170–200 atm. for 3.5 hours with 5 g. of copper barium chromite. The absorption of hydrogen was 0.5–0.7 mole. The filtered solution was freed of solvent by vacuum distillation. The residue when chilled yielded 9.1 g. of crystalline 1,8-octanediol, m.p. 59.5°, after recrystallization from chloroform–petroleum ether (reported[14] m.p. 60°). An additional 1.1 g. of the diol distilling at 120–130° (1.8 mm.) was recovered from the solvent, making the total yield of the diol 10.2 g. (61%).

Anal. Calcd. for $C_8H_{10}O_2$: C, 65.71; H, 12.41; mol. wt., 146. Found: C, 65.61; H, 12.34; mol. wt., 149, 152.

The diol was further identified as the bis-(N-phenylcarbamate), m.p. 175° (recrystallized from chloroform, reported[14] m.p. 173°).

The filtrate from the hydrogenation described above was distilled to give XIV, a colorless liquid with a peppermint-like odor boiling at 84–86° (1.8 mm.), 1.4 g., 8%.

Anal. Calcd. for $C_8H_{16}O_2$: C, 66.63; H, 11.18; mol. wt., 144. Found: C, 66.31; H, 11.21; mol. wt., 140, 139.

The infrared spectrum indicated the presence of a hydroxyl group. The allophanate of XIV melted at 150–151°.

Anal. Calcd. for $C_{10}H_{18}O_4N_2$: N, 12.17. Found: N, 11.92.

Dihydrobifurandione (XV).[15]—*trans*-Bifurandione (25 g.), dioxane (200 ml.) and reduced nickel molybdite catalyst[6] (1.6 g.) were shaken with hydrogen at 200 atm. and 120° for four hours. The product, after removal of catalyst and solvent, was 12.3 g. (49%) of solid dihydrobifurandione (XV) and 5.3 g. of a dark oil. The product was recrystallized repeatedly from ethyl acetate or methyl ethyl ketone to give almost colorless crystals melting at 153–156° with initial sintering at 148° and complete liquefaction at 166°. The lack of a sharp melting point may indicate a mixture of stereoisomers; infrared spectra: carbonyl of saturated lactone ring, 5.52 μ; carbonyl of unsaturated lactone ring, 5.70 μ; exocyclic double bond, 5.87 μ; and ring double bond, 6.51 μ.

Anal. Calcd. for $C_8H_6O_4$: C, 57.83; H, 3.64. Found: C, 57.72; H, 3.67.

Hydrogenation of bifurandione (100 g.) in dioxane (700 ml.) over 1% palladium-on-calcium carbonate catalyst (6 g.) at 90 atm. was stopped after the absorption of one mole of hydrogen (6 hours). The product, a dark brown oil, partly crystallized. Recrystallization from ethyl acetate gave dihydrobifurandione, m.p. 153–156°, yield 12%, that did not depress the melting point of a sample prepared by the previous procedure.

4,5-Dioxoöctanedioic Acid (XVI).—A solution of 4.9 g. of *trans*-bifurandione (I) in 100 ml. of concentrated sulfuric acid was reduced electrolytically[7] at a potential of −0.65 to −0.80 volt using a mercury pool cathode and a saturated mercurous sulfate reference cell. External cooling was necessary because of the very exothermic nature of the reaction. The product was poured into 500 ml. of ice-water to precipitate 3.5 g. (58%) of XVI, m.p. 182–183° (with darkening) after two recrystallizations from ethyl alcohol. It was quite insoluble in ethyl acetate and methyl ethyl ketone but also could be recrystallized from acetic acid or water; ultraviolet absorption: $k_{2570\text{ Å.}} = 0.73$; infrared absorption: 3.4 (saturated CH) and 5.8 μ (carbonyl and carboxyl).

Anal. Calcd. for $C_8H_{10}O_6$: C, 47.53; H, 4.99; neut. equiv., 101. Found: C, 47.66, 47.39; H, 5.18, 5.13; neut. equiv., 100.

Quinoxaline-2,3-dipropionic Acid.—A solution of 4,5-dioxoöctanedioic acid (XVI) (0.63 g.) and *o*-phenylenediamine (0.70 g.) in ethanol (30 ml.) was heated on a steam-bath for 45 minutes. The cooled solution yielded purplish-brown crystals (0.17 g.) of the quinoxaline derivative, m.p. 204–212° dec.

Anal. Calcd. for $C_{14}H_{14}O_4N_2$: C, 61.31; H, 5.15. Found: C, 61.14; H, 5.33.

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[14] H. Kondo, H. Suzuki and K. Takeda, *J. Pharm. Soc. Japan*, **55**, 741 (1935).

[15] H. E. Holmquist, U. S. Patent 2,866,792 (1958).

[CONTRIBUTION NO. 498 FROM THE CENTRAL RESEARCH DEPARTMENT, EXPERIMENTAL STATION, E. I. DU PONT DE NEMOURS AND CO.]

Bifurandione. III. Addition and Ring-opening Reactions

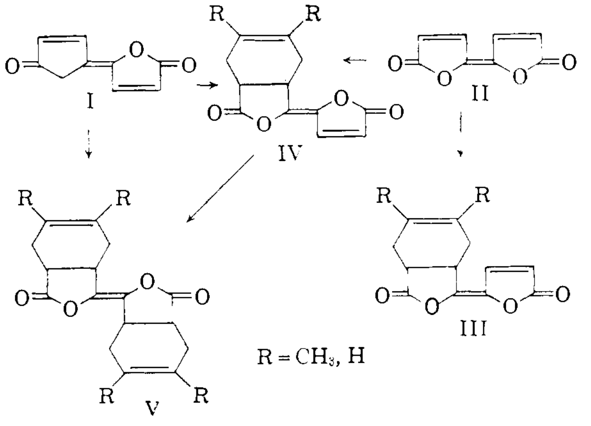
BY H. E. HOLMQUIST, J. C. SAUER, V. A. ENGELHARDT AND B. W. HOWK

RECEIVED DECEMBER 17, 1958

$\Delta^{2,2'(5H,5'H)}$-Bifuran-5,5'-dione (bifurandione) added either one or two molecules of a diene in the Diels–Alder reaction. Oxidation of the dilactone with nitric acid gave 2,2'-dihydroxy-2,2'-bifuran-5,5'(2H,2'H)-dione, which was hydrogenated to 4,5-dioxoöctanedioic acid. Bifurandione reacted with hydroxides, alkoxides and amines to give acids, esters and amides in which one or both lactone rings were opened. Prolonged treatment with strong bases degraded bifurandione to four-carbon compounds. The Meerwein reaction was used to add an aryl radical to bifurandione.

