The only crystalline product isolated was dimesitylphenylbutanedione, $C_9H_{11}COCH_2CH(C_6H_5)COC_9H_{11}$, which was the result of reduction. This product was identified by mixture melting point.

When the compound VI was treated with methylmagnesium iodide in the Zerewitinoff apparatus, one molecule of methane was evolved rapidly at room temperature, and when heated to 100° a second molecule was slowly evolved over thirty minutes; the final volume of methane was 1.9 moles. When the reaction mixture was hydrolyzed with ice and hydrochloric acid the starting material was recovered in 91% yield.

When a stream of dry hydrogen chloride was bubbled through a solution of the compound in boiling concd. acetic acid for thirty-two hours, an amorphous product was obtained which fused over a wide range and defied attempts to crystallize it. Distillation in the vacuum oven gave a glassy liquid. This may have been the furan, but it was not investigated further.

2-*t*-Butyl-1,4-dimesityl-3-phenyl-2-butenedione-1,4 (IV).—A sample (1.15 g.) of *t*-butyldimesitylbutenedione (V) was added to 8 cc. of ether containing four molecules of phenylmagnesium bromide at 0°. After standing for fifteen minutes the mixture was poured slowly with stirring into 75 cc. of ethanol containing 0.5 cc. of bromine, at $-10°$. Aqueous sodium bisulfite was then added and the product extracted with ether. Upon evaporation, the oily residue was crystallized from ethanol; yield 0.96 g. Repeated crystallization from ligroin gave rhombic prisms melting at 183°.

Anal. Calcd. for $C_{32}H_{36}O_2$: C, 84.9; H, 8.0. Found: C, 84.7; H, 8.2.

This compound (IV) was obtained also by enolization of the saturated diketone (VI) by means of methylmagnesium iodide and pouring the resulting mixture into alcoholic iodine or bromine maintained at -10 to 0°. In both cases yields of about 40% of the unsaturated diketone (IV) were isolated and identified by mixture melting points.

Reduction of IV by means of zinc dust and 80% acetic acid, refluxing for thirty minutes, gave an amorphous product very similar in character to that obtained in the attempted furanization of the saturated diketone. It was not investigated further.

Catalytic reduction of 0.2 g. of IV in 10 cc. of ethanol and 2 cc. of piperidine, using 0.02 g. of platinum oxide, showed absorption of one molecule of hydrogen in two hours. Upon filtering and diluting slowly with water, 0.2 g. of crystals separated and on recrystallization from ligroin was identified by mixture melting point as the saturated diketone (VI).

Summary

Methylmagnesium iodide adds 1,4 to the α,β-unsaturated ketone system of a β-mesitoyl furan, involving the double bond of the furan nucleus. The resulting dihydrofuran enolate undergoes a vinyl allyl ether cleavage by addition of a second molecule of methylmagnesium iodide. The structure of the final product and the presence of *t*-butyl group were demonstrated by reactions and synthesis.

CHARLOTTESVILLE, VIRGINIA RECEIVED AUGUST 18, 1941

[CONTRIBUTION FROM THE COBB CHEMICAL LABORATORY, UNIVERSITY OF VIRGINIA]

The Stereochemistry of the Enols and Di-enols of 2-*t*-Butyl-1,4-dimesitylbutanedione-1,4. A Proof of 1,4-Reduction of an α-Bromoketone

BY ROBERT E. LUTZ AND WILLIAM G. REVELEY[1]

The study of enols and their stereochemistry is difficult because those enols which are so substituted as to be persistent are affected by steric hindrance and usually fail to show many of the characteristic reactions. Nevertheless, at present a number of monoenols,[2] enediols,[2a,3] and di-enols[2c,4] have been investigated and some have been isolated in persistent or permanent crystalline forms. A preliminary investigation of the enols and di-enols in the trimesitylbutanedione series has already been reported,[2c] and this paper deals with a similar survey of the 2-*t*-butyl-1,4-dimesitylbutanedione series and a study of the effect of the *t*-butyl group.

The Synthesis of the Dimesityl-*t*-butyl Series.—The first approach to this series came through the investigation of the reaction between methylmagnesium iodide and 3-mesitoyl-5-mesityl-2-methylfuran (I). This reaction had been carried out originally as a test for active hydrogen before the structure of the furan was known. The course of the reaction was deduced from the analysis of the product (IV) and from consideration of the limited possibilities involving addition of two molecules of methylmagnesium iodide.[2c] A second synthesis subsequently carried out through 1,4-addition of *t*-butylmagnesium chloride to dimesitoylethylene (V), confirmed this conclusion

