NEW INFORMATION REGARDING THE TRANSFORMATIONS OF FURANS UNDER NITRATION CONDITIONS.

DIRECT OXIDATIVE CLEAVAGE OF 2-CYCLOPROPYL- AND 5-METHYL-2-CYCLOPROPYLFURANS BY MEANS OF A NITRATING AGENT

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The principal pathway of the reaction of 2-cyclopropylfurans with acetyl nitrate in acetic anhydride or with nitrogen tetroxide in methylene chloride is cleavage of the furan ring with the formation of unsaturated 1,4-dicarbonyl compounds. Nitrofurylcyclopropanes are formed in low yields via an independent pathway under these conditions. The possible pathways of nonhydrolytic cleavage of the furan ring under anhydrous nitration conditions are discussed.

Up until now, the formation, under the influence of a mixture of concentrated nitric acid and acetic anhydride, of a moderately stable reaction "intermediate," which, in the opinion of all authors, without exception, who have studied the indicated furan systems, corresponds to an adduct of acetyl nitrate with the starting furan substrate, has been regarded as characteristic for furan and a number of its derivatives that display increased acidophobic properties. The authors have disagreed only in their opinion relative to the structure of this adduct. Thus Marquis [1], who first obtained an "intermediate" in the nitration of furan with nitric acid in acetic anhydride and described it as an "uncrystallized oil" that gives several reactions of the formyl group, proposed the 4-acetoxy-2-nitro-3-buten-1-al structure or the structure of its isomer, viz., 4-acetoxy-2-nitro-1,3-butadien-1-ol, for the indicated "intermediate." Later, Rinkes [2, 3] proposed the 1-acetoxy-1-nitro-1,3-butadien-4-ol structure for the same furan adduct.

Freure and Johnson [4], taking into account the data of Marquis [5] indicating that the "intermediate" in the nitration of furan undergoes hydrolysis to give maleindialdehyde, expressed the assumption that Marquis was dealing with the cyclic form of the adduct, viz., 5-nitro-2(4)-acetoxy-2,5-dihydrofuran, rather than with the open form, assuming that the noncyclic form of the adduct cannot lead to the indicated dialdehyde upon hydrolysis.

It should be noted that, in contrast to acidophobic derivatives of furan, the adducts formed from acetyl nitrate and furans that contain strong electron-acceptor substituents are stable and actually have the substituted 2,5-dihydrofuran structure [6]; rearomatization of the latter leads to the corresponding nitrofurans in good yields [6, 7]. On the other hand, the oily "cyclic" (according to Freure and Johnson [4]) adduct of acetyl nitrate with the acidophobic (containing electron-donor or weak electron-acceptor groups) furan in this case gives, despite what was expected, low yields of nitro-substituted furans: Primarily polymerization occurs upon attempts to rearomatize the adduct. At the same time, in [8] it is noted that the hypothetical cyclic adducts of the indicated type form derivatives of dicarbonyl unsaturated compounds in virtually quantitative yields.

Such contradictory data, both with respect to the structure of the so-called "intermediate" in the nitration of furans and with respect to its chemical behavior, make it possible to conclude that in this reaction everything is not as clear as it has seemed to be up until now.

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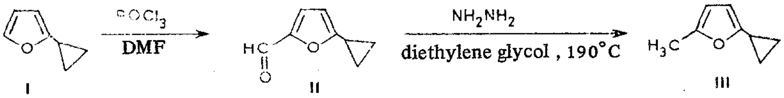
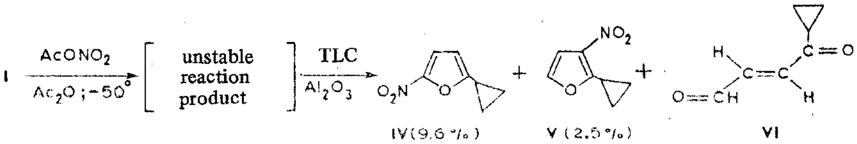
In this connection, in the present research we studied the behavior of acidophobic 2-cyclopropyl- (I) and 5-methyl-2-**cyclopropylfurans** (III) under conditions of nitration with acetyl nitrate in acetic anhydride or with nitrogen tetroxide (N_2O_4) in methylene chloride.