The multiple functionality of *cis*- and *trans*-$\Delta^{2,2'(5H,5'H)}$-bifuran-5,5-dione (I),[1] referred to in this paper as bifurandione, suggested that it should undergo a variety of reactions. The many types of hydrogenation reactions[2] described in Paper II of this series were the result of the complex structural features of the dilactone. The reactions of bifurandione with dienes, oxidizing agents, bases and free radicals are reported in this paper.

Diels–Alder Reaction.—Application of the Diels–Alder reaction in the structure proof of bifurandione was described in Paper I.[1] Further work was carried out to determine the scope of the reaction. Although bifurandione might be expected to act as either the diene or dienophile component in the Diels–Alder reaction, it was found that it functioned only as a dienophile under the conditions tried. Thus, either isomer of the dilactone reacted readily



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[1] Paper I, J. C. Suuer, et al. THIS JOURNAL, **81**, 3677 (1959).

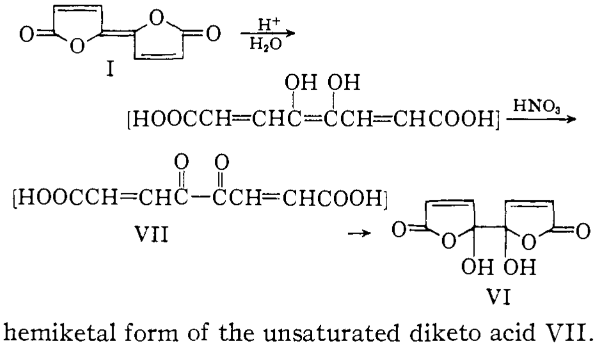
[2] Paper II, H. E. Holmquist, et al. *ibid.*, **81**, 3681 (1959).

with such dienes as butadiene,[1] 2,3-dimethylbutadiene and α-phellandrene at 150–200° to give crystalline adducts, while attempts to effect a reaction with maleic anhydride were unsuccessful. *trans*-Bifurandione exhibited bifunctionality as a dienophile while the *cis* isomer added only one mole of diene, apparently for steric reasons. The splitting of the carbonyl band in the infrared spectra of the monoadducts into two peaks confirmed that one of the double bonds adjacent to a carbonyl group acted as the dienophile. If the central double bond had reacted, the two lactone rings would have remained identical. The diadducts are symmetrical and have a single carbonyl peak in their spectra.

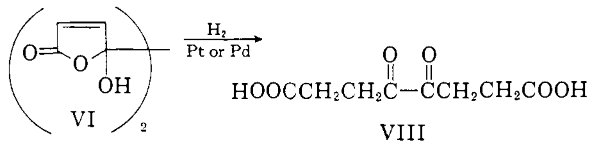
In the reaction of 2,3-dimethylbutadiene with *cis*-bifurandione (II), not only the expected *cis* adduct III (R = CH_3) was formed, but also the isomerized *trans* adduct IV (R = CH_3). The latter was the sole product from *trans*-bifurandione (I). The partial isomerization of the product from *ci* bifurandione was probably caused by steric hi drance between the newly formed six-membere ring and the unreacted ring of the *cis*-bifurandion *trans*-Bifurandione and its monoadduct IV (R = CH_3) could each be converted to the diadduct V (R = CH_3). The monoadduct III (R = CH_3) from *cis*-bifurandione would not add another molecule of 2,3-dimethylbutadiene at 150° but in the attempt was partially isomerized. The new, higher melting isomer is probably related to III (R = CH_3) by *cis-trans* isomerism at the points of junction of the fused rings (*i.e.*, of the decahydronaphthalene type). The only alternative structure for the new isomer, a spiro compound resulting from addition of the dimethylbutadiene to the bridge double bond of bifurandione, is rendered unlikely by the infrared spectrum.

Oxidation.—The oxidation of *trans*-bifurandione (I) with nitric acid in sulfuric acid gave a 63% yield of 2,2′-dihydroxy-2,2′-bifuran-5,5′(2H,2′H)-dione (VI), also obtainable in smaller conversion by oxidation with *t*-butyl hypochlorite. The use of aqueous calcium hypochlorite as oxidizing agent led to a 47% yield of fumaric acid.

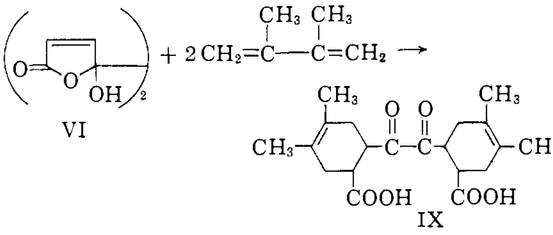
The nitric acid oxidation to dihydroxybifurandione (VI) presumably proceeded through the intermediates shown. Compound VI is the cyclic hemiketal form of the unsaturated diketo acid VII. The cyclic hemiketal VI is the structure favored by the infrared spectral evidence. Toward some reagents, however, it reacted in the open-chain form (VII). This type of isomerism has also been observed in the known benzolog of VI and its derivatives.[3] The white crystalline product VI appears to be a mixture of the racemic and *meso* isomers, indistinguishable by melting point but having somewhat different solubilities in organic solvents.



The two double bonds of dihydroxybifurandione (VI) were saturated easily by hydrogenation at room temperature over platinum or palladium in either acetic acid or a neutral solvent to give 4,5-dioxoöctanedioic acid (VIII) also obtained in one step by electrolytic reduction of bifurandione.[2]



Dihydroxybifurandione (VI) acted as a bifunctional dienophile toward 2,3-dimethylbutadiene. Not only did two moles of the diene add, but the cyclic hemiketal opened to the γ-keto acid form, as indicated by the absence of the lactone carbonyl band in its infrared spectrum. Thus, the yellow crystalline product was 2,2′-dicarboxy-4,4′,5,5′-tetramethyl-1,1′,2,2′,3,3′,6,6′-octahydrobenzil (IX). It is interesting that this reaction, which like hydrogenation removes the two lactone ring double bonds, gives a product that exists in the γ-keto acid form just as does the hydrogenation product VIII. Both of these products are yellow. In contrast, all of the functional derivatives of dihydroxybifurandione (VI) in which the double bonds are retained exist in the cyclic form and are colorless like the parent compound itself. The new acid IX resisted attempts at esterification in contrast to the facile reaction of methanol with VI.