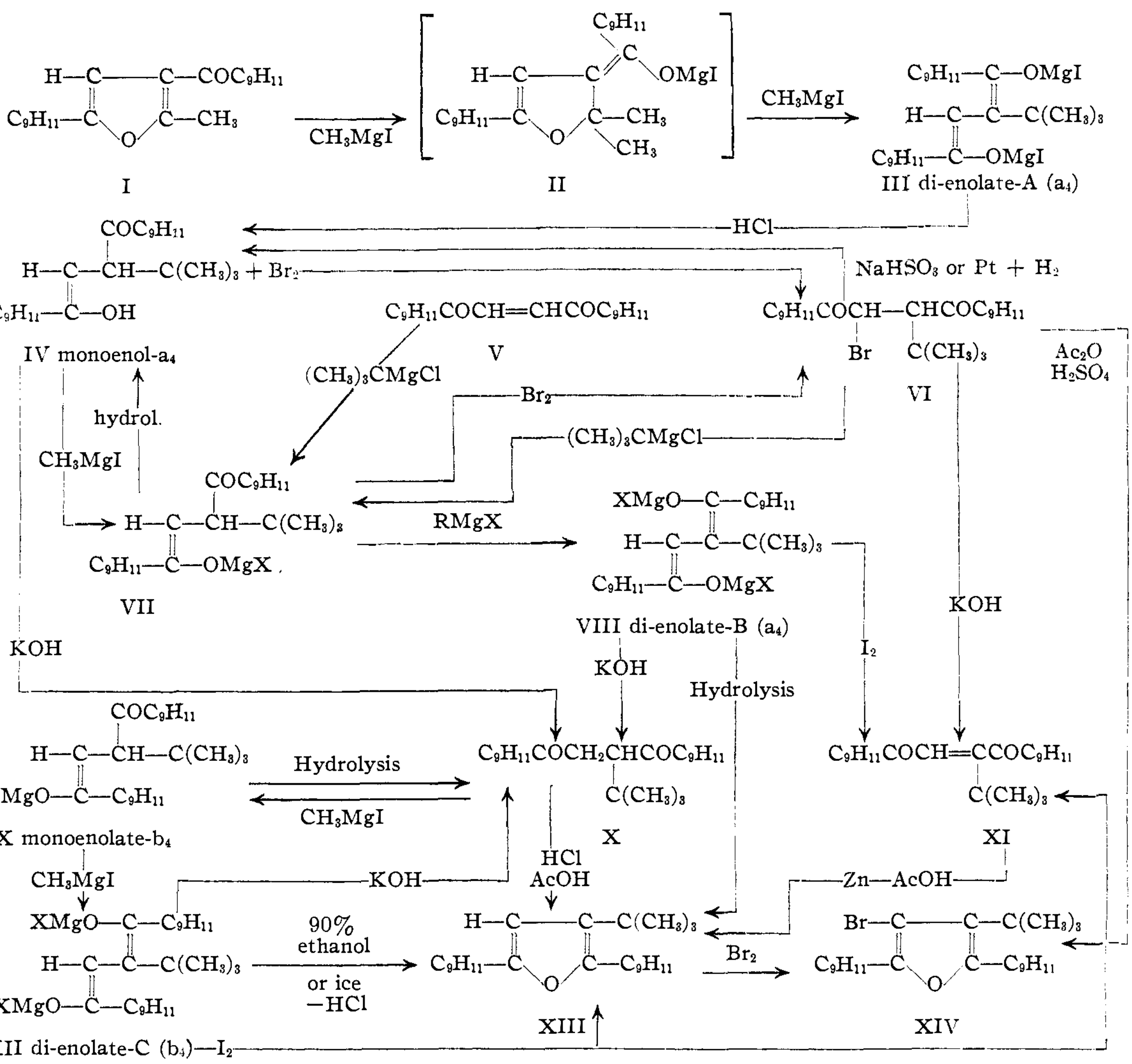
---

[1] Philip Francis du Pont Fellow, 1939–1941; present location, National Aniline and Chemical Company, Buffalo, New York.

[2] (a) Kohler and Thompson, THIS JOURNAL, **59**, 888 (1937); (b) Kohler, Tishler and Potter, *ibid.*, **57**, 2517 (1935); (c) Lutz and Kibler, *ibid.*, **62**, 360 (1940); (d) Fuson, Corse and McKeever, *ibid.*, **62**, 3250 (1940).

[3] (a) Lutz and Wood, *ibid.*, **60**, 705 (1938); (b) Fuson and Corse, *ibid.*, **61**, 975 (1939); (c) Thompson, *ibid.*, **61**, 1281 (1939).

[4] Lutz and Reveley, *ibid.*, **61**, 1854 (1939).



and demonstrated beyond any doubt the presence and location of the *t*-butyl group.

The greater part of the work in this series of compounds has been outlined for convenience in the diagram. The saturated diketone (X) was obtained when the various enolates (VII, VIII, XII) were hydrolyzed under alkaline conditions. Oxidation of the di-enolates by means of alcoholic iodine gave the unsaturated diketone (XI) which was obtained also by treatment of the bromodiketone (VI) with alkali. The furan (XIII) could be obtained by dehydration of the saturated diketone (X), by hydrolysis of certain of the di-enolates (namely, VIII and XII) and by reduction of the unsaturated diketone (XI) with zinc and acetic acid.

Nomenclature of the Enolates and Di-enolates.—The two 4-monoenolates have been characterized by reactions but only one of these has been isolated as a free enol in crystalline form. These monoenolates have been designated arbitrarily by small letters a_4 and b_4, the subscripts indicating the end of the molecule involved. The, as yet, unknown 1-monoenols, when they are found, may be designated a_1 and b_1.

Evidence for the existence of three of the four possible di-enolates has been obtained; these are designated by capital letters, A, B, and C. In order to specify these di-enolates configurationally in terms of the monoenolates as far as the stereochemical relationships are known, the proper small letter is placed after the capital letter; *e. g.*, di-enolate-A (a_4) for formula III. When both monoenolate configurations in the di-enolate become known, the capital letter may be followed or replaced by two appropriate small letters bearing subscripts.

Upon application of this nomenclature scheme in the previously described 1,2,4-trimesitylbutane-1,4-dione series,[2c] the 1- and 4-monoenolates-A and B of that series become, respectively, a_1, a_4, b_1 and b_4, and the di-enolates-A and -B become, respectively, A (a_1a_4) and B (b_1a_4).

The Monoenol-a_4.—The first step in the reaction between methylmagnesium iodide and the furan (I) must have involved 1,4-addition to the α,β-unsaturated ketone system. The primary product (II) was not isolated and the second addition followed immediately with fission of the unsaturated allyl ether system to give the di-enolate-A (III). Upon hydrolysis there was produced the crystalline monoenol-a_4 (IV).

The monoenol-a_4 did not react either with ferric chloride or with diazomethane. It was shown to be an enol by the facile rearrangement into the stable saturated diketone (X) under the influence of alkali, a behavior which is analogous to that of the one crystalline monoenol (a_1) isolated in the 1,2,4-trimesitylbutanedione series. That this product (IV) was actually the monoenol and not a di-enol was demonstrated by the following facts: (a) the compound was not oxidized by means of iodine to an unsaturated diketone as would be a di-enol; (b) it reacted rapidly with methylmagnesium iodide with evolution of one molecule of methane (the monoenol could be regenerated upon hydrolysis); (c) bromination of either the enol or its bromomagnesium derivative gave the monobromo derivative (VI); (d) the monoenolate was produced in the reductive enolization of the bromodiketone (VI) by means of Grignard reagent; and (e) the free monoenol was produced directly from the bromodiketone by reduction with ordinary reducing agents under conditions wherein enolization of the remaining carbonyl group would be inconceivable.

