was introduced, and the carbinol soon began to darken. When heated on a steam bath, the reaction proceeded rapidly, leaving a black solid residue. Alcohol would not dissolve this lactone even on boiling. Carbon tetrachloride, however, proved to be a good solvent for its recrystallization. A yellowish-brown, crystalline, compound precipitated on cooling. When purified several times in this manner the lactone melted at  $211^{\circ}$ . The yield was 27.1% of the theoretical amount.

Anal. Calcd. for  $C_{17}H_{10}O_2Br$ : Br, 39.38. Found: Br, 39.57, 39.75.

#### Preparation of Ethyl 3,4,5-Tribromo-2-furoate.

3,4,5-Tribromo-2-furoic acid was prepared according to Hill and Sanger (64). Thirty grams (0.157 mole) of 5-bromo-2-furoic acid was exposed to the vapors of bromine in a desiccator, until the weight had increased to that demanded by the

(64) Hill and Sanger, Proc. Am. Acad. Arts Sci., 21, 175 (1885-1886).



formula for monobromopyromucic tetrabromide. In this case, the weight increased to 80 g. in six days. This reddish, gummy mass was dissolved in 100 cc. of absolute ethyl alcohol and cooled in an ice-salt bath. While the mixture was being mechanically stirred, there was added slowly a saturated solution of sodium hydroxide in absolute ethyl alcohol, until no further precipitate formed. After filtering, the sodium salt was dissolved in a minimum quantity of water, and poured into an excess of iced sulfuric acid solution. The crude tribromofuroic acid was quite insoluble in cold water, but was recrystallized from boiling water, m.p. 218-219°. The yield was 9.4 g., or 17.1% of the theoretical amount. Hill did not give any yield.

The acid was esterified according to the directions of Hill and Sanger, using concentrated sulfuric acid and absolute ethyl alcohol. The yield of the ester was 94.3% of the theoretical amount. Some free tribromofuroic acid was recovered. The ester was purified by recrystallization from alcohol, and melted at 104°.

Action of Aqueous Sodium Hydroxide on alpha,beta-Dibromogamma-diphenylmethylene-crotonolactone.

This lactone was treated with 5% sodium hydroxide and heated with steam in the manner described above for the monobromo-

lactone. The purpose was merely to show that no oil steam-distilled, and hence no diphenylacetone was obtained. The solution in the distilling flask became wine-red in color. No further products were sought.

Preparation of alpha-Chloro-gamma-diphenylmethylene-crotonolactone from Ethyl 4,5-Dichloro-2-furoate and Phenylmagnesium Bromide.

An ether solution containing 8.9 g. (0.042 mole) of ethyl 4,5-dichloro-2-furoate, prepared according to Hill and Jackson (19) and called 3,5- by them, was added to 0.09 mole of phenylmagnesium bromide in 50 cc. of ether. After hydrolysis, the ether layer was dried with anhydrous sodium sulfate. A small amount of this solution was evaporated, leaving a viscous yellow oil which looked as though it might crystallize. Hence it was cooled and scratched with a glass rod. Instead of solidifying, it decomposed at the point of contact, hydrogen chloride being evolved. The residue was dark purple in color. The remainder of the carbinol solution was then added to the part already decomposed, and the ether was removed by a stream of dry air. Instead of a dark colored residue, as in all other similar cases of decomposition, a light brown solid was obtained, after the loss of hydrogen chloride. When recrystallized several times from alcohol, using norite, 9.7 g. of yellow lactone formed, showing a constant melting point of 127°.

This yield of 80.1% represents the highest ever attained with this type of decomposition.

Anal. Calcd. for  $C_{17}H_{11}O_2Cl$ : Cl, 12.55. Found: Cl, 12.56, 12.48.

Action of Aqueous Sodium Hydroxide on  $\alpha$ -Chloro- $\gamma$ -diphenylmethylenecrotonolactone.

One-half gram of this lactone was placed in a 100 cc. distilling flask equipped with a condenser, and 25 cc. of 5% of sodium hydroxide was added. Steam was passed through the mixture, the level of the liquid being kept approximately constant by the application of more heat. When no more volatile oil was visible in the distillate, the reaction was stopped and the oil collected with ether. After evaporation of the solvent, the residue was treated with hydroxylamine, giving 0.09 g. of asymm-diphenylacetone oxime, m.p.  $163^{\circ}$ . This was identified by means of a mixed melting point with an authentic sample. The yield was 19.8% of the theoretical amount.