Dihydroxybifurandione (VI), when treated with *o*-phenylenediamine, reacted in its open chain form and yielded its quinoxaline derivative, benzopyrazine-2,3-diacrylic acid. However, reactions of VI with methanol, acetic anhydride and thionyl chloride gave the 2,2-dimethoxy, diacetoxy, dichloro and cyclic sulfite derivatives of the lactone form VI.

Reactions with Basic Reagents.—The structure of bifurandione indicated that it could react in several ways toward bases and acids. It was found to be stable toward acids except for isomerization,[1] but with a large variety of organic and inorganic bases readily underwent reactions involving the opening of one or both of the lactone rings. The available data indicate that the *trans* and *cis* isomers I and II of bifurandione react in the same manner. Some of the open chain derivatives can

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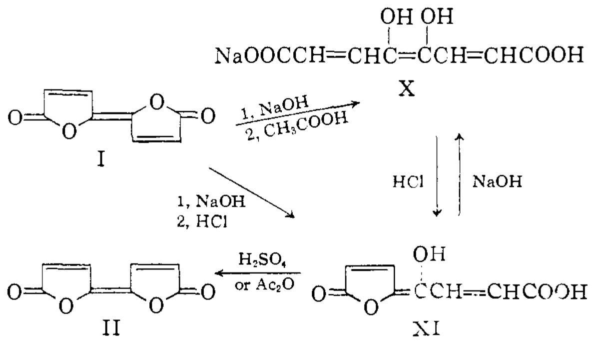
[3] (a) C. Graebe and F. Hönigsberger, *Ann.*, **311**, 257 (1900), (b) A. Hantzsch and A. Schwiete, *Ber.*, **49**, 213 (1916).

be recyclized to *cis*-bifurandione by stringent treatment.

trans- or *cis*-bifurandione and aqueous sodium hydroxide gave, after partial or complete acidification, the monosodium salt X of 4,5-dihydroxy-2,4,6-octatrienedioic acid in 74% yield and the monolactone XI of the acid in 93% yield, respectively. Heating with acetic anhydride or sulfuric acid converted XI to *cis*-bifurandione (II). Diphenylbifurandione,[1] heated with alkali followed by acidification, gave a monolactone acid corresponding to XI.

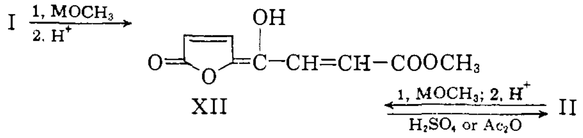


The acid XI and the salt X are quantitatively interconvertible. When the salt X was heated it lost one mole of water to form the bright orange monolactone salt of XI. The disodium and trisodium salts of 4,5-dihydroxy-2,4,6-octatrienedioic acid were prepared by addition of stoichiometric quantities of sodium hydroxide solution to the acid XI or monosodium salt X, but the tetrasodium salt could not be prepared by any technique investigated.

Hydrogenation of the monosodium salt X gave a 12% yield of 4-oxooctanedioic acid.[2]

Because of the enediol system in the completely hydrolyzed form of bifurandione, vigorous or prolonged treatment with bases causes cleavage to four-carbon fragments. Thus, when an alkaline solution of bifurandione was heated or allowed to stand for a few hours, considerable degradation to maleic acid and tar took place.

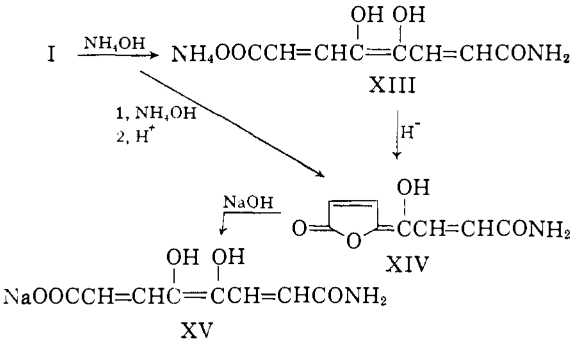
The reactions of *cis*- or *trans*-bifurandione with methanolic solutions of lithium or sodium methoxides at room temperature gave high yields of salts whose structures are not known with certainty; but both lactone rings have been opened, since the lactone carbonyl absorption is absent from the salt's infrared spectrum. Upon treatment of the salt with either weak or strong acids, the yellow crystalline monolactone methyl ester XII was obtained essentially quantitatively. Vigorous treatment with strongly acidic reagents converted XII to *cis*-bifurandione (II).



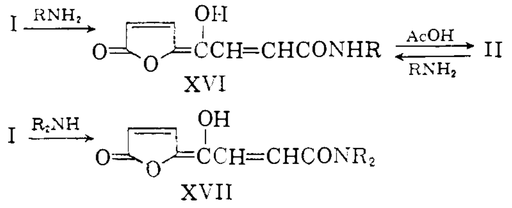
Diphenylbifurandione reacted with sodium methoxide to form a monolactone ester salt, which upon mild acidification, gave *cis*-diphenylbifurandione. This is in contrast to the stability of XII to acids under mild conditions.

Hydrazine hydrate apparently did not open the ring of the lactone ester XII but instead formed a salt from which XII could be recovered by acidification. This is in contrast to the vigorous reaction of hydrazine with bifurandione itself, which gave an intractable solid having the composition of two molecules of hydrazine and one of I.

Bifurandione dissolved readily in aqueous ammonia to give a deep red solution from which the ammonium salt of the monoamide of 4,5-dihydroxy-2,4,6-octatrienedioic acid (XIII) was obtained by evaporation to dryness. Acidification of the solution with either strong or weak acids gave the monolactone amide XIV in 71% yield based on bifurandione. This compound could also be obtained by the action of liquid ammonia on bifurandione. The sodium salt XV of the monoamide was prepared in 92% yield by reaction of XIV with the stoichiometric quantity of alkali.



The reactions of bifurandione with aliphatic primary or secondary amines at room temperature gave, after acidification, crystalline monolactone amides of type XVI or XVII in yields up to 75%. They gave positive enol tests with ferric chloride. *cis*- and *trans*-bifurandione each gave the same amide with *n*-butylamine. The amide could be cyclized to *cis*-bifurandione (II) by boiling acetic acid.



The behavior of bifurandione with primary aromatic amines is less straightforward than with aliphatic bases. The monolactone amide structure XVIII, expected by analogy to the aliphatic amide adducts, was obtained in three instances, with *p*-toluidine, *p*-aminobenzoic acid and a dodecylaniline. *p*-Chloroaniline gave a 2:1 adduct, still containing a lactone ring, which was assigned the structure XIX.