Compound I was obtained by a method similar to that proposed in [9], while 5-methyl-substituted furylcyclopropane III was obtained from 2-cyclopropylfuran (I) via the scheme



A solution of acetyl nitrate in acetic anhydride, which was prepared immediately prior to the reaction, was used as the nitrating agent in our study of the behavior of 2-cyclopropylfuran (I) in nitration; nitration was carried out at –50°C. In this case, regardless of the method of treatment of the reaction mixture (see the Experimental section), the same reaction product (according to data from the IR spectra of the reaction mixtures), which slowly evolved gaseous products* during storage, was formed. Treatment of the reaction product under the conditions that are ordinarily used for the aromatization of 1,2 or 1,4 adducts of furans [6] did not lead to the corresponding nitrofurans – the reaction mass underwent resinification. At the same time, by chromatography of the reaction mixture in a thin layer of aluminum oxide we were able to isolate (in low yields) two nitro-substituted heterocycles, viz., 5-nitro- and 3-nitro-2-cyclopropylfurans (IV, V) in a ratio of 4:1, respectively, and traces of a substance, which, judging from the set of bands of carbonyl groups in its IR spectrum and the absorption band characteristic for compounds that contain a double bond, is β-cyclopropylcarbonylcrotonaldehyde (VI).



A distinctive peculiarity of the PMR spectrum of V was the location in it of a signal of a methylidyne proton of a three-carbon ring shifted by ~1 ppm to weaker field as compared with the position of the analogous signal for 5-nitro-2-cyclopropylfuran (IV). A similar phenomenon was also previously observed in the o- and p-nitrophenylcyclopropane series [10]; it was noted that the significant shift (~0.5 ppm) of the signal of the methylidyne proton of the cyclopropane ring to weak field in the case of the ortho isomers may serve as a reliable criterion in the determination of the orientation of the nitro group in the aryl grouping. In all likelihood, the principle found in the nitroarylcyclopropane series is also characteristic for nitro-substituted cyclopropylfurans; it follows from a comparison of the chemical shifts of the corresponding protons that in the case of furan compounds the anisotropic effect of the nitro group on the methylidyne proton of the small ring is manifested to a much greater degree than in the case of nitrophenylcyclopropanes.

The formation of 3-nitro derivative V should be regarded as the most interesting result obtained in the study of the nitration of 2-cyclopropylfuran (I).†

Up until now, there have been no examples of electrophilic substitution in the 3 position of substituted furans with a free 5 position in the literature. The formation of 3-nitro-2-cyclopropylfuran (V) from I is evidently due to the specific effect of the cyclopropane substituent on the reactivity of the furan system, which is expressed in the high degree of activation of the 3 or 2 position of the heteroring with respect to electrophilic reactions. In the latter case the formation of nitro compound V should occur through 1,2 migration of the electrophile (the nitrile cation or nitrile radical) in the initially formed ipsocomplex [11].

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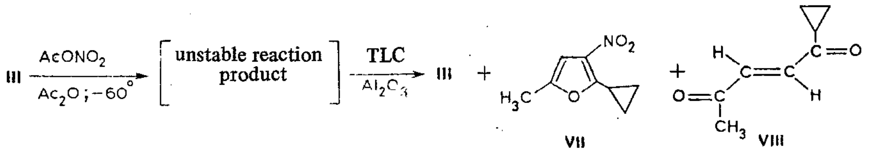
*Similar behavior of the "intermediates" in the nitration of acidophobic furans has been noted by almost all authors (see, for example, [1, 8]).

†The formation of 5-nitro derivatives of monosubstituted furans is the usual phenomenon in nitration.

Identical "oily" reaction products, judging from the IR spectral data, which slowly evolve gaseous substances on standing or storage, were formed in the nitration of 5-methyl-2-cyclopropylfuran (III) under the conditions used for I, also regardless of the method of treatment of the reaction mixture.

Assuming that the overall scheme of the nitration of 2,5-dialkyl-substituted furan III should be similar to the scheme via which the other 2,5-disubstituted furans are transformed, we also assumed that the unstable reaction product consists primarily of isomeric adducts of 5-methyl-2-cyclopropylfuran with acetyl nitrate. However, when we treated the reaction mixture obtained under the conditions for which the corresponding nitrofurans are obtained in relatively high yields from genuine 1,2 and 1,4 adducts of 2,5-disubstituted furans with acetyl nitrate [12], we, just as in the case of the "oily product" obtained from the reaction of I with acetyl nitrate, were unable to isolate significant amounts of nitrofurans; 3-nitro-5-methyl-2-cyclopropylfuran (VII) and starting cyclopropylfuran III were obtained from the distillate only by means of steam distillation (see the Experimental section).

