

reduced pressure to less than one-fifth of the original volume. Chloroform and petroleum ether were added. The solution was chilled and 20 mg. of crude IV, m.p. 300–308°, separated. Purification by recrystallization from chloroform gave IV melting at 331–334°. Further concentration of the mother liquor yielded another 50 mg., which was recrystallized from ethyl acetate to give a sample melting at 341–344°; infrared spectrum: 5.6 (lactone), 6.2, 6.25 and 6.75 μ (conjugated unsaturation); 13.15 and 14.65 μ (disubstituted aromatic). *Anal.* Calcd. for $C_{18}H_{10}O_4$: C, 72.73; H, 3.05. Found: C, 72.72; H, 3.27. Biphthalyl thus has the *trans* configuration, since the less symmetrical *cis* isomer would have absorption around 6.0 μ for the bridge double bond.

Preparation of Biphthalyl from Phthaloyl Chloride.—This preparation follows one described in the literature.¹⁰ A mixture of unsymmetrical phthaloyl chloride¹¹ (8 g.), copper powder (10 g.) and pyridine (100 ml.) was stirred for six hours while being cooled externally by an ice-bath. The reactants were kept under a nitrogen atmosphere and were protected from moisture. The mixture was filtered to give 0.2 g. (3% yield) of the pale yellow IV, m.p. 339–341° after recrystallization from chloroform. A mixed melting point, taken at the same time, with the sample of biphthalyl prepared from III occurred at 338–339°. The two samples were found to have identical infrared spectra and X-ray patterns. Biphthalyl has the following ultraviolet spectrum: $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 369 $\mu\mu$, ϵ 22,440; $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 357 $\mu\mu$, ϵ 27,456; $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 304 $\mu\mu$, ϵ 13,200; $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 292 $\mu\mu$, ϵ 11,616; $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 257 $\mu\mu$, ϵ 13,200; $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 226 $\mu\mu$, ϵ 27,720; $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 221 $\mu\mu$, ϵ 24,816.

Bifurandiones from Mono- and Disubstituted Acetylenes.—The substituted acetylene (usually 0.2–1.0 mole) was charged into a shaker tube with 1–2 g. of dicobalt octacarbonyl catalyst dissolved in 100 ml. of acetone. The reaction was carried out at temperatures of 100–110° and carbon monoxide pressures of 800–1000 atm. The products, except for the bifurandione from 1-hexyne, were purified by recrystallization (see Table II).

The reaction of phenylacetylene with carbon monoxide gave mainly the isomer of m.p. 295–297° (6% yield) from a reaction mixture consisting of phenylacetylene (100 ml.), acetone (50 ml.) and phenyl isocyanate (30 ml.). The more soluble isomer melting at 176–178° (3%) also was isolated in the experiment and was the main product (9%) in the

(10) P. Karrer, W. Wehrli, E. Biedermann and M. dalla Vedova, *Helv. Chim. Acta*, **11**, 233 (1928).

(11) A. H. Blatt, "Organic Syntheses," Coll. Vol. 11, John Wiley and Sons, Inc., New York, N. Y., p. 528.

absence of phenyl isocyanate, using an otherwise identical charge. The isomer of m.p. 207–210° (21%) was obtained in a run in which the charge consisted of phenylacetylene (80 ml.) and acetone (100 ml.). The catalyst in all cases was dicobalt octacarbonyl. The isomer melting at 207–210° has strong absorption in the 6.05–6.10 μ region, indicating lack of symmetry with respect to the bridge double bond. This isomer therefore must have the *cis*-4,4' configuration, since the *cis*-3,3' isomer is sterically impossible. The isomer of m.p. 176–178° has little absorption in this region, and the isomer of m.p. 295–297° none at all. They are the symmetrical or *trans* isomers, but it is not known which isomer is 3,3' and which is 4,4'.