With aniline and α-naphthylamine, the reaction took still another course and gave small yields of products (XX) in which three moles of the amine had reacted with one of bifurandione. The solvent for these reactions was boiling acetic acid or, in the case of aniline, the amine itself.

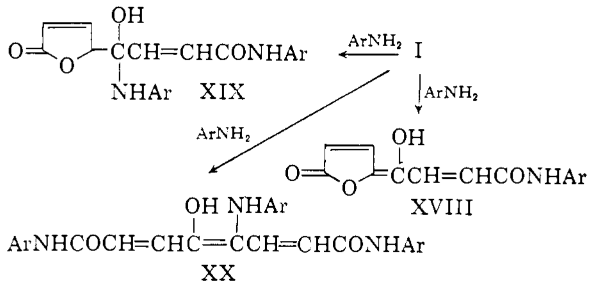
TABLE I

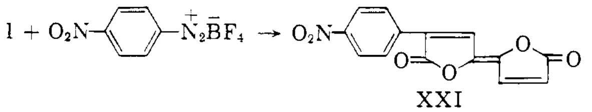
DIELS–ALDER ADDUCTS OF BIFURANDIONE AND DERIVATIVES

Dienophile	Diene	Moles diene per mole dienophile	Temp., °C.	Product	Yield, %	M.p., °C.	Carbon, %		Hydrogen, %		Mol. wt.	
							Calcd.	Found	Calcd.	Found	Calcd.	Found
I	A[a]	1	150	IV ($R = CH_3$)[b]	84	153–154	68.28	68.71	5.73	5.56	..	..
II	A	1	150	III ($R = CH_3$)[c]	24	174–178	68.28	67.95	5.73	5.71	..	..
				IV ($R = CH_3$)	53	156	...[d]	...	..	..	..	..
IV ($R = CH_3$)	A	1	150	V ($R = CH_3$)[e]	23[f]	244	73.14	72.67 72.15	7.37	7.26 7.00	328	314
I	A	2	175	V ($R = CH_3$)	23	240–243	...[d]	...	..	..	..	..
				IV ($R = CH_3$)	67	154–156	...[d]	...	..	..	..	..
III ($R = CH_3$)	A	1	150	Isomerized adduct	11	208–209	68.28	68.28 68.57	5.73	5.88 5.93	246	264 260
				Unchanged III	39	173–176	...[d]		..	..	..	..
I	B[a]	6	150	IV ($R = H$)[g]	75	109.5	66.05	65.95 66.15	4.62	4.66 4.77	218	227 228
I	B	6	200	V ($R = H$)		See paper I[1]	...	...	..	..	..	..
I	α-Phellandrene	1	175	Monoadduct	..	168–175	71.98	71.84	6.71	6.88	300	305 310
VI	A	2	150	IX[h,i]	33	176	66.28	65.06 65.51 65.24	7.23	7.34 7.37 7.33	181[j]	175

[a] A = 2,3-dimethyl-1,3-butadiene; B = 1,3-butadiene. [b] Infrared absorption: 5.50, 5.60, 5.70, 5.90, 6.50 μ. [c] Infrared absorption: 5.50, 5.60, 5.70, 5.90, 6.50 μ. [d] Compared with analyzed sample by mixed m.p. test (no depression). [e] Infrared absorption: 5.60 μ. [f] At 50% conversion. [g] Infrared absorption: 5.50, 5.60, 5.70, 5.90, 6.50 μ. [h] Infrared absorption: 5.80 (ketone carbonyl), 10.8 μ (carboxyl). [i] See text for derivative. [j] Neutral equivalent.

Other Addition Reactions.—One example of free-radical substitution of *trans*-bifurandione was demonstrated. The reaction of *p*-nitrophenyl radicals, generated by the action of copper chloride upon *p*-nitrobenzenediazonium fluoborate, with I gave a 41% yield of a reddish-brown *p*-nitrophenyl-$\Delta^{2,2'(5H,5'H)}$-bifuran-5,5'-dione. No evidence relating to the position of substitution was obtained, but the 4-substituted formula XXI has been assigned by analogy to the arylation products of coumarin.[4] Addition of radicals from other diazonium salts or of a second mole of *p*-nitrophenyl radical resulted in complex mixtures containing unchanged bifurandione. Direct chlorination of I in acetic acid gave a different crystalline isomer of dichlorobifurandione than that obtained by the action of thionyl chloride on dihydroxybifurandione.





XXI

Experimental

Diels–Alder Reactions of Bifurandione (I and II).[5]—The reactions of I and II with dienes were run in closed steel vessels with dioxane as solvent for 16–19 hours except in the case of α-phellandrene which was used without solvent at atmospheric pressure. Products are described in Table I.

Oxidation of I to Dihydroxybifurandione (VI).[6] **A. With Nitric Acid.**—To a stirred solution of bifurandione (32.8 g., 0.2 mole) in sulfuric acid (150 ml.), cooled by an ice-bath, was added a solution of concentrated nitric acid (15 ml.) in concentrated sulfuric acid (35 ml.) over a one-hour period. The solution was allowed to come to ambient temperature during three hours additional stirring, during which time some evolution of nitrogen tetroxide was observed. The solution was poured onto about 3 l. of ice to give an almost white precipitate of 2,2'-dihydroxy-2,2'-bifuran-5,5'(2H, 2'H)-dione (VI) (25.1 g., 63%), m.p. 170–190° dec. After recrystallization from ethyl acetate or methyl ethyl ketone it melted at 187–189° dec. It was moderately soluble in water and slowly reacted with dilute sodium bicarbonate; infrared spectrum: see under B.

Anal. Calcd. for $C_8H_6O_6$: C, 48.49; H, 3.05; mol. wt., 198. Found: C, 48.79; H, 3.20; mol. wt., 212, 194.

The reaction was exothermic and external cooling had to be employed, since the yield was diminished if the temperature of the solution was allowed to rise. For the same reason it is necessary to avoid excess nitric acid or the use of dilute acids in the reaction.

B. **With *t*-Butyl Hypochlorite.**—To a stirred solution of bifurandione (5 g., 0.03 mole) in acetic acid (1 l.) at 70° was added 7.9 g. (0.065 mole) of *t*-butyl hypochlorite over a period of 3 hours. After another 3 hours at 70°, the solution was allowed to stand overnight at room temperature and was then evaporated to less than 100 ml. Some unchanged bifurandione (1.15 g.) was removed by filtration and the filtrate evaporated to dryness to give an oil which solidified almost entirely to give 3.4 g. (73%) of VI. Large white prisms crystallized from methyl ethyl ketone, m.p. 189° dec.; infrared spectrum: 2.95 (hydroxyl), 3.2 (unsaturated CH), 5.65 (lactone carbonyl), 6.15 μ (conjugation).