In the case of chromatography on aluminum oxide or on silica gel in various systems the bulk of the "oily product" was tied up by the support; however, in each case we were able to isolate three substances, viz., starting III, nitro compound VII, and trans-1-cyclopropyl-2-pentene-1,4-dione (VIII).



In order to establish the structure of the product formed in the nitration of furan III, which, according to the features that we observed, does not correspond to an adduct of the substrate with acetyl nitrate [the absence in the IR spectrum of absorption bands that are characteristic for nitro groups and the absence in the PMR spectra of the corresponding signals of acetate fragments (see Fig. 1a)], we made a detailed study of it by physicochemical methods.

We found that the IR, PMR, and ^{13}C NMR (with complete and incomplete decoupling of the protons) spectra of the "oily product" obtained in the nitration of 5-methyl-2-cyclopropylfuran (III) with acetyl nitrate in acetic anhydride corresponds to the spectra of one of the substances that was isolated in individual form, viz., trans-1-cyclopropyl-2-pentene-1,4-dione (VIII). Thus we ascertained that the IR spectra of the unstable reaction product and diketone VIII are virtually identical. The chemical shifts of the signals of the corresponding groups of protons in the PMR spectra (see Fig. 1) of the investigated substances* are also in agreement, and the ratios of the integral intensities of the signals of individual groups of protons are of the same order of magnitude for each of the compounds.

An analysis of the ^{13}C NMR spectra with complete and incomplete decoupling of the protons (see Fig. 2) enabled us, we feel, to give a definitive answer to the problem of the structure of the principal product formed from cyclopropylfuran III under the conditions of its nitration with acetyl nitrate in acetic anhydride. It is apparent from the ^{13}C NMR spectra that there are only eight carbon atoms in the composition of a molecule of the compound obtained. Generally speaking, this carbon composition corresponds to both starting substrate III and the diketone formed from it. The choice in favor of diketone VIII was made on the basis of an analysis of the ^{13}C NMR spectrum of starting furan III and the weak-field part of the spectrum of the "oily product": The signals of the carbon atoms (of the quaternary type) in the ^{13}C NMR spectrum of the reaction product at 197.29 and 201.43 ppm indicate unambiguously the presence in the investigated compound of two carbonyl groups. The presence of an intense absorption band of a conjugated carbonyl group in the IR spectrum of the "oily product" also serves as a confirmation of the correctness of our conclusion (see the Experimental section).

Thus we were able to show that in the nitration of cyclopropylfuran III with acetyl nitrate in acetic acid, diketone VIII, rather than the corresponding adduct of the substrate with the reagent, which, as was assumed up until most recently, should be formed

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*The PMR spectrum of the "oily product" remains unchanged for 5-7 days if the sample is stored at −10 to 0°C.

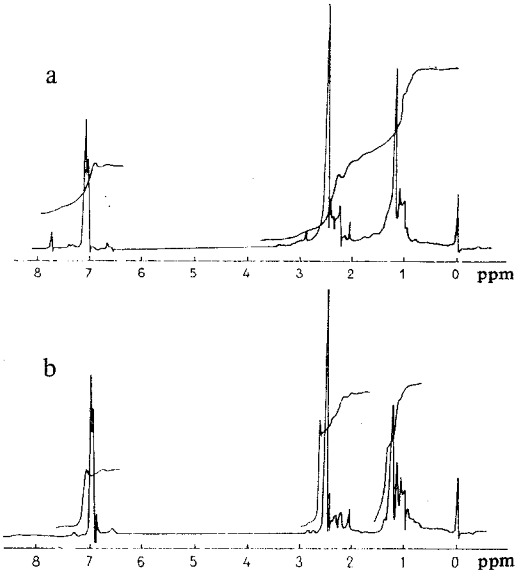


Fig. 1. PMR spectra: a) the reaction mixture obtained in the nitration of 5-methyl-2-cyclopropylfuan (III) with acetyl nitrate in acetic anhydride (with $CDCl_3$ as the solvent and hexamethyldisiloxane as the standard); b) trans-1-cyclopropyl-2-pentene-1,4-dione (VIII) (with $CDCl_3$ as the solvent and hexamethyldisiloxane as the standard).