When the above basic solution was acidified, the precipitate which formed was filtered and dried, m.p.  $143-144^{\circ}$ . It proved to be diphenylacetic acid and was identified by means of a mixed melting point with a known sample. The corresponding acid amide was made and further identified by its melting point,  $167^{\circ}$ . The yield was 53.4% of the theoretical amount.

The acidic filtrate from the diphenylacetic acid was made basic with sodium hydroxide and extracted with ether to remove any undesirable material. The aqueous layer was acidified and carefully evaporated to dryness on a sand bath. The residue, after being pulverized, was extracted twice with small portions of hot alcohol, to remove any oxalic acid. The remaining acid was treated with *p*-toluidine to get oxal-*p*-toluidide, m.p. 268-269°. A mixed melting point with an authentic sample was not lowered. The yield was 0.02 g. or 5% of the theoretical amount.

Preparation of beta-Chloro-gamma-diphenylmethylene-crotonolactone from Ethyl 3,5-Dichloro-2-furoate and Phenylmagnesium Bromide.

An ether solution containing 5.7 g. (0.0272 mole) of ethyl 3,5-dichloro-2-furoate, prepared according to Hill and Jackson (18) and called *γ*-dichloro- by them, was added to 0.06 mole of phenylmagnesium bromide. After hydrolysis, the ether layer was dried and evaporated. The yellow oil remaining was warmed on a water bath for a few minutes and then it suddenly decomposed. The reaction was quite violent and almost foamed out of the flask. The reddish-brown oil which was left after the hydrogen chloride was lost, soon solidified. After several recrystallizations from alcohol, using norite, the yellow crystals melted at 128.5°. A mixed melting point with the corresponding α-chlorolactone was 98°, showing the dissimilarity of the two

isomers.

Anal. Calcd. for  $C_{17}H_{11}O_2Cl$ : Cl, 12.55. Found: Cl, 12.69, 12.60.

Action of Aqueous Sodium Hydroxide on  $\beta$ -Chloro- $\gamma$ -diphenylmethylene-crotonolactone.

One-half gram of this lactone was treated with 25 cc. of 5% sodium hydroxide in the same manner as the  $\alpha$ -chlorolactone (65). No volatile diphenylacetone steam distilled. The only change was the development of a wine-red color in the distillation flask. The result of this experiment was identical with that obtained from the  $\alpha$ ,  $\beta$ -dibromolactone (66).

Preparation of  $\alpha$ ,  $\beta$ -Dichloro- $\gamma$ -diphenylmethylene-crotonolactone from Ethyl 3,4,5-Trichloro-2-furoate and Phenylmagnesium Bromide.

To 0.12 mole of phenylmagnesium bromide in 90 cc. of ether, there was added 10.67 g. (0.05 mole) of ethyl 3,4,5-trichloro-2-furoate dissolved in 100 cc. of ether. A dark purple color soon developed, but disappeared upon hydrolysis. The light brown ether layer was dried, and a small amount was evaporated, leaving a viscous yellow oil with the characteristic odor of

(65 ) This Thesis, page 87.

(66 ) This Thesis, page 85.

furyl carbinols. This odor resembles that of furfural but is much more fragrant, and not quite so intense. The carbinol seemed to be quite stable when heated for a few minutes on a water bath. To hasten decomposition, a trace of hydrogen chloride was added and the carbinol heated again. The product lost hydrogen chloride and changed to a brown solid in approximately thirty minutes. The main ether solution was added to this material and the solvent evaporated. The residue was heated on a steam bath for five or ten minutes, until it suddenly decomposed and solidified in about thirty seconds. There remained a dark red material which was first washed with alcohol, and then dissolved in 50 cc. of hot chloroform. After adding an equal volume of alcohol, and cooling, light colored orange-brown crystals were obtained. Upon crystallization from an ether-alcohol mixture, the orange lactone melted at  $178^{\circ}$ . The yield was 54.9% of the theoretical amount.

Anal. Calcd. for  $C_{17}H_{10}O_2Cl_2$ : Cl, 22.37. Found: Cl, 22.60, 22.82.

Preparation of Ethyl 3,4,5-Trichloro-2-furoate.