Anal. Calcd. for $C_8H_6O_6$: C, 48.49; H, 3.05; mol. wt., 198. Found: C, 48.64; H, 3.16; mol. wt., 195, 197.

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[4] H. Meerwein, E. Büchner and K. van Emster, *J. prakt. Chem.*, **152**, 237 (1939).

[5] J. C. Sauer, U. S. Patent 2,859,220 (1958).

[6] H. E. Holmquist, U. S. Patent 2,866,793 (1958).

Hydrogenation of Dihydroxybifurandione (VI) to 4,5-Dioxoöctanedioic Acid (VIII).—Dihydroxybifurandione (VI) (25 g., 0.13 mole), dioxane (350 ml.) and platinum oxide (0.13 g.) were shaken with hydrogen at room temperature at a maximum pressure of 3 atm. Approximately two moles of hydrogen per mole of starting material was absorbed in less than 7 hours. The filtered solution was evaporated to give 21.1 g. (83%) of crude 4,5-dioxoöctanedioic acid (VIII), 16.4 g. in crystalline form. After recrystallization from ethyl alcohol, the bright yellow acid melted at 182–183° dec. and did not depress the melting point of the sample of VIII obtained by electrolytic reduction of bifurandione.[2]

The hydrogenation of VI to VIII can also be carried out over 10% palladium-on-carbon in dioxane or over platinum in acetic acid.

Quinoxaline Derivative of IX. See Table I for Preparation of IX.—A small sample of IX was warmed with an equimolar quantity of *o*-phenylenediamine in ethyl alcohol to give the quinoxaline derivative, 2,3-bis-(6-carboxy-3,4-dimethyl-3-cyclohexenyl)-benzopyrazine, m.p. 212–214° dec. after two recrystallizations from ethyl alcohol–water.

Anal. Calcd. for $C_{26}H_{30}O_4N_2$: C, 71.87; H, 7.12; N, 6.45; neut. equiv., 217. Found: C, 71.61, 71.40; H, 7.17, 6.97; N, 6.26; neut. equiv., 204.

Benzopyrazine-2,3-diacrylic Acid.—A mixture of dihydroxybifurandione (VI) (9.9 g., 0.05 mole), *o*-phenylenediamine (5.6 g., 0.05 mole) and ethyl alcohol (50 ml.) was heated on a steam-bath for one hour. A heavy, tan precipitate of the quinoxaline derivative formed immediately; 12.9 g. (83%). It reacted with 5% sodium bicarbonate solution and after washing by decantation with hot ethyl acetate or with hot methanol darkened at 240°.

Anal. Calcd. for $C_{14}H_{10}O_4N_2$: N, 10.37; mol. wt., 270. Found: N, 10.80; mol. wt., 280, 297.

Other Derivatives of VI. 2,2'-Diacetoxy-2,2'-bifuran-5,5'-dione.—Dihydroxybifurandione (VI) (2 g.) and acetic anhydride (25 ml.) were heated on a steam-bath for 6 hours while protected from atmospheric moisture. Five hours was required for the solid to go completely into solution. Ethyl alcohol (50 ml.) was added to the solution, which was evaporated to small volume. This operation was repeated twice. The residue partly crystallized. The crystals of the diacetate weighed 0.8 g. and melted at 185° after two recrystallizations from ethyl acetate; infrared spectrum: unsaturation (3.25), carbonyls (5.55 and 5.65), conjugation (6.15 μ).

Anal. Calcd. for $C_{12}H_{10}O_8$: C, 51.07; H, 3.57. Found: C, 50.68; H, 3.57.

2,2'-Dimethoxy-2,2'-bifuran-5,5'-dione.—A. Dihydroxybifurandione (VI) (10 g., 0.05 mole), α,α,α-trichlorotoluene (20 g., 0.10 mole) and one drop of sulfuric acid were heated gently until a vigorous exothermic reaction took place with copious evolution of hydrogen chloride. Much degradation also occurred. The mixture was concentrated under reduced pressure to leave a tar, which after several days was taken up in hot methanol. The cooled solution gave 1.9 g. of one stereoisomer of the dimethoxy compound as colorless crystals, m.p. 213° after recrystallization from ethyl acetate; infrared spectrum: 5.65 μ (lactone carbonyl).

Anal. Calcd. for $C_{10}H_{10}O_6$: C, 53.10; H, 4.45. Found: C, 53.39; H, 4.54.

B. A solution of 20 g. (0.10 mole) of dihydroxybifurandione (VI) and a trace of *p*-toluenesulfonic acid in 600 ml. of methanol was refluxed for 7 hours while protected from atmospheric moisture. The cooled solution yielded 5.2 g. (23%) of white crystals, which were recrystallized from methanol to give one stereoisomer of the dimethoxy compound, m.p. 213°; mixed m.p. with the compound described above gave no depression.

The liquid portion of the esterification product was treated with a little solid sodium bicarbonate and anhydrous magnesium sulfate, filtered and evaporated to give 15.2 g. (67%) of a tan solid which after two recrystallizations from ethyl acetate or methanol gave white crystals, m.p. 149.5°, of the other stereoisomer of the dimethoxy compound having a similar infrared spectrum.

Anal. Calcd. for $C_{10}H_{10}O_6$: C, 53.10; H, 4.46. Found: C, 53.19, 52.95; H, 4.36, 4.49.

Reaction of Dihydroxybifurandione with Thionyl Chloride.—Dihydroxybifurandione (VI) (5.7 g., 0.029 mole) and thionyl chloride (30 ml., 0.42 mole) were refluxed for 8 hours while protected from atmospheric moisture. Most of the dihydroxy compound (3.4 g.) did not dissolve and was recovered unchanged. The filtrate was evaporated under reduced pressure and the residue was taken up in ethyl acetate. Upon dilution with petroleum ether the solution yielded 1.0 g. of white crystals which were recrystallized from ethyl acetate to give the dichloride, m.p. 213–214°; infrared spectrum: 3.2 (CH), 5.5 (acid chloride), 6.2 μ (C=C).

Anal. Calcd. for $C_8H_4O_4Cl_2$: C, 40.87; H, 1.75. Found: C, 40.20; H, 2.11.