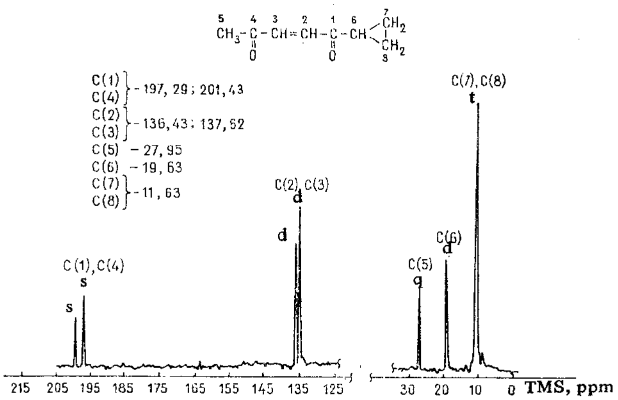


Fig. 2. ^{13}C NMR spectrum of the reaction mixture (diketone VIII) obtained in the nitration of furan III with acetyl nitrate in acetic anhydride (with CCl_4 as the solvent and tetramethylsilane as the standard; the multiplicities of the signals with allowance for the "off-resonance" ^{13}C NMR spectrum of the same reaction mixture are indicated).

in one of the steps of the reaction, is primarily formed. As regards VII, which was isolated as one of the reaction products, it, in all likelihood, is included in the composition of the principal substance in amounts that cannot be reliably interpreted by means of the physicochemical methods of analysis used in the study of the resulting reaction mixture.

It should be noted that the observed (in all cases) instabilities of the "oily products" of nitration of acidophobic furans may be due to the instability of the acetyl nitrate that is present in them in very small amounts. At relatively high (for acetyl nitrate) temperatures it, as is well known [13], can undergo decomposition of the radical type to form gaseous decomposition products, viz., oxides of nitrogen, carbon dioxide, and methane.

This behavior of acetyl nitrate, by the way, constitutes indirect evidence that transformations of acidophobic furans under nitration conditions may be realized under the influence of a radical nitrating particle.

In order to verify this assumption we studied the behavior of 5-methyl-2-cyclopropylfuran (III) under conditions of radical nitration with nitrogen tetroxide [14]. We found that the reaction of substrate III with nitrogen tetroxide in methylene chloride at −60°C with subsequent evacuation of the solvent and the reagents at room temperature leads to a reaction product that is identical (IR spectrum) to that which was obtained from the reaction of furan III with acetyl nitrate in acetic anhydride. Just as in the case of the product of the reaction of III with acetyl nitrate, III, VII, and VIII were isolated by chromatography of the reaction mixture obtained in the nitration of 5-methyl-2-cyclopropylfuran (III) with nitrogen tetroxide, and the products were obtained in approximately the same ratios.

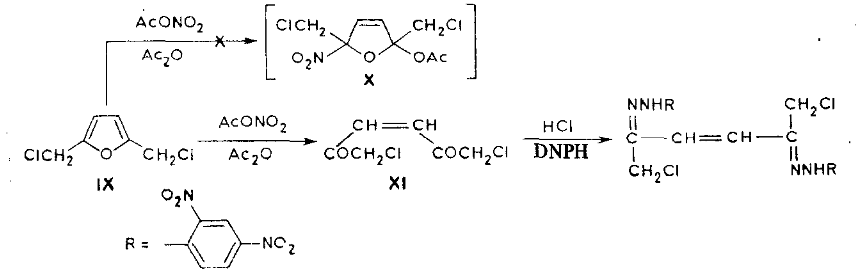
$$\mathrm{III} \xrightarrow[\mathrm{CH_2Cl_2};\,-60^\circ]{\mathrm{N_2O_4}} \left[\text{unstable reaction product}\right] \xrightarrow[\mathrm{Al_2O_3}]{\text{TLC}} \mathrm{III} + \mathrm{VII} + \mathrm{VIII}$$

This result constituted evidence that cleavage of the furan ring under nitration conditions actually may be realized under the influence of a nitrile radical.

In the light of the results obtained in this research it is interesting to discuss the facts previously observed in the nitration of acidophobic furans [1-5, 8].

A number of authors assume that unsaturated diketones of the VIII type can be formed from furans only as a result of acidic hydrolysis of the initially obtained (under nitration conditions) relatively stable "oily products" of the substrates with the reagent [5, 8]. At the same time, in [8] it is pointed out that adduct X, which, the authors assume, is formed when 2,5-bis(chloromethyl)furan is treated with acetyl nitrate in acetic anhydride, without prior hydrolysis in the presence of hydrochloric acid and dinitrophenylhydrazine (DNPH) gives the corresponding hydrazone of unsaturated diketone XI in quantitative yield, while direct treatment of the "adduct" with hydrochloric acid solution leads only to complete resinification of the reaction mixture.