The crude bifurandione from 1-hexyne was distilled to give a liquid–solid mixture distilling at 190–205° (2–3 mm.) (58%). This cut was quite pure di-*n*-butylbifurandione as judged by elemental analysis. Repeated recrystallizations of the solid portion from ethyl acetate–petroleum ether gave an isomer, m.p. 123–124°, whose exact structure was not determined.

Di-*n*-butylsuberic Acid from Di-*n*-butylbifurandione.—The crystalline isomer of di-*n*-butylbifurandione (0.75 g.) was hydrogenated in acetic acid using platinum catalyst. Almost exactly 5 moles of hydrogen was absorbed. The reaction mixture was filtered, and the acetic acid was removed at 20–50 mm. on a steam-bath. The residual heavy oil was warmed for 2 hours on a steam-bath with 7 ml. of thionyl chloride and then evacuated at 80° and 20–30 mm. pressure for 30 minutes. Then aniline (8 g.) dissolved in ether (200 ml.) was added. After washing the mixture with water and dilute hydrochloric acid, the ether was removed by evaporation and the solid residue recrystallized from ethanol (0.44 g., m.p. 130–138°). This bis-anilide of a di-*n*-butylsuberic acid was characterized by elemental and infrared analyses. *Anal.* Calcd. for $C_{28}H_{40}O_2N_2$: N, 6.42. Found: N, 6.41, 6.54. The infrared spectrum showed strong absorption at 6.0 and 6.5 μ for secondary amide, 3.0

μ absorption for –N–, and the usual bands for saturated CH, CH₃ and monosubstituted aromatic groups.

Commercial-grade acetylene was purified according to a previously described procedure.¹² The infrared spectra were determined on a Perkin–Elmer double-beam spectrometer. The ultraviolet spectra were determined on a Cary model 11 spectrophotometer.

(12) J. C. Sauer, *THIS JOURNAL*, **79**, 5314 (1957).

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[CONTRIBUTION NO. 497 FROM THE CENTRAL RESEARCH DEPARTMENT, EXPERIMENTAL STATION, E. I. DU PONT DE NEMOURS AND CO.]

Bifurandione. II. Hydrogenation

By H. E. HOLMQUIST, F. D. MARSH, J. C. SAUER AND V. A. ENGELHARDT

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Hydrogenation of $\Delta^{2,2'(\text{6H},\text{5}^{\prime}\text{H})}$ -bifuran-5,5'-dione in the presence of palladium, ruthenium or nickel gave γ,γ' -bibutyrolactone or γ -(γ -carboxypropyl)-butyrolactone, depending on the conditions, as principal product. Further hydrogenation of γ,γ' -bibutyrolactone over copper chromite gave 1,4,5,8-octanetetrol. Hydrogenation with ruthenium or nickel under more stringent conditions led to products with only one lactone ring intact, and with nickel molybdate to a dihydrobifurandione. Hydrogenation of bifurandione over copper chromite at 250–300° gave 1,8-octanediol, but at 160–190° yielded suberic acid. Electrolytic reduction of bifurandione resulted in 4,5-dioxooctanedioic acid.

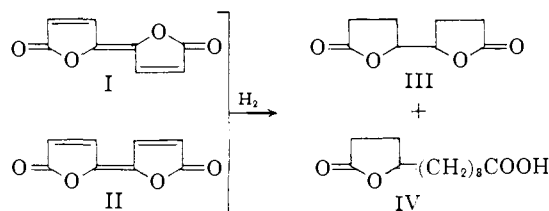
Hydrogenation of $\Delta^{(2,2'(\text{6H},\text{5}^{\prime}\text{H}))}$ -bifuran-5,5'-dione^{1,2} has made available a large number of compounds inaccessible through ordinary synthetic methods. The variety of ways in which the dilactone reacts with hydrogen can be explained by the fact that it is structurally both an α,β -unsaturated ester and an enol ester. Thus, with some catalysts the reactive bonds between the oxygen atoms

(1) Paper 1 of this series, *THIS JOURNAL*, **81**, 3677 (1959).