Trichlorofuroic acid was prepared according to Hill and Jackson (67) by the chlorination of ethyl furoate in two suc-

(67) Hill and Jackson, Am. Chem. J., 12, 119 (1890).

cessive stages, first, by substitution, and second, by addition. When the tetrachloride of the ethyl chlorpyromucate was decomposed by alcoholic sodium hydroxide, the sodium trichlorofuroate precipitated in an impure state. The free acid was purified by recrystallization of the ammonium salt. The acid melted at  $172^{\circ}$ .

The ester was prepared by saturating a mixture of 29.5 g. (0.1595 mole) of trichlorofuroic acid and 200 cc. of absolute ethyl alcohol with dry hydrogen chloride gas. The liquid was poured into a cold sodium carbonate solution and the solid ester was filtered, m.p.  $62^{\circ}$ . The yield was 63.9% of the theoretical amount. There was also 4.7 g. of trichlorofuroic acid recovered. Hill did not give any yields.

Action of Aqueous Sodium Hydroxide on alpha, beta-Dichloro-gamma-diphenylmethylenecrotenolactone.

One-half gram of this lactone was treated with 25 cc. of 5% sodium hydroxide in the same manner as the alpha-chloro-lactone (68). No volatile diphenylacetone steam distilled. The only change was the development of a wine-red color in the distillation flask. The result of this experiment was identical with that obtained from the alpha, beta-dibromolactone (69).

(68) This Thesis, page 87.

(69) This Thesis, page 85.

Preparation of  $\alpha$ ,  $\beta$ -Dichloro- $\gamma$ -diphenylmethylenecrotonolactone from Ethyl 5-Bromo-3,4-dichloro-2-furoate and phenylmagnesium Bromide.

To 0.072 g. (0.00025 mole) of ethyl 5-bromo-3,4-dichloro-2-furoate dissolved in 5 cc. of ether, there was added 1 cc. of ether containing 0.0016 mole of Phenylmagnesium bromide. The light purple color which developed disappeared upon hydrolysis with 5 cc. of saturated ammonium chloride solution. The clear yellow ether solution was evaporated and the remaining oil, upon heating with steam, began to darken in a few minutes, evolving hydrogen bromide. Upon the application of further heat, the oil gradually solidified. The residue was recrystallized from an alcohol-chloroform mixture and melted at  $178^{\circ}$ . The yield was 0.033 g., or 41.7% of the theoretical amount.

Preparation of Ethyl 5-Bromo-3,4-dichloro-2-furoate.

a. 3,4-Dichloro-2-furoic acid (70) was first prepared by passing chlorine into 70 g. (0.5 mole) of ethyl furoate at  $0^{\circ}$ , until the weight had increased to 141 g. The mixture was then poured into an ice cold, saturated, alcoholic, sodium hydroxide solution. The sodium salts thus precipitated, were filtered, dried, and suspended in 300 cc. of water. This mixture was

(70) Hill and Jackson, Am. Chem. J., 12, 38 (1890).



acidified with hydrochloric acid, and the free dichlorofuroic acid filtered. The crude material was crystallized from benzene, and the color removed with norite. The pure acid melted at 168-169° and was obtained in a yield of 30.5%.

b. Eighteen and one-tenth grams (0.1 mole) of 3,4-dichloro-2-furoic acid was placed in a desiccator containing 18 g. (0.1 mole) of bromine. When the gain in weight of the acid showed that approximately one atom of hydrogen had been substituted, the mixture was treated with 100 cc. of boiling water and filtered while hot. The precipitate obtained upon cooling and filtering the solution, was recrystallized from 50% alcohol. The 5-bromo-3,4-dichloro-2-furoic acid (71) melted at 185-186°. The yield was 17.9 g. or 68.8% of the theoretical amount. Hill did not give any yield.

c. A mixture of 13.4 g. (0.051 mole) of 5-bromo-3,4-dichloro-2-furoic acid and 75 cc. of absolute ethyl alcohol was saturated with dry hydrogen chloride and then poured into a cold saturated solution of sodium carbonate. The ester which precipitated was filtered and recrystallized from 90% alcohol until a constant melting point of 99-100° was obtained. The yield of ethyl 5-bromo-3,4-dichloro-2-furoate was 5 g. or 34% of the theoretical amount. Six grams of the original acid was recover-

(71) Hill and Jackson, Am. Chem. J., 12, 125 (1890).

ed.