These data compel us to assume that the corresponding dicarbonyl compound XI, rather than an adduct (X) of the substrate with the reagent, is formed in the reaction of bis(chloromethyl)furan (IX) with acetyl nitrate in acetic anhydride, just as in the case that we studied.



As regards the unsuccessful attempt by Novitskii and co-workers [8] to obtain a product of acidic cleavage of bis(chloromethyl)urethane (IX) by hydrolysis of the so-called "oily adduct," this should have been expected when one takes into account the extrmely low stability of the actually formed diketone XI in an acidic medium.*

Thus, on the basis of the literature data, as well as the results obtained in the present research, it should be stated that in the case of nitration with acetyl nitrate in acetic anhydride furan and its derivatives with electron-donor substituents or with substituents that display weak electron-acceptor properties generally do not form stable adducts of the starting substrates with the nitrating agent of the type that were isolated in the nitration of furans that contain strong electron-acceptor groupings [12]; they are converted to α,β-unsaturated diketones of the VIII type, but through intermediates with a structure other than that which was previously assumed.

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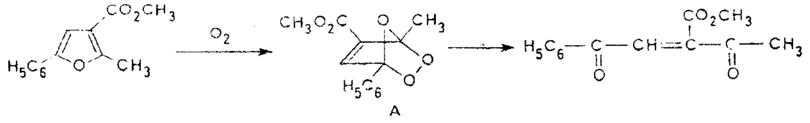
*Novitskii and co-workers [8] have demonstrated by special experiments that 1,6-dichloro-3-hexene-2,4-dione (XI) is unstable, not only in acidic media but also in weakly alkaline media.

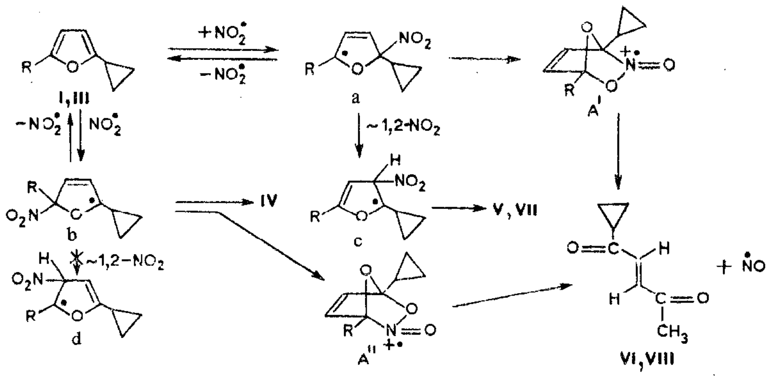
If this were not the case, and diketone were formed from an adduct of starting substrate III with acetyl nitrate as a result of hydrolytic cleavage of the latter, as assumed in [4, 8], first, at least part of the adduct should have been recorded spectrally or isolated during evacuation of the volatile reaction products immediately after the nitration of 5-methyl-2-cyclopropylfuran (III) with acetyl nitrate in acetic anhydride, and, second, the indicated diketone VIII should not have been formed when substrate III was treated with nitrogen tetroxide in methylene chloride, since the formation of acetoxy nitrate adducts is excluded under these conditions.

Since diketone VIII is formed under the conditions of nitration of 5-methyl-2-cyclopropylfuran (III) both by nitrogen tetroxide in methylene chloride (radical-nitration conditions [14]) and by treatment of substrate III with acetyl nitrate in acetic anhydride (radical- or electrophilic-nitration conditions [13]), it may be assumed that in both cases identically constructed intermediates that are responsible for the formation of diketone VIII are formed in an intermediate stage of the process.

It is known from the literature that furans may react with molecular oxygen to give bicyclic endo peroxides (type A), which are then capable of readily undergoing modification to give carbonyl-containing compounds with an open chain [15, 16]: It has been noted that the indicated endo peroxides are converted to carbonyl compounds via, in all likelihood, a radical pathway [17].