The filtrate from the recrystallization (above) was diluted with petroleum ether to precipitate the cyclic sulfite, which after recrystallization from ethyl acetate–petroleum ether melted at 134–135°; infrared spectrum: 3.2 (CH); 5.5, 5.6 shoulder (lactone carbonyl); 6.2 μ (C=C).

Anal. Calcd. for $C_8H_4O_7S$: C, 39.34; H, 1.65; S, 13.13. Found: C, 39.14; H, 1.66; S, 12.62, 12.88.

Fumaric Acid from Bifurandione.—A mixture of bifurandione (8.2 g.), 25 g. of calcium hypochlorite (commercial bleaching powder) and 200 ml. of water was warmed overnight on a steam-bath. The mixture was filtered and the filtrate acidified with hydrochloric acid. A small amount of precipitate was collected. The filtrate was continuously extracted with ether for three days to bring the total yield of fumaric acid to 5.4 g. (47%), m.p. 274° in a sealed tube.

Anal. Calcd. for $C_4H_4O_4$: C, 41.39; H, 3.47; neut. equiv., 58. Found: C, 41.81; H, 3.55; neut. equiv., 58.

Reaction of I with Sodium Hydroxide. Preparation of Salts of 4,5-Dihydroxy-2,4,6-octatrienedioic Acid.—*trans*-Bifurandione (30 g., 0.18 mole) was added to a solution of 24 g. (0.6 mole) of sodium hydroxide in 300 ml. of water and dissolved rapidly and exothermically. After a few minutes the solution was filtered. Into it was poured a solution of 60 ml. of concentrated hydrochloric acid in 300 ml. of water. The yellow precipitate of the acid XI was collected on a sintered glass filter and dried in a vacuum oven at 65°; yield 31.1 g. (93%).

Anal. Calcd. for $C_8H_6O_5$: C, 52.75; H, 3.32; neut. equiv., 91. Found: C, 52.73, 52.62; H, 3.54, 3.59; neut. equiv., 93.

Acidification of an alkaline solution from bifurandione (56.8 g.) and 10% sodium hydroxide (450 ml.) with 10% acetic acid (1 l.) precipitated the yellow-orange monosodium salt X (46.7 g.). Concentration of the filtrate by distillation under reduced pressure gave another 10.4 g. of the salt, bringing the yield to 74%; ultraviolet absorption: λ_{max} 3930 Å., ϵ 18,900; infrared spectrum: carboxylate anion absorption at 6.46 and 7.23 μ. The salt, insoluble in organic solvents, was soluble in water to the extent of 3.5% to give a solution of *p*H 5.3.

Anal. Calcd. for $C_8H_7O_6Na$: C, 43.25; H, 3.18; Na, 10.35. Found: C, 43.33, 43.20; H, 3.31, 3.31; Na, 10.2.

When the salt was heated at 110–120°, it lost water rapidly to form the bright red salt of the monolactone acid XI, m.p. 250–255° dec., which on contact with water immediately reverted to XI; ultraviolet absorption: λ_{max} 3930 Å., ϵ 19,200.

Anal. Calcd. for $C_8H_5O_5Na$: C, 47.08; H, 2.47. Found: C, 47.21, 47.32; H, 2.48, 2.59.

Less soluble nickel, cobalt, aluminum, manganese, ferric, cupric and barium salts were precipitated from an aqueous solution of the salt X by addition of the proper cations. No precipitation occurred in attempts to prepare lithium, tetraethylammonium and N-methylquinolinium salts.

The di- and trisodium salts of 4,5-dihydroxy-2,4,6-octatrienedioic acid were much more soluble in water than the monosodium salt. They were prepared from the monosodium salt X or monolactone acid XI by addition of the calculated amount of 1 *N* sodium hydroxide. The resulting solutions were filtered, evaporated to dryness under reduced pressure and purified by trituration with ethyl alcohol. The yellow disodium salt was in the form of a dihydrate.

Anal. Calcd. for $C_8H_{10}O_8Na_2$: C, 34.29; H, 3.60. Found: C, 33.97; H, 3.76.

When heated in a vacuum oven at 120° for several hours, the salt became orange.

The trisodium salt was dried in a vacuum oven at 120° until orange.

Anal. Calcd. for $C_8H_5O_6Na_3$: C, 36.10; H, 1.89; Na, 25.92. Found: C, 37.30; H, 2.19; Na, 24.55.

A slurry of the monosodium salt X (10.0 g.) and platinum oxide (0.08 g.) in water (250 ml.) was shaken with hydrogen at room temperature until absorption ceased. The solution was acidified with hydrochloric acid and extracted three times each with chloroform and methyl ethyl ketone. Only a small amount of material was obtained from the chloroform extract. The methyl ethyl ketone extract gave a liquid–solid mixture from which 1.0 g. of 4-oxoöctanedioic acid crystallized. After several recrystallizations from water it did not depress the melting point of the sample obtained by direct hydrogenation of bifurandione.[2] This hydrogenation could also be carried out over 10% palladium-on-carbon, but the yield of 4-oxoöctanedioic acid was much diminished.

Reaction of Diphenylbifurandione with Sodium Hydroxide.—Crude diphenylbifurandione[1] (4.3 g., 0.14 mole), sodium hydroxide (1.2 g., 0.30 mole) and water (25 ml.) were heated on a steam-bath until complete dissolution was achieved (2 hours). Addition of acetic acid after cooling precipitated 1.8 g. (40% yield) of a yellow-orange diphenyl-4,5-dihydroxy-2,4,6-octatrienedioic acid mono-γ-lactone, m.p. 132–134° after recrystallization from ethyl acetate.

Anal. Calcd. for $C_{20}H_{14}O_5$: C, 71.85; H, 4.22. Found: C, 71.68; H, 4.29.

Reaction of Bifurandione with Metal Alkoxides.—Addition of 15.3 g. (0.093 mole) of *trans*-bifurandione to a solution of 5.2 g. (0.096 mole) of sodium methoxide in 200 ml. of methanol with stirring and external cooling resulted in complete solution within two minutes. Glacial acetic acid (6 ml.) was added to give the yellow precipitate (15.7 g.) of XII. Chilling the filtrate gave another 1.1 g., bringing the total yield to 16.8 g. (92%). The ester XII, which is sparingly soluble in water, insoluble in dilute sodium bicarbonate and soluble in dilute sodium hydroxide, was purified by recrystallization from methanol or methyl ethyl ketone, m.p. 184° dec.; infrared spectrum: 3.8 (hydrogen bond to carbonyl), 5.65 (lactone carbonyl), 5.75 (ester carbonyl), 6.2 and 6.3 μ (conjugated unsaturation).