Anal. Calcd. for  $C_7H_5O_3Cl_2Br$ : AgCl and AgBr from  
0.2000g., 0.3298 g. Found: 0.3298 g., 0.3504 g.

Preparation of Hill's alpha-Anilido-crotonolactone from  
4,5-Dibromo-2-furoic Acid.

This lactone was prepared according to the rather indefinite directions given by Hill and Cornelison (72).

a. Preparation of 4,5-Dibromo-2-furoic Acid.

This compound, melting at  $167-168^{\circ}$ , was made by the saponification of ethyl 4,5-dibromo-2-furoate (73) when an alcoholic solution of the ester was slowly added to an excess of alcoholic potassium hydroxide. The potassium salt of the acid precipitated immediately and was filtered. After being dried, it was dissolved in a minimum quantity of hot water and poured, with stirring, into an excess of 15% hydrochloric acid. The yield of dibromofuroic acid, based on the ester, was 88.5%.

b. Preparation of Brommaleyl Bromide.

Ten grams (0.037 mole) of 4,5-dibromo-2-furoic acid was suspended in 300 cc. of water contained in a 500 cc. round-

(72) Hill and Cornelison, Am. Chem. J., 16, 278 (1894).

(73) This Thesis, page 80.

bottomed flask equipped with a mechanical stirrer. To this mixture was slowly added 11.8 g. (0.074 mole) of bromine with cooling. The disappearance of the bromine color was accompanied by formation of a yellow oil which solidified when allowed to stand over night. The white brommaleyl bromide melted at 53-54° and was sufficiently pure for the next step. The yield was 6.95 g., or 59% of the theoretical yield.

c. Preparation of alpha-Bromocrotonolactone.

To 6.95 g. (0.0216 mole) of brommaleyl bromide dissolved in 11 cc. of 80% acetic acid there was slowly added, in small amounts, 4.6 g. of zinc dust. The mixture was cooled with cold water and stirred mechanically for thirty minutes. It was then allowed to stand for one hour longer. At the end of this time it was filtered, poured into 100 cc. of water, and extracted with three small portions of ether. The ether solutions were dried with calcium chloride and evaporated. The white needle-like crystals, melting at 75-76°, were called alpha- bromocrotonolactone by Hill. Upon recrystallization from ligroin (77-115°), the pure substance melted at 77°. The yield was 62.3% of the theoretical amount.

d. Preparation of alpha-Anilido- crotonolactone.

A mixture of 5 g. (0.0033 mole) of the above bromo-

lactone, 20 drops of aniline, and 10 cc. of 50% alcohol was left standing over night. The brown crystals were filtered and recrystallized, first from glacial acetic acid, and then from alcohol. The color was removed with norite. The crystals were deposited in the form of short thick needles with a pinkish tint, m.p.  $220^{\circ}$ . The yield was 17.3% of the theoretical amount.

Preparation of Wolff's beta-Anilido-crotonolactone using beta-Bromotetronic acid.

a. Preparation of beta-Bromotetronic Acid.

beta-Bromotetronic acid was prepared according to Wolff and Schwabe (24) by bromination of acetoacetic ester followed by the elimination of ethyl bromide upon heating. Some trouble was experienced with the reduction, hence the following directions are given. One-half gram of beta-bromotetronic acid was dissolved in 3 cc. of saturated sodium carbonate solution to which there was added, in four portions, 10 g. of sodium amalgam. The temperature was kept at  $50^{\circ}$  by external cooling. After being stirred for 5 - 10 minutes, the mixture was cooled and carefully acidified with 1:1 sulfuric acid. A little ether was added to prevent loss through foaming. The clear aqueous layer was extracted with five small portions of ether. The combined ether layers were dried and evaporated, leaving tetronic acid. The melting point was  $135-138^{\circ}$ . The yield was

not determined, but was apparently low.

b. Preparation of beta-Anilido-Crotonolactone.

Without further purification the tetronic acid was warmed on a water bath with a few drops of aniline (23). The reaction took place very quickly and was completed in thirty seconds. The residue was recrystallized twice from hot alcohol, giving a snow-white solid, m.p.  $221^{\circ}$ . The yield was approximately 0.05 g.

Preparation of beta-Anilido-crotonolactone using the Synthesis of Anschütz and Bertram (25).

a. Preparation of Acetylglycollic Acid.