Taking into account the data on the behavior of furans in the reaction with molecular oxygen, it may be assumed that under the conditions of nitration of 2-cyclopropylfurans I and III, as a result of reaction of the latter with a nitrating particle, intermediates with a similar structure, which are capable of undergoing conversion to dicarbonyl compounds via the following scheme, are formed:



I, IV—VI R=H; III, VII, VIII R=CH_3

It is interesting that, regardless of the direction of initial attack by the nitrile radical on the substrate, intermediates (A' and A"), the intramolecular redistribution of the electrons in which should lead to the same final product (VI or VIII), can be formed.

It is not difficult to imagine that the process initiated by the nitrile cation also will have a similar result; the difference will consist only in the fact that in the ionic process the NO fragment will be eliminated in the form of a nitrosyl cation rather than as the corresponding radical particle.

However, in our case preference should evidently still be given to a process initiated by a nitrile radical, since, as a result of attack by the ionic particle on, for example, 2,5-disubstituted furan III, compounds that do not contain three-carbon rings should have been formed [18, 19]; this is not observed, judging from the data from the PMR and ^{13}C NMR spectra of the reaction mixture obtained.

It should be noted that the formation of 3-nitro-5-methyl-2-cyclopropylfuran (VII) under the reaction conditions can be explained both by direct attack of the nitrating particle at the 3 position of III with subsequent stabilization of the corresponding σ complex (type c) and by ipso attack; in the latter case the σ complex (type c) should be formed from an ipso σ intermediate (type *a*) due to a 1,2 shift of the nitro group [11].

The absence of 4-nitro-5-methyl-2-cyclopropylfuran in the reaction products may serve as an indication that neither direct attack of the electrophile at the 4 position of the furan ring of substrate III nor 1,2 shift of the nitro group in the ipso ion (type b) occurs; i.e., the formation of a σ complex of the d type is a less favorable process than that which leads to the σ complex responsible for the formation of 3-nitro-5-methyl-2-cyclopropylfuran (VIII).

EXPERIMENTAL

The IR spectra of thin layers of the compounds or suspensions in hexachlorobutadiene were recorded with a UR-20 spectrometer. The PMR spectra of solutions in CCl_4 and $CDCl_3$ were recorded with JNM-60 and XL-100 spectrometers with hexamethyldisiloxane as the internal standard. The ^{13}C NMR spectra were obtained with Varian CFT and Jeol XL-100 spectrometers with operating frequencies of 20 and 25 MHz, respectively. Analysis by gas–liquid chromatography (GLC) was performed with a Tsvet-102 chromatograph with a 3 m by 4 mm column packed with 5% SE-30 siloxane elastomer on Chromaton N-AW with helium as the carrier gas.

2-Cyclopropylfuran (I) was synthesized by the method described in [9]; it was obtained in 47% yield and had bp 125°C (759 mm) and n_D^{20} 1.4801 [9]. The formylation of 2-cyclopropylfuran (I) was carried out as described in [10]; 21 g of I yielded 18.5 g (70%) of 2-cyclopropyl-5-formylfuran (II) with bp 115°C (15 mm) [10].

5-Methyl-2-cyclopropylfuran (III). An 8-ml (0.14 mole) sample of 85% hydrazine hydrate was added in portions with cooling with running water and shaking to a solution of 9 g (0.07 mole) of 2-cyclopropyl-5-formylfuran (II) in 45 ml of diethylene glycol, and the mixture was maintained at 20°C for 15 min. It was then treated with 2 g of NaOH, and the mixture was heated at 100°C for 1 h. The temperature was then raised to 190°C, and the 5-methyl-2-cyclopropylfuran (III) was removed by distillation along with water and excess hydrazine hydrate. The distillate was extracted with ether, and the ether extracts were washed with water and dried with $MgSO_4$. The solvent was removed by distillation, and the residue was distilled to give 5.7 g (75%) of III with bp 152°C (752 mm) and n_D^{20} 1.4853. PMR spectrum: 0.52-0.84 (m, 4H) and 1.46-1.98 (m, 1H) (cyclopropane ring protons); 2.11 (s, 3H, CH_3); 5.64 ppm (s, 2H, furan 3-H and 4-H). Found: C 78.9; H 8.3%. $C_8H_{10}O$. Calculated: C 78.7; H 8.2%.