Demonstration in another way that monoenolization only was involved and proof that this enolization involved the 4-carbonyl rather than the 1-carbonyl, came through synthesis of the compound by 1,4-addition of *t*-butylmagnesium chloride to dimesitoylethylene (V). In this reaction the monoenolate (VII) must have been formed initially since the monoenol-a_4 was one of the products of hydrolysis even when this hydrolysis was carried out under the iodine oxidation conditions which would be expected to convert a di-enolate into the unsaturated diketone (XI). This evidence is not conclusive as it stands, however, because it is conceivable that a di-enol might ketonize so rapidly during the oxidative hydrolysis as to escape oxidation, a result which has been observed in one instance, namely, the reduction of the dimolecular condensation product of dimesitoylethylene.[5] The secondary enolization of the monoenolate-a_4 (VII) to a di-enolate does not occur even under prolonged action of *t*-butylmagnesium chloride, as was shown in experiments carried out on samples of this compound prepared from the monoenol itself (IV) or from the bromodiketone (VI). The secondary enolization to the di-enolate actually could be effected, however, by the prolonged action of methylmagnesium iodide used in place of *t*-butylmagnesium chloride; the production of a di-enolate under these conditions could then, and only then, be demonstrated by the iodine oxidation method.

Attempts to use in similar experiments samples of the monoenolate-a_4 (VII) produced by the action of *t*-butylmagnesium chloride on dimesitoylethylene (V) were complicated by the reducing action of this reagent and the formation of large amounts of dimesitoylethane, $C_9H_{11}COCH_2CH_2COC_9H_{11}$. The experiments in this case were only partially successful (see experimental section). However, there can be no doubt as to the correctness of the formulation of the reaction as given in the diagram in view of the following facts: (a) the monoenol-a_4 was actually obtainable from this reaction; (b) it was not obtainable from the supposed stereoisomer (IX) by rearrangement under these conditions; and (c) bromination of the crude mixture obtained in this preparation from dimesitoylethylene (V) gave characteristically the bromodiketone (VI), and no unsaturated diketone (XI) could be isolated from the reaction mixture.

The fact that the monoenolate is produced as the primary product in this addition of *t*-butylmagnesium chloride to dimesitoylethylene is proof that the monoenolate group of the product involves the 4- and not the 1-position as indicated in the formula VII. Independent proof of this was sought, however, because of the possible questions which might be raised concerning the validity or completeness of this proof and because in the rearrangement of the di-enolate-A to the monoenol the 1- rather than the 4-monoenol might have been expected in consequence of the hindering action of the *t*-butyl group, just as ac-

---

[5] Lutz and Disque, unpublished results.

tually happens in the trimesityl series.[2c] The desired proof was found in the following relationships. The bromodiketone (VI) obtained from the monoenol (IV) was furanized by means of acetic anhydride and sulfuric acid. The resulting bromofuran (XIV) was then synthesized in another way by direct bromination of *t*-butyldimesitylfuran (XIII). This proves beyond question that the bromine and *t*-butyl group in the bromodiketone are on different and adjacent carbon atoms as formulated in VI. Since the bromodiketone gives the monoenol upon reduction by means of ordinary reducing agents or Grignard reagent (as will be discussed later) and goes only to the monoenolate and not the di-enolate, then it follows that the 4- rather than the 1-carbonyl group must be involved.

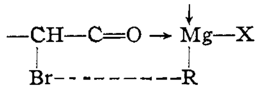
The configuration at the 4-enolate group of the monoenol-a_4 is based on the mode of formation of the di-enolate-A wherein the 3,4-double bond of the furan (I) is carried from the ring structure through II, presumably without change. It is very unlikely that any configurational alteration would occur since the monoenolate-b_4 (IX) and the corresponding and stereoisomeric monoenolate groups of VIII and XII, as described below, are stable under comparable conditions.

A Proof of 1,4-Reduction of an α-Bromoketone.—The bromodiketone (VI) is of interest because it contains a typical second order conjugated system[6] which should be easily reducible by a 1,4-reaction mechanism.

The structure of this bromo compound is certain from the mode of formation from the monoenolate-a_4 or the free enol (IV), and from its reactions, including reduction to the monoenol-a_4, dehydrohalogenation to the unsaturated diketone (XI), and dehydration to the furan (XIV).

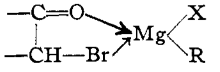
Definite proof of the 1,4-reaction mechanism of reduction of the bromodiketone by means of platinum and hydrogen or sodium bisulfite, comes as the result of the formation of the permanent but thermodynamically unstable monoenol-a_4 (IV) as the primary product. The only other mechanism possible which would account for the formation of this product, namely, direct reduction at the α-bromide linkage followed by enolization of the resulting saturated diketone (X), is excluded since enolization of the saturated diketone would be impossible under the conditions involved.

The process by which Grignard reagent also converts the bromodiketone (VI) into the monoenolate-a_4 is being called reductive enolization and has already been expressed as a 1,4-reaction.[7] The formation of the specific monoenolate-a_4 supports this mechanism because the only alternative, namely, reduction directly at the α-bromide linkage followed by partial enolization of the resulting saturated diketone (X), is excluded by the fact that under comparable conditions the saturated diketone is enolized to a different monoenolate (b_4, IX). The fine mechanism of the reductive enolization may well involve coördination between the magnesium and the carbonyl oxygen (XV) and possibly also coördination at the same time with the α-bromine to form a transitory chelate ring (XVI).



XV

or



XVI

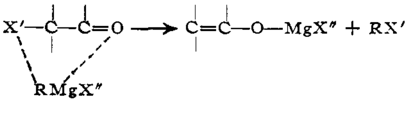
This mechanism would not predetermine the configuration of the enolate group produced.

The Configuration of the Di-enolate-A (a_4).—The di-enolate-A (a_4) was obtained, as already described, in the reaction between methylmagnesium iodide and the furan (I). It was characterized by hydrolysis and partial ketonization to the 4-monoenol-a_4 (the di-enolates-B and -C on hydrolysis gave instead the furan (XIII)). This ketonization first at the 1-enolate group was contrary to expectation based on the course of the partial ketonization of di-enolates in the trimesitylbutanedione series,[2c] and on the anticipated effect of steric hindrance of the *t*-butyl group. Evidently the 1-enolate group of III must have a

---

(6) Conjugation effects have long been recognized in systems including singly bonded groups such as C–O, C–Br, C–N, C–Mg, and the like. Of course, all of the linkages between the atoms of these systems and the attached hydrogens, alkyls, or other groups or atoms are also involved in the total conjugation, but attention has centered on those parts of the system which actually can function as units in reaction. In a recent paper entitled "Hyperconjugation" [Mulliken, Rieke and Brown, THIS JOURNAL, **63**, 41 (1941)] the terms second and third order conjugation have been applied to HC≡C—CH_3 and CH_3—CH_3, respectively. We shall apply these terms to such systems as C=C—C—Br and Br—C—C—Br. However, it seems to us that hypoconjugation rather than "hyper-conjugation" would be a more appropriate special term to cover this type of conjugation because these systems obviously involve lower conjugation energies and lower orders of unit reactivity than do ordinary "first order" conjugated systems of multiple bonds.