To 100 g. (1.31 mole) of glycollic acid, contained in a 500 cc. distilling flask provided with a reflux condenser, there was carefully added 200 g. (2.55 mole) of acetyl chloride. The mixture was heated to insure complete reaction. When the evolution of hydrogen chloride ceased, the excess acetyl chloride was distilled. The residue, when cooled, solidified. After recrystallization from benzene, the acetylglycollic acid melted at  $66-68^{\circ}$ . The yield was 129 g. or 83.7% of the theoretical amount.

b. Preparation of Acetylglycollyl Chloride.

To 100 g. (0.848 mole) of melted acetylglycollic acid contained in a 500 cc. round-bottomed flask provided with a reflux condenser, there was added, dropwise, 130 g. (0.946 mole) of phosphorus trichloride. After the evolution of hydrogen chloride had ceased, the liquid was decanted from the viscous phosphorous acid into a 250 cc. Claisen flask and distilled in vacuum, b.p. 54°/14 mm. The quantity of acetylglycollyl chloride obtained was 54 g., which represented a yield of 47.3% of the theoretical amount. This acid chloride was very irritating to the eyes.

c. Preparation of alpha-Carbomethoxy-tetronic Acid.

A solution of 52 g. (0.41 mole) of dimethylmalonate dissolved in 400 cc. of dry benzene was added to 9.2 g. (0.4 mole) of powdered sodium. The mixture was refluxed until all the sodium had reacted. A white gelatinous precipitate formed. To this there was added 17.4 g. (0.127 mole) of acetylglycollyl chloride dissolved in 25 cc. of benzene. The mixture was stirred mechanically for thirty hours, but no "off-brown" color developed as Anschütz and Bertram reported. For this reason the yellow precipitate was filtered and refluxed fifteen hours with 50 cc. of methyl alcohol. The cream colored solid was filtered and dried. It weighed 29 g. To this sodium salt, suspended in 500 cc. of ice cold water, was added 15 cc. of

concentrated hydrochloric acid, with stirring. The white precipitate which formed was filtered and recrystallized from methyl alcohol. The yield was 14 g., or 70% of the theoretical amount. The melting point obtained was 191-193° (decomposition) as compared to 171-173° (decomposition) given by Anschütz and Bertram. The rate of heating was approximately 2° per minute.

d. Preparation of Tetronic Acid.

Four grams (0.25 mole) of this material was refluxed with 4.5 g. of sodium methoxide prepared by dissolving 1.9 g. of sodium in 23 cc. of methyl alcohol. There was also added 20 cc. of water. A flocculent white precipitate formed, which contained the sodium salt of tetronic acid along with a small amount of sodium carbonate. After filtration, it was dissolved in 15 cc. of warm water, cooled, and carefully acidified with 1:1 sulfuric acid. On cooling, a precipitate formed, although Anschütz and Bertram reported no such result. It proved to be an unstable acid which lost carbon dioxide when heated on a water bath. The acid solution, however, was extracted with five small portions of ether. After the ether solution was dried and evaporated, 0.08 g. of tetronic acid was obtained, m.p. 136°. Wolff reported the melting point as 141°, with previous sintering at 135°.

e. Preparation of beta-Anilido-crotonolactone.

The tetronic acid was treated with 5 or 6 drops of aniline and the mixture warmed on a water bath. The reaction was complete in a few seconds. After recrystallizing from 4 cc. of alcohol, the beta-anilido-crotonolactone melted at 221-222°.

Proof of the Identity of All Three Anilido-crotonolactones.

In order to show that Hill's so-called alpha-anilido-crotonolactone was really beta-anilido-crotonolactone, a mixed melting point was taken with both Wolff's lactone and that of Anschütz and Bertram. Both mixtures were observed to melt at 221-222°, showing that all three were the same compound. A mixed melting point of a mixture composed of Wolff's compound and that of Anschütz and Bertram was 221-222°.

Bromination of Diphenylfurylcarbinol.

To 5 g. (0.02 mole) of freshly prepared diphenylfurylcarbinol dissolved in 35 cc. of carbon tetrachloride and cooled to -3°, there was slowly added 6.4 g. (0.04 mole) of bromine in 25 cc. of carbon tetrachloride, with constant stirring. The solution became purple in color and gave off hydrogen bromide. The mixture was stirred for one and one-half hours after all the bromine had been added. The solvent was then removed by a



stream of air. The residue, a dark purple oil, lost hydrogen bromide freely when warmed on a water bath. It was allowed to stand over night. At the end of this time there remained a black solid, along with a small amount of oil. After this residue was extracted with hot alcohol, there remained 0.01 g. of a brown solid which, upon recrystallization from alcohol, gave light brown needles, m.p. 206-207°. A mixed melting point with known alpha,beta-dibromo-gamma-diphenylmethylenecrotonolactone was not lowered.