Nitration of 2-Cyclopropylfuran (I). A 0.6-g (0.01 mole) sample of nitric acid (sp. gr. 1.51) was added to 5 ml of acetic anhydride cooled to −50°C, after which the temperature was raised to 10°C, and the mixture was maintained at this temperature for 10 min. The solution of acetyl nitrate was cooled to −50°C, a solution of 1 g (0.01 mole) of 2-cyclopropylfuran (I) in 2 ml of acetic anhydride was added to it, and the mixture was stirred at the same temperature for 3 h. It was then poured into 80 ml of water, and the aqueous mixture was extracted with chloroform. The chloroform extracts were washed with water until the washings were neutral and were then dried with $MgSO_4$. The solvent was evaporated to give a viscous cherry-red oil, which slowly evolved gaseous substances on standing. The oily reaction product was chromatographed on activity II neutral aluminum oxide in an ether–hexane system (1:3) to give 0.12 g (9.6%) of 5-nitro-2-cyclopropylfuran (IV)* [PMR spectrum: 0.82-1.29 (m, 4H) and 1.53-2.18 (m, 1H) (three-membered ring protons); 6.12 (d, 1H, 3-H, J_{34} = 4 Hz); 7.12 ppm (d, 1H, 4-H, J_{43} = 4 Hz). IR spectrum: 1360, 1545 cm^{-1} (NO_2). Found: C 54.8; H 4.5; N 9.0%. $C_7H_7NO_3$. Calculated: C 54.9; H 4.6; N 9.2%] and 0.03 g (2.5%) of 3-nitro-2-cyclopropylfuran (V), which, according to the GLC data, contained up to 5% of isomer IV [PMR spectrum: 1.33-1.71 (m, 4H) and 2.93-3.61 (m, 1H) (cyclopropane ring protons); 7.21 (d, 1H, 5-H, J_{54} = 3 Hz); 7.48 ppm (d, 1H, 4-H, J_{45} = 3 Hz). IR spectrum: 1365, 1570 cm^{-1} (NO_2). Found: C 54.9; H 4.6; N 8.8%. $C_7H_7NO_3$. Calculated: C 54.9; H 4.6; N 9.2%].

The reaction mass obtained after nitration of 1 g of I as described above was evacuated, and the excess acetic anhydride and volatile substances were removed by distillation at 20°C (1 mm). The residual viscous cherry-red oil was dissolved in chloroform and chromatographed

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*According to GLC data, the sample contained 3% admixed 3-nitro isomer V.

as in the preceding experiment to give IV and V in the same amounts. The spectral characteristics of IV and V were in agreement with those for the samples isolated previously.

Nitration of 5-Methyl-2-cyclopropylfuran (III) with Acetyl Nitrate in Acetic Anhydride. A solution of 2.45 g (0.02 mole) of III in 4 ml of acetic anhydride was added at −60°C to a solution of acetyl nitrate prepared from 0.9 ml (0.022 mole) of nitric acid (sp. gr. 1.51) in 10 ml of acetic anhydride as described above, and the mixture was stirred at the same temperature for 3 h. The reaction mixtures obtained three times by this method were worked up by different methods.

A) The reaction mixture was poured into ~100 ml of water, and the aqueous mixture was extracted with chloroform. The extract was washed with water, dried with $MgSO_4$, and evaporated to give 3.1 g of a viscous dark-red oil, which at room temperature evolved brown vapors of nitrogen oxides.

B) The reaction mixture obtained by nitration was poured into water, and the aqueous mixture was extracted with chloroform. The extract was washed three times with water, dried with $MgSO_4$, and evaporated to give 3 g of a viscous oil with the properties of the reaction product described above.

C) The volatile substances were evaporated at room temperature and reduced pressure (1 mm) from the reaction mixture obtained after nitration. After evacuation for 4 h, 3.11 g of an oily substance, which also evolved oxides of nitrogen oxides on storage, was obtained.