(7) *Cf.* ref. 2c, p. 364. There is an obvious typographical distortion in the formula given for the product. The reaction should read as follows

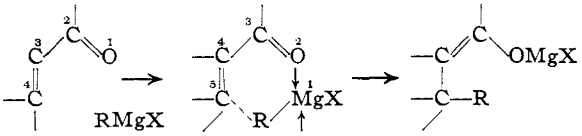


$$X'—C—C=O \longrightarrow C=C—O—MgX'' + RX'$$

specific configuration favorable for ketonization, coupled perhaps with an opposite configurational effect at the 4-enolate group. Configuration thus appears to be a more important stabilizing factor here than the steric hindrance of the *t*-butyl group.

The configuration at the 4-enolate group of the di-enolate-A (a_4, III) and the monoenol-a_4 is established by the synthesis from the furan (I) as already mentioned. A tentative configuration at the 1-enolate group is based on the following considerations. Two other di-enolates-B and -C (VIII and XII) have been found and differ from the di-enolate-A (a_4) in undergoing furanization upon hydrolysis instead of partial ketonization to the monoenol-a_4. The furanization presumably occurs through interaction between the 1-enol group of favorable configuration and the 4-carbonyl group which is affected to a minimum degree by steric hindrance.[2c,4] The di-enolate-A, therefore, presumably has the configuration at the 1-enolate group unfavorable for furanization, as is depicted in formula III.

An independent basis for assigning this particular 1-enolate configuration to the di-enolate (III) was found in the hypothesis that the fine mechanism of 1,4-addition of methylmagnesium iodide to the conjugated system involves first coördination of the carbonyl oxygen with the magnesium atom and subsequent development of the 1,4-reaction by interaction of the methyl group with the nearest furan α-position (the 5-position in the numbered pentad system of XVII)[8]; the simultaneous attachment of the methyl group to this α-position and the consequent electronic readjustment to produce the 1,4-addition product (XVIII) would thus be regarded as involving the ephemeral or transitory ring phase (XVII). This obviously would predetermine the configuration of the enolate produced (XVIII) and would lead in the case of (I) to the enolate (II) with the iodomagnesiumoxy group *cis* with respect to the α,α-dimethyl group. The necessary assumption that the transition between the coördinated complex (XVII) and the final 1,4-addition product (XVIII) is a smooth continuous process and one allowing no time for rearrangement of the groups at the newly developing enol double bond, seems reasonable in the light of modern views on the mechanism of organic reactions, particularly rearrangements.[9]



XVII XVIII

In the foregoing discussion, the coördinate bond assumed to exist at least momentarily between the carbonyl oxygen and magnesium, is regarded as a real bond holding the two reacting molecules together and knitting the system into a type of second order conjugation.

Incidentally, the above-described concept of 1,4-addition in terms of an intermediate transitory but nevertheless real ring phase offers a reasonable explanation for many reactions including especially the 1,2- and 1,4-addition of Grignard reagent, and it accounts for the rarity of 1,6-addition or longer. Also, carrying this idea further, it is possible to depict dimolecular reduction in similar terms as a smooth continuous process initiated by attraction of two molecules of the ketone to the metal surface by forces analogous to those involved in coördination.

It is worthy of note that data are already available which support to a degree the views expressed above in respect to the mechanism of 1,4-addition of Grignard reagent to an α,β-unsaturated ketone system. The configuration of the trimesitylbutanedione 4-monoenolate-A (now to be designated as a_4) may be deduced from its mode of formation on the basis of this mechanism, and it is found actually to be the same as that already assigned on other and independent grounds. In this case and that of VII, configurations predictable on this hypothesis are supported by independent evidence. However, the formation of the proper stereoisomer in these two cases might be coincidence, and many more examples will be needed to test this hypothesis adequately.

In connection with the foregoing, it is of interest to note that according to prediction the 1,4-reaction between Grignard reagent and the second order conjugated systems, H—C—C=O and Br—C—C=O, should not lead necessarily to one fixed enolate configuration because the main chain at the moment of consummation of the reaction would not be restricted in its space location by the necessity of the β-carbon taking part in the reaction, as is the case in the 1,4-addition to the α,β-unsaturated ketone system. The ac-

---

[8] *Cf.* Johnson, THIS JOURNAL, **55**, 3829 (1933); Carothers and Berchet, *ibid.*, **55**, 2807 (1933).

[9] *Cf.* chapter on rearrangements by E. S. Wallis in Gilman, "Organic Chemistry," John Wiley and Sons, Inc., New York, N. Y. (1938).

tual, though fortuitous, formation consistently of different 4-monoenolates in these two reactions in the dimesityl-*t*-butyl and trimesityl series demonstrates this point.

The di-enolate-B (a_4), obtained by the action of methylmagnesium iodide on the monoenolate-a_4 (VII) is characterized by iodine oxidation to the unsaturated diketone (XI), by alkali hydrolysis to the saturated diketone (X), and by hydrolysis to the furan (XIII) under acid conditions which previously had caused the di-enolate-A (a_4) to rearrange to the monoenol-a_4. Since it is unlikely that the configuration at the 4-enolate group would be altered under the relatively mild conditions involved in the further enolization at the 1-carbonyl, the configuration at the 1-enolate group follows by difference from that in di-enolate-A (a_4). Furthermore, the ease of furanization, as far as this can safely be used as evidence here, supports the 4-enolate configuration which has been assigned in formula VIII. If the above conclusions are correct, it may be noted that in the hydrolysis of the di-enolate-B, in contrast to di-enolate-A, the less sterically hindered 4-enol group ketonizes first, as would be expected.

The monoenolate-b_4 (IX) was believed to be formed by the direct enolization of the saturated diketone (X) by Grignard reagent. Upon oxidation of the products by alcoholic iodine the unsaturated diketone (XI) could not be obtained. On hydrolysis only the saturated diketone could be isolated. Attempts to isolate the free enol were unsuccessful. Under prolonged treatment with Grignard reagent a di-enolate was then formed as shown by iodine oxidation to the unsaturated diketone. These facts indicate that a monoenolate actually was formed which was different from the monoenolate-a_4 described above. Unfortunately, the results were unsatisfactory because of the low yields in these experiments.