Anal. Calcd. for $C_9H_8O_5$: C, 55.10; H, 4.11. Found: C, 55.19, 55.18; H, 4.40, 4.14.

Isolation of Intermediate Salt.—To a stirred solution of sodium methoxide (34 g., 0.63 mole) in methanol (300 ml.) was added *trans*-bifurandione (50 g., 0.30 mole). After one hour, an orange salt was collected by filtration, 46.6 g. (56%). The salt, which probably consists of the mono- and disodio derivatives of dimethyl 4,5-dihydroxy-2,4,6-octatrienedioate, had m.p. 160° dec. and did not give reproducible analyses; ultraviolet spectrum: λ_{max} 3740 Å., ε 19,600; infrared spectrum: 5.8 μ, 5.9, and 8.3 μ (ester carbonyl); 6.15 and 6.35, and 6.65 μ (conjugated unsaturation).

Anal. Calcd. for $C_{10}H_{10}O_6Na_2$: C, 44.12; H, 3.70; Na, 16.90. Found: C, 44.76, 44.64; H, 3.49, 3.59; Na, 14.9.

The salt was converted to XII (m.p. 177–181°) in 95% yield by dissolving in methanol and adding acetic acid and in 67% yield by trituration with 85% phosphoric acid.

cis-Bifurandione (5.15 g., 0.031 mole) was added to a well-stirred solution of sodium methoxide (1.9 g., 0.035 mole) in methanol (100 ml.) and dissolved within a few minutes. Some of the salt precipitated. About 3 ml. of acetic acid was added to precipitate XII (5.55 g., 90%). After recrystallization from methanol the ester melted at 177–182° and did not depress the melting point of a sample of XII prepared from *trans*-bifurandione.

Lithium wire (4.5 g., 0.65 g. atom) was dissolved in 300 ml. of methanol. Bifurandione (50 g., 0.30 mole) was added and the mixture stirred for two hours and then filtered to give 54.9 g. (79%) of the salt and 2.8 g. of unchanged bifurandione. The salt decomposed at 217–223° and probably contains the mono- and dilithio derivatives of dimethyl 4,5-dihydroxy-2,4,6-octatrienedioate.

Anal. Calcd. for $C_{10}H_{10}O_6Li_2$: C, 50.01; H, 4.20; Li, 5.8. Found: C, 50.68; H, 3.97; Li, 4.1.

Reaction of Diphenylbifurandione with Sodium Methoxide.—To a stirred mixture of diphenylbifurandione (5.2 g., 0.016 mole) and methanol (100 ml.) was added sodium methoxide (1.8 g., 0.033 mole). A red precipitate (4.3 g., 71% yield) of the monolactone ester salt formed almost immediately.

Anal. Calcd. for $C_{21}H_{15}O_5Na$: C, 68.13; H, 4.08. Found: C, 68.75, 68.00, 68.33; H, 4.43, 4.24, 4.41.

Acetic acid (2 ml.) was added to a solution of 4.2 g. of this salt in 30 ml. of methanol. A yellow precipitate of *cis*-diphenylbifurandione (2.9 g., 81% yield) formed slowly, m.p. 208°.

Anal. Calcd. for $C_{20}H_{12}O_4$: C, 75.94; H, 3.82. Found: C, 75.34; H, 3.76.

Reaction of I with Ammonia. Preparation of Monoamides of 4,5-Dihydroxy-2,4,6-octatrienedioic Acid and Derivatives.—Bifurandione (24.4 g.) was dissolved in 400 ml. of concentrated ammonium hydroxide with slight warming. The solution was filtered into a solution of 350 ml. of acetic acid in 150 ml. of water cooled by an ice-bath. The yellow precipitate of XIV weighed 19.1 g. (71%), m.p. ~250° dec.

Anal. Calcd. for $C_8H_7O_4N$: C, 53.04; H, 3.90; N, 7.73. Found: C, 53.28, 53.16; H, 4.17, 4.09; N, 7.71, 7.46.

The ammonium salt XIII was prepared by evaporation of a solution of bifurandione in ammonium hydroxide under reduced pressure.

Anal. Calcd. for $C_8H_{12}O_5N_2$: N, 12.96. Found: N, 12.85.

The monolactone amide XIV (5.43 g., 0.03 mole) was converted to the monosodium salt XV by dissolution in 30 ml. of 1 *N* sodium hydroxide followed by evaporation to dryness under reduced pressure. The brick-red solid was washed by trituration with ethyl alcohol to give 6.46 g. (92% yield); ultraviolet spectrum: λ_{max} 3880 Å., ε 12,200; infrared absorption at 2.95 and 3.15 μ (—OH, —NH_2), 6.0 and 6.5 μ (amide, salt or unsaturation).

Anal. Calcd. for $C_8H_{10}O_6NNa$: C, 40.17; H, 4.21. Found: C, 40.22; H, 4.19.

Reactions of I and II with Amines. Preparation of Amides XVI, XVII, and XVIII.—The amides XVI, XVII and XVIII were prepared by action of the corresponding amine on bifurandione followed by acidification. Details and properties are given in Table II. Refluxing XVI (R = *n*-C_4H_9) in acetic acid to which two drops of sulfuric acid had been added gave *cis*-bifurandione (II). The enolic hydroxyl of the amide XVI (R = *n*-C_4H_9) was indicated by a broad band at 4.2 μ. It was insoluble in 5% sodium bicarbonate, soluble in and recoverable from 5% sodium hydroxide, and gave a positive ferric chloride test.

Reaction of I with *p*-Chloroaniline.—Bifurandione (9.8 g., 0.06 mole), *p*-chloroaniline (23 g., 0.18 mole) and dioxane (500 ml.) were heated at the boiling point for 24 hours. The cooled solution deposited 2.9 g. of the yellow XIX (Ar = *p*-C_6H_4Cl). After concentration of the filtrate, another 7.3 g. was obtained, making the total yield 10.2 g. (41%). The new compound was recrystallized from a large amount of ethyl acetate, m.p. 210–215° dec. The infrared spectrum shows a hydroxyl band at 2.9 μ and a carbonyl band at 5.75 μ.

Anal. Calcd. for $C_{20}H_{16}O_4N_2Cl_2$: C, 57.29; H, 3.85; N, 6.68; Cl, 16.91. Found: C, 57.57, 57.55; H, 3.61, 3.60; N, 6.56; Cl, 16.76.