The oily reaction products obtained by the various methods were analyzed by IR and NMR (^1H and ^{13}C) spectroscopy. Found for the reaction mixture: C 65.3; H 6.8%. Calculated for the adduct of substrate III with acetyl nitrate ($C_{10}H_{13}NO_5$): C 52.9; H 5.7%. Calculated for diketone VIII ($C_8H_{10}O_2$): C 69.5; H 7.3%. Calculated for 3-nitro-5-methyl-2-cyclopropylfuran (VII) ($C_8H_9NO_3$): C 57.5; H 5.5%. Chromatography of the 3.11 g of the oily reaction product on activity II neutral aluminum oxide in an ether–hexane system (1:1) gave 0.32 g (9.5%) of 5-methyl-3-nitro-2-cyclopropylfuran (VII) [mp 84°C; PMR spectrum: 0.85-1.41 (m, 4H) and 2.61-3.17 (m, 1H) (cyclopropane ring protons); 2.27 (s, 3H, CH_3); 6.33 ppm (s, 1H, 4-H); IR spectrum: 1340, 1580 cm^{-1} (NO_2). Found: C 57.8; H 5.7; N 8.5%. $C_8H_9NO_3$. Calculated: C 57.5; H 5.6; N 8.4%], 0.19 g (7%) of 1-cyclopropyl-2-pentene-1,4-dione (VIII) [viscous light-green oil; PMR spectrum: 0.77-1.17 (m, 4H) and 1.86-2.29 (m, 1H) (three-membered ring protons); 2.29 (s, 3H, CH_3); 6.52-7.11 ppm, AB system (trans-olefin protons, J = 17.6 Hz); IR spectrum: 1600 (C=C) and 1680 cm^{-1} (C=O). Found: C 69.1; H 7.1%. $C_8H_{10}O_2$. Calculated: C 69.5; H 7.3%] and 0.08 g (3%) of starting furan III.

Nitration of 5-Methyl-2-cyclopropylfuran (III) with Nitrogen Tetroxide in Methylene Chloride. A 0.95-g (0.01 mole) sample of nitrogen tetroxide was condensed by cooling and dissolved in 10 ml of methylene chloride, and the solution was cooled to −60°C. A solution of 2.45 g (0.02 mole) of 5-methyl-2-cyclopropylfuran (III) in 10 ml of methylene chloride was added to the nitrating agent, and the mixture was stirred at −60°C for 3 h. It was then worked up by methods B and C as described above. Method B gave 2.85 g of product, and method C gave 3.02 g of the same product as a dark-red oil, the physicochemical characteristics of which were identical to those observed for the reaction product isolated in the nitration of III with acetyl nitrate in acetic anhydride.

Chromatography on neutral aluminum oxide of the reaction product obtained after workup of the reaction mixture obtained by method C in an ether–hexane system (1:1) yielded 0.27 g (8%) of 3-nitro-5-methyl-2-cyclopropylfuran (VII), 0.23 g (9%) of trans-1-cyclopropyl-2-pentene-1,4-dione (VIII), and traces of the starting compound.

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SYNTHESIS OF 4-(HYDROXYMETHYL)TETRAHYDRO-4-PYRANOL — A NEW INTERMEDIATE FOR THE PREPARATION OF SYNTHETIC CITRIC ACID

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The hydroxylation of 4-methylenetetrahydropyran with hydrogen peroxide in the presence of various acidic catalysts was investigated. The oxidation of 4-(hydroxymethyl)tetrahydro-4-pyranol with concentrated nitric acid leads to citric acid in 50% yield.

In the present communication we describe the results of the hydroxylation of 4-methylenetetrahydropyran (I) to 4-(hydroxymethyl)tetrahydro-4-pyranol (II). We became interested in the synthesis of tetrahydropyranol II in connection with the fact that citric acid, which, up until now, has been obtained almost exclusively by the biochemical oxidation of foodstuffs, can be synthesized by direct oxidation of II.

Taking into account data on the hydroxylation of olefins [1] and the double bond of dihydropyrans [2-4] we investigated the oxidation of I with hydrogen peroxide in the presence of various acidic catalysts. We showed that methylenetetrahydropyran I is readily oxidized by this reagent to give glycol II in good yields. The reaction is catalyzed by $Na_2WO_4 \cdot 2H_2O$, NH_4NO_3, H_2MoO_4, H_2WO_4, Cr_2O_3, and CrO_3. The best yields of glycol II were obtained when the reaction was carried out in the presence of sodium tungstate at 50-60°C and H_2O_2:I ratios of 1:1 to 1:1.5. It should be noted that even 2% (by mass) of this catalyst ensures a 96% yield of glycol II.

The H_2O_2–formic acid system is also a good reagent for the hydroxylation of II. Similar oxidation can be accomplished with aqueous potassium permanganate solution.

Taking into account the possibility of oxidation of primary alcohols [5] and oxacyclanes [6, 7] to carboxylic acids upon reaction with nitric acid, we investigated the behavior of 4-(hydroxymethyl)tetrahydro-4-pyranol under the influence of this reagent. We showed that, as expected, nitric acid readily oxidizes glycol II to give citric acid in 50% yield.

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