The 4-monoenolate structure (b_4, IX) has tentatively been assigned on the following basis. (a) It is assumed that the 4-carbonyl would be the first to enolize, the other being hindered by the adjacent *t*-butyl group (as in the case in the trimesityl series),[2c] and (b) only after the second enolization to the di-enolate-C does there appear an enolate group capable of furanization merely upon hydrolysis. The latter argument is based on the apparently reasonable assumptions that only the free 1-enol group of favorable configuration as it appears in the di-enolate-B (a_4) would be capable of ready furanization and that the individual configurations are stable under the conditions involved in these transformations.

It is interesting in this connection to note the stepwise enolizability in the case of both the *t*-butyldimesityl and trimesityl saturated 1,4-diketones, but not the dimesitylphenyl compound and dimesitylbutanedione itself. The third mesityl group seems to be more effective than the *t*-butyl group and the phenyl offers practically no resistance. This implies that the effect is due to steric hindrance rather than to chemical character.

If the monoenolate-b_4 actually has the 4-enolate structure, as seems very probable from the above discussion, then the configuration must be that given in formula IX since it is different from that of the isomer-a_4. This corresponds with the configuration assigned to the 4-monoenolate-B of the trimesityl series[2c] (now to be designated as b_4).

The di-enolate-C (b_4) was obtained by the action of methylmagnesium iodide on the monoenolate-b_4. It was characterized by iodine oxidation which produced some of the expected unsaturated diketone (XI) and also the furan (XIII) which must have resulted from partial ketonization of the di-enol in competition with oxidation. This result is consistent with the formulations assigned because it indicates that the 4-enolate group (b_4), in contrast to the 4-enolate group (a_4), is the more easily ketonized, and also it indicates that the configuration at the 4-enolate group has not changed during the conversion of the monoenolate-b_4 into the di-enolate-C (b_4).

Hydrolysis of the di-enolate-C (b_4) by means of ice and hydrochloric acid or in a 90% ethanol medium gave exclusively the furan (XIII), and alkali hydrolysis produced the saturated diketone (X).

The configuration indicated in formula XII has been assigned tentatively on the basis of (a) the preparation from the monoenolate-b_4 (IX) which determines the 4-enolate configuration in view of the improbability of inversion during the preparation, and (b) the ease of furanization, which determines the configuration at the 1-enolate group, assuming that the present theory of the mechanism of furanization is correct.[2c,4]

Experimental Part[10]

2-*t*-Butyl-1,4-dimesitylbutanedione-1,4 4-Enol (a_4) (IV).—(a) Fifty grams of powdered dimesitylbutenedione (V)

---

[10] A number of the microanalyses were carried out by Mrs. E. C. J. Mathers.

was added portionwise over one hour to a solution of five equivalents of *t*-butylmagnesium chloride (titrated) at room temperature. After continued stirring for a half hour longer the mixture was cooled to −10° and added to a solution of 100 g. of iodine in one liter of ethanol (also at −10°). This treatment converted the dimesitylbutanedione di-enolate produced by reduction of V back again into the corresponding unsaturated diketone (V). The temperature during this operation did not exceed 0°. Upon slow and careful dilution with water a crystalline precipitate appeared (55.1 g.). This crude product was treated with 33 g. of sodium bisulfite in 500 cc. of 60% ethanol, the mixture being refluxed for one hour. This operation converted the unsaturated diketone (V) into the sulfonate by 1,4-addition and thus facilitated separation by rendering this material soluble in water. Upon diluting the mixture with water and cooling, 29.6 g. of crystals was obtained.

Attempts to improve this preparation and to minimize the reduction failed, the ratio of products remaining approximately constant.

(b) A second preparation is as follows. Dry powdered 3-mesitoyl-5-mesityl-2-methylfuran (I) was added with efficient stirring to 138 cc. of ethyl ether and 150 cc. of isopropyl ether containing six equivalents of methylmagnesium iodide. The ethyl ether was distilled off and the remaining isopropyl ether mixture was refluxed under an atmosphere of dry nitrogen for six hours. The colored solution was poured into ice and hydrochloric acid. The ether extract was washed with dilute sodium bicarbonate and then with water. Upon distilling the ether there remained a red oil which was taken up in ligroin. Three grams of crystals appeared on cooling and seeding, and this was purified and identified as IV by mixture melting point with the sample prepared as described above and also by conversion to the saturated diketone (X) by the action of alkali, this in turn being identified by mixture melting point.

Upon repeated crystallizations from an ethanol–ethyl acetate mixture the purified product was obtained as rectangular prisms melting at 197° *in vacuo*.

Anal. Calcd. for $C_{26}H_{34}O_2$: C, 82.8; H, 8.9. Found: C, 82.5; H, 9.2.

Methylmagnesium iodide reacted at room temperature with the enol (IV) with evolution of 0.94 molecule of methane in one minute. Evolution of methane continued very slowly and was incomplete after five hours (1.8 molecules). Upon heating for half an hour at 100° the evolution of methane reached 1.94 molecules.

Diazomethane in ether at room temperature for three hours was without action on IV.

When subjected to the action of refluxing ethanolic sodium bisulfite solution the enol (IV) was unaffected over short periods of time but was converted to the saturated diketone (X) on long continued treatment.

A solution of the monoenolate-a_4 prepared from 2 g. of dimesitylbutenedione (V) by the action of an ether solution (32 cc.) of five equivalents of *t*-butylmagnesium chloride at room temperature for one hour, was cooled to −10°, poured slowly with stirring into 100 cc. of ethanol containing 2 cc. of bromine, cooled to −10°. Dilution slowly with water gave, after standing for thirty minutes at 0°, 2.25 g. of crystals which proved to be a mixture of the unsaturated diketone (V) and the bromodiketone (VI). Fractional crystallization had not proved successful. The mixture was washed rapidly on the filter with ethyl ether, the bromo compound dissolving out the more rapidly although the solubilities were about the same. Practically pure saturated diketone remained on the filter. Upon evaporation of the ether and repetition of the process on the residue, a nearly pure sample of the bromodiketone was obtained. This was purified further. Identification was difficult because the compound has no melting point and decomposes over a range when heated. The properties and crystal form of the sample corresponded closely with those of other samples. Further identification was made by conversion by the action of alkali in 84% yield into the unsaturated diketone (XI) according to the procedure described under that compound.