The mother liquors from this solid yielded, on evaporation, a black solid which, when crystallized from alcohol and decolorized with norite, gave lemon-yellow crystals melting at 156°. A mixed melting point with alpha-bromo-gamma-diphenylmethylenecrotonolactone was not lowered. The yield was 0.85 g., or 13% of the theoretical amount.

Isolation of Bis(diphenylfurylmethyl) Ether from a Decomposition Resin.

A bottle of diphenylfurylcarbinol which had been loosely corked for several years had changed to a reddish-brown resinous solid. This material was ground in a mortar and triturated with acetone until the soluble coloring substances were removed. A slightly pinkish compound remained and was filtered. This was quite insoluble in all common organic solvents, benzene

proving to be the most promising for recrystallization. In order to remove the color, alcohol was employed in a Soxhlet extractor. This solvent was then replaced by benzene. The white crystalline ether precipitated and melted at  $213^{\circ}$ . A mixed melting point with the ether prepared in the following experiment was not lowered. The yield cannot be given here, as the compound was discovered more or less by chance, and the weight of the original material was not recorded. It would be, however, approximately 50%.

Preparation of Bis(diphenylfurylmethyl) Ether from Diphenylfurylcarbinol.

A mixture of 87 g. (0.347 mole) of diphenylfurylcarbinol and 150 cc. of 10% acetic acid was heated on a steam bath for seventeen hours. At the end of this time there remained a dark red solid cake. After the liquid was decanted and washed with water, the material was broken into small pieces by means of a spatula. To the mixture was added 100 cc. of acetone. It was then triturated until all lumps had disappeared, and a finely divided solid remained. After being filtered and washed with small amounts of acetone, a pinkish residue remained, m.p.  $215^{\circ}$  (decomposition). The yield of crude product was 61 g., or 72.6% of the theoretical amount. The compound was placed in a Soxhlet and extracted with alcohol for three hours in order to

remove the color. This treatment was followed by extraction with benzene until practically all of the solid had dissolved from the thimble. There was 50 g. of the crystalline material, m.p.  $214^{\circ}$  (decomposition) deposited from the benzene solution. Small amounts were recrystallized from other solvents such as ligroin ( $69-70^{\circ}$ ) and a mixture of ethyl acetate and benzene, but the melting point remained  $215-216^{\circ}$ . In a duplicate experiment using small quantities of carbinol, a product was obtained melting at  $225^{\circ}$  (decomposition). Hence the melting point seemed to vary at times. The rate of heating may have been slightly greater with this sample.

Anal. Calcd. for  $C_{34}H_{26}O_3$ : C, 84.8; H, 5.38; mol.wt. 482. Found: C, 85.2; H, 5.38; mol.wt. by cryoscopic method in benzene 485.

Cleavage of Bis(diphenylfurylmethyl) Ether to Diphenyllevulinic Acid.

Into a suspension of 1 g. (0.00207 mole) of bis(diphenylfurylmethyl) ether in 50 cc. of absolute ethyl alcohol, dry hydrogen chloride was passed for 15 - 30 seconds, until a slight warming was noticed. This mixture was refluxed gently for seventeen hours. The solid dissolved in fifteen minutes and the solution became a wine-red in color. After the required time had passed, the contents of the flask were poured into

200 cc. of 5% sodium carbonate. The oil which precipitated was extracted with ether. Without drying, the solvent was removed and the remaining oil was refluxed with 5% hydrochloric acid for thirteen hours. After cooling, the oil was extracted with ether. The ether solution was then extracted with two 25 cc. portions of 5% sodium hydroxide to remove the diphenyllevulinic acid. After the basic solution was heated to 50° with 1 g. of norite for a few minutes, it was filtered, cooled, and acidified. The cream colored acid melted at 107-108° and a mixed melting point with known diphenyllevulinic acid was not lowered. The yield was 0.73 g. or 65.7% of the theoretical amount.

Attempted Cleavage of Bis(diphenylfurylmethyl) Ether with Sodium-Potassium Alloy (74).