Reaction of Bifurandione with Aniline.—A solution containing bifurandione (14.8 g., 0.09 mole), aniline (36 g., 0.39 mole), acetic anhydride (20 g.) and acetic acid (250 ml.) was refluxed for two hours. (Excess aniline at its reflux temperature could also be used as solvent). A brown crystalline precipitate (16.8 g., 44%, m.p. 245–250°) formed in the cooled solution. The sparingly soluble compound was recrystallized from a large quantity of methyl ethyl ketone to give yellow crystals of XX (Ar = C_6H_5), m.p. 257° dec.

Anal. Calcd. for $C_{26}H_{23}O_3N_3$: C, 73.39; H, 5.45; N, 9.88. Found: C, 72.59, 72.80; H, 5.45, 5.62; N, 9.84, 9.94.

Reaction of Bifurandione with α-Naphthylamine.—A solution of bifurandione (13.0 g., 0.08 mole) and α-naphthylamine (24 g., 0.17 mole) in acetic acid (300 ml.) was heated at its boiling point for six hours. The cooled solution yielded 2 g. of precipitate, which was extracted with hot acetic acid, methyl ethyl ketone, and other solvents. The extracts yielded bifurandione. The residue was dissolved in dimeth-

TABLE II

AMIDES FROM BIFURANDIONE

	Reactant	Solvent	Reaction temp., °C.	Product	Yield, %	M.p., °C.	Analyses							
							Calculated				Found			
							C	H	N	Mol. wt.	C	H	N	Mol. wt.
1	n-$C_4H_9NH_2$	Dioxane, methanol or none	Room	XVI	75	166	60.75	6.37	5.90	237	60.65 60.55	6.38 6.18	5.96 5.96	230 245
2	i-$C_4H_9NH_2$	Dioxane	Room	XVI	57	175 d.	60.75	6.37	5.90		61.24	6.43	5.92	
3	$(CH_3)_2NH$	Water	Room	XVII	28	200–220 d.	57.41	5.30	6.70	209	57.54	5.20	6.74 6.63	235 235
4	n-Octadecyl amine	Dioxane	100	XVI	20	135–140	72.01	10.00	3.23		71.95 71.55 71.49	10.19 10.13 10.18	3.39 3.35	
5	p-Toluidine	Dioxane	100	XVIII	49	244–252 d.	66.41	4.83	5.16		66.23	4.89	5.31	
6	p-Aminobenzoic acid	Acetic acid	110	XVIII	94	258–263	59.80	3.68	4.65		59.10	3.95	4.70 4.41	
7	Dodecylaniline (mixt. of isomers)	Dioxane	100	XVIII	1	199–201	73.38	8.29	3.29		73.13	8.35	3.38 3.46	

ylformamide, from which a yellow powder (XX, Ar = α-$C_{10}H_7$), m.p. 298–302°, was obtained by addition of water.

Anal. Calcd. for $C_{38}H_{29}O_3N_3$: N, 7.30. Found: N, 7.33, 7.38.

Reaction of I with p-Nitrophenyl Radicals.—A sample of bifurandione (8.2 g., 0.050 mole) was almost completely dissolved in 800 ml. of acetone by warming on a steam-bath. After addition of 1 g. of cupric chloride dihydrate, the solution was removed from the steam-bath and a slurry of 12 g. (0.051 mole) of p-nitrobenzenediazonium fluoborate[7] in 120 ml. of water was slowly added with stirring. The mixture, which was at about room temperature by the time addition was complete, was warmed on the steam-bath for another two hours; then 5.8 g. of a reddish-brown precipitate was collected by filtration. Some unchanged bifurandione was removed by extraction with hot methyl ethyl ketone from the sparingly soluble p-nitrophenyl-$\Delta^{2,2'(5H,5'H)}$-bifuran-5,5'-dione (XXI), which was then recrystallized from acetone, m.p. 230–240° dec.; ultraviolet absorption: λ_{max} 3800 Å., ϵ 47,300; infrared absorption: similar to bifurandione with additional bands at 6.6 and 7.45 (—NO_2 group) and 11.75 μ (p-substituted aromatic).

Anal. Calcd. for $C_{14}H_7O_6N$: C, 58.96; H, 2.47; N, 4.91. Found: C, 59.12; H, 2.54; N, 5.48, 5.10.

Chlorination of Bifurandione.—A solution of 23.4 g. of bifurandione in 1800 ml. of acetic acid was chlorinated at 100° for 12 hours. Some hydrogen chloride was evolved during this period. The solution, which turned green, was concentrated under reduced pressure to remove not only the solvent but some chlorinated acetic acids which had formed during the reaction. A gelatinous solid remained. Recrystallization from chloroform gave a brown powder (1.0 g., 3%), m.p. 150–160°. After repeated recrystallizations from ethyl alcohol, white needles of the dichloride were obtained, m.p. 169.5°.

Anal. Calcd. for $C_8H_4O_4Cl_2$: C, 40.87; H, 1.75; Cl, 30.17. Found: C, 41.09, 41.06; H, 1.90, 1.94; Cl, 29.82, 29.78.

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Bifurandione. IV. Polarographic Reduction

BY E. A. ABRAHAMSON

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The polarographic reductions of *cis*- and *trans*-$\Delta^{2,2'(5H,5'H)}$-bifuran-5,5'dione have been studied as a function of pH in 1:1 acetonitrile–water solutions and also in 50% H_2SO_4 solutions by volume. In acetonitrile–water solutions the half-wave potential of the first wave shifts about 0.060 mv. per pH unit over the range 0 to 5.5. Evidence is presented for stepwise hydrolysis of the two lactone rings of each isomer to give rise to reducible forms having different half-wave potentials from the original isomer. In both acetonitrile–water and 50% sulfuric acid solutions the reduction appears to be a two-electron reduction.

Synthesis of the unusual unsaturated dilactone[1] $\Delta^{2,2'(5H,5'H)}$-bifuran-5,5'-dione has prompted a polarographic study of its behavior at the dropping mercury electrode. The present work was undertaken to determine whether or not differences would be observed in the polarographic behavior of the *cis* and *trans* isomers and whether or not stepwise hydrolysis of the rings of the two isomers would lead to different reducible products. In addition, since its structure bears some resemblance to coumarin, it was of interest to compare its polarographic behavior with published information on that of coumarin.[2-5] To this end we have studied the polarographic behavior of the *cis* and *trans*

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