2-*t*-Butyl-1,4-dimesitylbutanedione-1,4 (X).—A solution of 0.1 g. of the enol (IV) in 10 cc. of 2% methanolic potassium hydroxide was refluxed for three hours. Upon diluting with water and extracting with ether, then evaporating, an oil was obtained. This was taken up in ethanol and gave 0.08 g. of diamond-shaped prisms. Upon repeated crystallization from ethyl acetate it melted at 112°.

Anal. Calcd. for $C_{26}H_{34}O_2$: C, 82.5; H, 9.05. Found: C, 82.7; H, 9.2.

When treated in isoamyl ether with methylmagnesium iodide at room temperature 0.86 molecule of methane was evolved in one minute; after five minutes the volume evolved was 0.98 molecule; and the evolution continued slowly over a period of several hours, finally reaching 1.84 molecules, and after heating for half an hour at 100°, 1.95 molecules.

3-*t*-Butyl-2,5-dimesitylfuran (XIII).—Dry hydrogen chloride was bubbled slowly through a refluxing solution of 0.5 g. of *t*-butyldimesitylbutanedione (X) in 16 cc. of 96% acetic acid for thirty-two hours. Upon dilution with water while still hot and cooling, 0.46 g. of the furan (XIII) crystallized. The pure product was obtained as truncated prisms on repeated crystallization from ethanol; melting point 132°.

Anal. Calcd. for $C_{26}H_{32}O$: C, 86.6; H 9.0. Found: C, 86.7; H, 9.1.

4-Bromo-3-*t*-butyl-2,5-dimesitylfuran (XIV).—(a) A suspension of 0.4 g. of the bromodiketone (VI) in 5 cc. of acetic anhydride and eight drops of concd. sulfuric acid was heated to boiling. The suspended solid did not appear to dissolve even at the boiling point. After one minute the mixture was cooled and the crystalline material filtered off and washed with concd. acetic acid. The yield was 0.35 g.; melting point 186–187°.

(b) A solution of 0.2 g. of bromine in 2 cc. of dry chloroform was added to 0.5 g. of *t*-butyldimesitylfuran (XIII) in 5 cc. of dry chloroform. Immediate reaction occurred with evolution of hydrogen bromide. Upon evaporation and digestion of the residue with boiling concd. acetic acid, 0.45 g. of residual and nearly pure material of melting point 182–185° was filtered off; 0.07 g. crystallized from the filtrate. The compound showed no mixture melting point depression with the sample prepared as in (a).

The bromofuran was very soluble in benzene, difficultly soluble in hot alcohol and acetic acid, and was crystallized from butanone and from ethyl acetate as thin hexagonal plates. After sublimation in the vacuum oven it melted sharply at 189°.

Anal. Calcd. for $C_{26}H_{31}BrO$: C, 71.0; H, 7.1. Found: C, 71.0; H, 7.2.

2-*t*-Butyl-1,4-dimesityl-2-butenedione-1,4 (XI).—(a) A suspension of 3.25 g. of the bromodiketone (VI) in 125 cc. of ethanol and 3 g. of potassium hydroxide was refluxed for one hour and diluted with water while hot. On cooling 2.52 g. of crystals separated. It was obtained upon repeated crystallization from ethanol as colorless, elongated, rectangular prisms of melting point 115°. It dissolved to form yellow solutions.

Anal. Calcd. for $C_{26}H_{32}O_2$: C, 82.95; H, 8.6. Found: C, 83.0; H, 8.8.

Reduction of 0.5 g. in 10 cc. of 95% acetic acid with 1 g. of zinc dust, refluxing for one hour with shaking, gave a 75% yield of the furan (XIII).

3-Bromo-2-*t*-butyl-1,4-dimesitylbutanedione-1,4 (VI).—A solution of 0.013 mole of methylmagnesium iodide was added to 100 cc. of ethanol to form a buffered mixture. This was cooled to −10° and 0.5 cc. of bromine added, followed by 0.5 g. of the monoenol-a_4 (IV), with stirring for fifteen minutes at −10°. The mixture was then slowly diluted with water containing enough acetic acid to react with the magnesium hydroxide present. The crystalline precipitate was filtered (0.5 g.). It crystallized from acetone as flat rectangular needles. It decomposed over the range 100–125° and no characteristic melting point could be obtained.

Anal. Calcd. for $C_{26}H_{35}BrO_2$: C, 68.3; H, 7.3. Found: C, 68.3; H, 7.5.

When 0.5 g. of the monoenol-a_4 was brominated in ethanol at 0° with a large excess of bromine (1 cc.) and the reaction mixture diluted with water, 0.8 g. of substance was obtained melting at 148°. Crystallization from petroleum ether and ethyl acetate raised the melting point to 151°.

Anal. Calcd. for $C_{26}H_{33}Br_3O_2$: C, 50.75; H, 5.1. Found: C, 50.5; H, 5.4.

Reduction of this product with zinc and concd. acetic acid in the usual way (refluxing for six hours) gave a different product, not the saturated diketone (X), which still contained bromine. This compound has not been investigated further. The action of refluxing ethanolic sodium acetate (six hours) on the bromodiketone (VI) produced no change.

Reductive Enolization of the Bromodiketone (VI).—Half a gram of VI was added to an ether solution (10 cc.) of two equivalents of methylmagnesium iodide at 0°. The resulting clear solution was hydrolyzed by means of ice and hydrochloric acid. A little alcohol was added to cause disappearance of the ether layer. The hydrolysis product then crystallized and was identified by mixture melting point as the monoenol-a_4 (IV) (yield almost quantitative).

Reduction of the Bromodiketone.—(a) A suspension of 0.2 g. of the bromodiketone and an excess of zinc dust, in 28 cc. of 10% acetic acid in 60% ethanol was refluxed for two hours. Upon filtering and diluting the solution with water 0.15 g. of the saturated diketone (X) crystallized and was identified by mixture melting point.

(b) A mixture of 0.2 g. of VI, 0.3 g. of sodium bisulfite, and 25 cc. of 60% ethanol was refluxed for two hours. Dilution with water precipitated 0.15 g. of the monoenol-a_4 which was identified by mixture melting point.

(c) The action of potassium iodide in acidified ethanol (refluxing for 15 min.) was without effect. When a mixture of 0.2 g. of VI, 0.2 g. of potassium iodide, in 20 cc. of ethanol and 4 cc. of concd. hydrochloric acid was refluxed for fourteen hours and poured into water, 0.15 g. of the furan (XIII) was obtained and identified by mixture melting point.