To a suspension of 4.82 g. (0.01 mole) of bis(diphenylfurylmethyl) ether in 150 cc. of dry ether, there was added 2 cc. of sodium-potassium alloy containing 80% potassium. The whole experiment was conducted in an atmosphere of dry nitrogen. After stirring for three days with no apparent change, the mixture was refluxed for two days more. Little or no reaction could be noticed. The excess alloy was destroyed by slowly adding 50 cc. of wet ether containing 2 cc. of alcohol. After being filtered, the unchanged compound weighed 3.5 g. The ether

(74) Ziegler and Thielmann, Ber., 56, 1740 (1923).

layer was separated, cooled with water, dried, and evaporated. No diphenylfurylcarbinol could be detected in the oily residue when it was extracted with ligroin, (77-115°). The basic aqueous layers were acidified and extracted with ether. This ether solution also yielded no carbinol when treated in a similar manner.

Attempted Synthesis of Bis(diphenylfurylmethyl) Ether using Gomberg's Method.

Gomberg (28) prepared bis(triphenylmethyl) ether by treating triphenylmethyl chloride in dry benzene solution with mercuric oxide. A similar method for the preparation of bis(diphenylfurylmethyl) ether required the synthesis of diphenylfurylmethyl chloride. The attempted preparation of this halide was similar to that used by Kirner (75), in his synthesis of furfuryl chloride.

To a mixture of 10 g. (0.04 mole) of diphenylfurylcarbinol, 3.8 g. (0.048 mole) of pyridine, and 20 cc. of dry ether, cooled to -5°, there was slowly added, with stirring, 5.2 g. (0.044 mole) of thionyl chloride in 5 cc. of ether. A very sticky precipitate settled on the bottom of the flask. After decanting the ether solution, the residue was extracted four

(75) Kirner, J. Am. Chem. Soc., 50, 1959 (1928).

times with small portions of ether. The combined ether solutions were dried with anhydrous sodium carbonate and treated with 17.3 g. (0.08 mole) of dry mercuric oxide. A deep purple color developed and an insoluble precipitate formed. The mixture was tightly stoppered and shaken over night. The mercuric oxide was removed by means of 100 cc. of cold 5% hydrochloric acid. There remained a dark colored solid which did not melt when heated on a platinum foil.

The failure to obtain the desired ether was probably due to the fact that no diphenylfurylmethyl chloride was formed. This appears to be true because triphenylcarbinol was treated in the same manner as diphenylfurylcarbinol, with the result that no triphenylmethyl chloride was found. The unchanged carbinol was recovered.

#### Bromination of Bis(diphenylfurylmethyl) Ether.

To 4.82 g. (0.01 mole) of this ether, m.p.  $214^{\circ}$ , suspended in 50 cc. of carbon tetrachloride, there was added, dropwise, with constant stirring, 6.4 g. (0.04 mole) of bromine dissolved in 25 cc. of carbon tetrachloride. Hydrogen bromide was evolved and the mixture became slightly warm. The color deepened to a dark red. After stirring for ten minutes, the clear solution was decanted and evaporated. The residue was a clear yellow oil which began to decompose in a few minutes. It slowly evol-

ed hydrogen bromide. The oil was warmed on a steam bath for twelve hours, or until the evolution of gas had ceased. The black semi-solid mass was heated with 15 - 20 cc. of alcohol and allowed to settle. The clear supernatant liquid was decanted. On standing a short time, a yellow precipitate formed. After several recrystallizations from alcohol, it melted at 155°. A mixed melting point with known alpha-bromo-gamma-di-phenylmethylene-crotonolactone was not lowered. The yield of this lactone was 0.22 g., or 6.72% of the theoretical amount.

**SUMMARY**

1. The reaction of 5-halogeno-2-furoic esters and 5-halogeno-2-furfural with phenylmagnesium bromide has been found to be a normal one.

2. The intermediate compound formed by the reaction of 5-halogeno-2-furfural with phenylmagnesium bromide has been found to be a bis(5-halogeno-2-furylphenylmethyl) ether.

3. These halogenofurylcarbinols are extremely unstable and lose halogen acids with ease, giving substituted crotonolactones.

4. These lactones have been identified by degradation methods.

5. Further proof has been given for the structure of Hill's dihalogenofuroic acids.

6. Several mechanisms have been offered for the decomposition of 5-halogeno-2-furylarylcarbinols.