(d) A buffer mixture was prepared by adding 5 cc. of ethyl ether containing 1.3 g. of methylmagnesium iodide to 20 cc. of ethanol. To this was added 0.2 g. of the bromodiketone and 0.02 g. of platinum oxide. After shaking with hydrogen until one molecule was absorbed, the mixture was filtered and diluted with water which had been acidified with enough acetic acid to neutralize the magnesium hydroxide. The crystalline precipitate was filtered off and identified as the monoenol-a_4 (IV).

The Di-enolate-A (a_4) (III).—This di-enolate was formed as described in the reaction between methylmagnesium iodide and the furan (I). Attempts to characterize it were not successful. It did not behave like the dienolates-B and -C, however. The difficulties were greater here because of the presence of non-crystalline by-products and the known difficulty of crystallization and isolation of the unsaturated diketone (XI) which was expected in the iodine oxidation reaction but which was not found in this case. Hydrolysis, as already described, gave the monoenol-a_4.

The Monoenolate-a_4 (VIII).—The monoenolate-a_4 is obtainable in three ways. Two are described under the preparation of the free enol. The best preparation is through the action of methylmagnesium bromide on the bromodiketone and is described under the heading reductive enolization. The monoenolate may be obtained also by the action of methylmagnesium iodide directly on the free enol, as described. The solutions of the monoenolate produced by these various methods all gave IV upon hydrolysis under suitable conditions.

The mixture obtained by the action of *t*-butylmagnesium chloride in 6 cc. of ethyl ether on 0.5 g. of the bromodiketone (VI) at room temperature, was evaporated and the ethyl ether displaced by isopropyl ether; a heavy white precipitate appeared. The mixture was then refluxed for two hours, allowed to stand overnight at room temperature, and hydrolyzed by pouring into 75 cc. of ethanol and 1.5 g. of iodine, at −10°. The temperature did not rise above 0° during this process. Treatment with sodium bisulfite, washing the ether layer with water, and evaporation gave a yellow oil from which 0.24 g. of the enol (IV) crystallized and was identified by mixture melting point.

The di-enolate-B(b_4) (VIII) is formed in the reaction between methylmagnesium iodide or mesitylmagnesium bromide on the monoenolate-a_4, and was characterized by oxidation to the unsaturated diketone (XI) or hydrolysis to the furan (XIII). Some typical experiments follow.

(a) A solution of the monoenolate-a_4 prepared from 0.5 g. of the bromodiketone and five equivalents of *t*-butylmagnesium chloride in ethyl ether (standing overnight), was treated with five equivalents of methylmagnesium iodide in ethyl ether and the mixture refluxed for one hour. The mixture was cooled to −10° and poured into 75 cc. of ethanol containing 2 g. of iodine, at −10°. Upon working up the product in the usual way 0.2 g. of the unsaturated diketone (XI) was isolated and identified by mixture melting point.

(b) In a similar reaction carried out using the monoenolates-a_4 prepared from 4 g. of dimesitylbutenedione (V) in 72 cc. of ether and six equivalents of *t*-butylmagnesium chloride, four equivalents of methylmagnesium iodide in 41 cc. of ether was added and then 50 cc. of isopropyl ether. This mixture was refluxed for one hour and added to 200 cc. of ethanol containing 7 g. of iodine, at −10°. Acidification with a slight excess of acetic acid and addition of aqueous sodium bisulfite resulted in crystallization. The product was filtered off and dissolved in 50% ethanol containing 2.6 g. of sodium bisulfite; refluxing for one hour to remove the dimesitylbutenedione (V), cooling, diluting with water, extracting with ether, and evaporating gave an oil from which 1.24 g. of saturated diketone (X) crystallized and was identified by mixture melting point.

(c) A sample of the monoenolate-a_4 made as above from 0.6 g. of the bromodiketone was treated with ten equivalents of mesitylmagnesium bromide in isopropyl ether (refluxing for one hour). Hydrolysis in ice and hydrochloric acid, separation of the ether layer and evaporation gave an oil from which 0.1 g. of the furan (XIII) was obtained on crystallization from ethanol.

(d) To an excess of methylmagnesium iodide in 5 cc. of isoamyl ether was added 0.56 g. of the monoenol-a_4. After three hours at room temperature and at 100° for a half hour, the initial heavy white precipitate passed into solution. The mixture was cooled to −10° and poured with stirring into 50 cc. of ethanol containing 1 g. of iodine, at −10°. Slow dilution with aqueous sodium bisulfite solution precipitated an oil which was extracted by means of ether. After washing with water, evaporating and digesting the residual oil in alcohol, 0.29 g. of the unsaturated diketone (XI) crystallized and was identified.

(e) In an experiment similar to (d) a sample of the dienolate prepared from 0.55 g. of the monoenol-a_4 was added to 50 cc. of ethanol containing 5 cc. of 30% hydrogen peroxide at −10°. Iodine color slowly developed. Upon working up the product as before 0.32 g. of furan (XIII) was isolated and identified by mixture melting point.

(f) A solution of the di-enolate prepared from 0.5 g. of VI as in (d) was added to 50 cc. of 2% ethanolic potassium hydroxide, at −10°. The mixture was acidified, diluted with water and extracted with ether, and on working up as described above gave 0.34 g. of the saturated diketone (X) which was identified by mixture melting point.

(g) Hydrolysis by means of ice and hydrochloric acid of a solution of the di-enolate prepared as in (d) from 0.56 g. of IV, gave 0.24 g. of the furan (XIII) which was identified by mixture melting point.

(h) An attempt was made to isolate the free di-enol. A sample of the di-enolate was made from 1 g. of the bromodiketone by the action of four equivalents of methylmagnesium iodide in isopropyl ether (refluxing for three hours). The mixture was cooled to 0° and poured into 100 cc. of 80% ethanol containing 10 cc. of added acetic acid, cooled to −10°. Upon diluting further with water an ether layer separated and was washed several times with ice cold water and evaporated under reduced pressure. A mixture of oil and crystals resulted and was digested in ethanol, more crystals separating. This product (0.45 g.) was identified by mixture melting point as the furan (XIII). No other crystalline product was isolated.

The monoenolate-b_4 (IX) was prepared by the action of methylmagnesium iodide or mesitylmagnesium bromide on the saturated diketone (X), the reaction proceeding stepwise and ultimately giving the di-enolate-C(b_4) (XII). The reaction with methylmagnesium iodide could easily be followed by the evolution of methane, using the Zerewitinoff apparatus. In a typical experiment 0.51 g. of the saturated diketone was treated with an excess of methylmagnesium iodide in isoamyl ether. After the evolution of one molecule of methane, which occurred in two minutes, the mixture was poured into ice and hydrochloric acid. Upon working up the product in the usual way 0.1 g. of starting material was recovered and no other product was isolated.

When a similarly prepared solution of the monoenolate-b_4 was treated with ten equivalents of mesitylmagnesium bromide in isopropyl ether (refluxing for one hour) a 28% yield of the furan (XIII) was the only product isolated.

The Di-enolate-C(b_4) (XII).—(a) A solution of the dienolate, prepared from the saturated diketone (X) by an excess of methylmagnesium iodide in refluxing isopropyl ether, was hydrolyzed in alcoholic iodine and the product worked up as in the experiments (a) and (b) described under the di-enolate-B(a_4). There resulted a mixture (0.38 g.) of the unsaturated diketone (XI) and the furan (XIII) which was partially separated by taking advantage of the lesser solubility of the furan in ethanol. Fractional crystallization gave 0.04 g. of the furan and 0.09 g. of the unsaturated diketone, and the remaining mixture was shown by microscopic examination of the crystal form to be a mixture of the two with the unsaturated diketone apparently in somewhat greater proportion.

(b) When hydrogen peroxide was substituted for iodine in the above experiment a 70% yield of the saturated diketone was obtained. Evidently the hydrogen peroxide was without any effect and simple ketonization occurred rapidly in the medium which was approximately 90% ethanol.

(c) Hydrolysis of a similar preparation of the di-enolate, in ethanolic potassium hydroxide gave a 90% yield of the saturated diketone.

(d) Hydrolysis of a similar preparation of the dienolate, in ice and hydrochloric acid, gave a 40% yield of the saturated diketone. No other crystalline product was isolated.

Summary

The 2-*t*-butyl-1,4-dimesityl 1,4-diketone series was prepared through the reaction between methylmagnesium iodide and 3-mesitoyl-5-mesityl-2-methylfuran, and by 1,4-addition of *t*-butylmagnesium chloride to dimesitoylethylene. *t*-Butyldimesitylfuran was made by dehydration of the saturated diketone and by hydrolysis of two of the

di-enolates. The unsaturated diketone was obtained by oxidation of the di-enolates.

A crystalline 4-monoenol of the saturated diketone was isolated and evidence given for its structure and configuration. The structural proof included relation to the bromo saturated diketone and bromo-*t*-butyldimesitylfuran.

Evidence for the existence and configuration of the stereoisomeric 4-monoenolate is described.

Evidence for the existence and configurations of three di-enolates is given. The configuration of the di-enolate obtained from mesitoylmesitylmethylfuran is based partly on the probable mechanism of 1,4-addition of Grignard reagent to the α,β-unsaturated ketone system.

A rigorous proof is outlined for 1,4-reduction and 1,4-reductive enolization of a typical α-bromoketone.

CHARLOTTESVILLE, VIRGINIA
RECEIVED SEPTEMBER 6, 1941

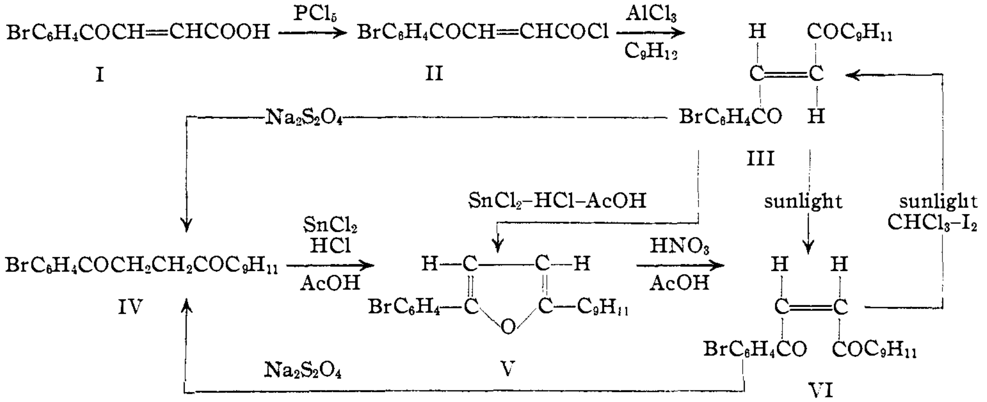
[CONTRIBUTION FROM THE COBB CHEMICAL LABORATORY, UNIVERSITY OF VIRGINIA]

The Mechanism of Oxidative Fission of the Furan Nucleus. Furans with Steric Hindrance by One α-Aryl Group

BY ROBERT E. LUTZ AND WILLIAM P. BOYER

It has been suggested that the characteristic oxidative ring fission of 2,5-diarylfurans to *cis*-unsaturated diketones involves 1,4-addition of the reagent to the diene system followed by break-up, generating necessarily the unsaturated diketone of *cis* configuration.[1] The failure generally of 2,5-dimesitylfurans to undergo this reaction was regarded as consistent with the hypothesis.[1c] The purpose of this investigation was to prepare and test some typical unsymmetrical 2,5-disubstituted furans carrying one and only one sterically hindering α-aryl group. Two compounds of this type have now been studied successfully and are the subject of this report.

2-Bromophenyl-5-mesitylfuran.—In connection with the synthesis of this and related compounds, the following reactions were carried out.



The unsaturated diketone (III) was prepared from *p*-bromobenzoylacrylic acid (I) by the Friedel–Crafts reaction on the acid chloride (II).[2] It was converted into the *cis*-isomer (VI) by the action of sunlight; and the *cis*-compound was converted back into the *trans* by the action of iodine on a chloroform solution with iodine as a catalyst. Reduction of both stereoisomeric unsaturated diketones by means of sodium hydrosulfite gave the saturated diketone (IV). Reduction of the *trans*-isomer by stannous chloride in an acetic–hydrochloric acid mixture gave the furan (V), a reaction which evidently involved first reduction to the saturated diketone. The latter compound in a separate experiment was shown to be convertible readily into the furan under these conditions.

The oxidation of the furan with the nitric–acetic

---

[1] (a) Freure and Johnson, THIS JOURNAL, **53**, 1142 (1931); (b) Lutz and Wilder, *ibid.*, **56**, 978 (1934); (c) Lutz and Kibler, *ibid.*, **62**, 1520 (1940).

[2] Kohler and Woodward, *ibid.*, **58**, 1933 (1936).