(2) Throughout this paper, the compound is referred to as bifurandione.

and the bridge carbon atoms apparently are cleaved before any of the double bonds become saturated. An example of this, the hydrogenation of bifurandione over platinum to suberic acid in 87% yield, was described in Paper I of this series.¹

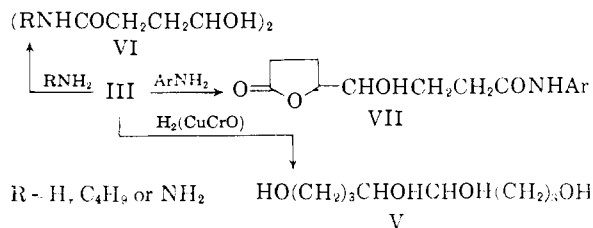
Hydrogenation of the dilactone over supported palladium catalysts gave a mixture of γ,γ' -bibutyrolactone (III) and γ -(γ -carboxypropyl)-butyrolactone (IV). These compounds form an azeotrope but can be separated by careful neutralization of IV with sodium bicarbonate solution.



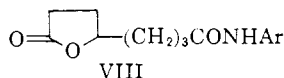
Crystalline amine salts of IV also can be separated directly from the mixture of III and IV. The conversion of bifurandione to the mixture is essentially quantitative, but the ratios of the two products vary with the type of palladium catalyst and with the conditions. Thus, preparation of either compound in good yield can be accomplished (83% of III with palladium-on-alumina; 69% of IV with 10% palladium-on-carbon). No difference has been observed in the ratios of products from *cis*- or *trans*-bifurandione. When the hydrogenation was stopped after only one mole of hydrogen had been absorbed, the product was a dihydrobifurandione (XV) (see below).

γ,γ' -Bibutyrolactone (III) exists in two stereoisomeric forms, racemic and *meso*, separable by fractional crystallization. The isomer that separates first melts at 106° and is reported in the literature³ as an oxidation product of a butadiene copolymer. Its steric configuration is not known. The second form, m.p. 64°, has not been obtained completely free of its isomer. The high-melting form was converted to an equilibrium mixture by heating with alkali, but strong acid apparently had no effect.

Hydrogenation of γ,γ' -bibutyrolactone (III) over copper chromite at 225–274° gave the new 1,4,5,8-octanetetrol (V) in 29% yield. The tetrol yielded a crystalline tetraacetate derivative when treated with acetic anhydride.



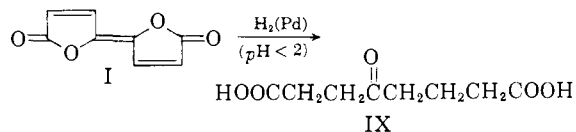
Both rings of bibutyrolactone were opened in the presence of aliphatic amines to give products of type VI. In contrast, aromatic amines opened only one ring of the dilactone, even at 150°, to give derivatives of type VII. Direct amidation of the hydrogenation mixture of III and IV with aromatic amines gave a mixture from which VII and VIII were separated readily by fractional crystallization.



The oxidation of bibutyrolactone with permanganate to succinic acid afforded additional evidence for its structure. Attempts to dehydrogenate it to bifurandione over a palladium catalyst were unsuccessful.

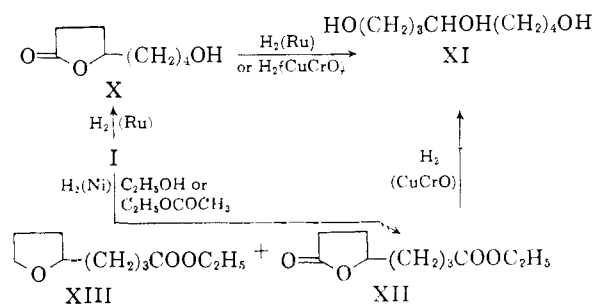
(3) T. Handa, *Chem. High Polymers*, **6**, 382 (1949).

The hydrogenation of *trans*-bifurandione (I) over 10% palladium-on-carbon to a mixture of III and IV can be effected in acetic acid as well as in neutral solvents. However, when the pH of the reaction medium was brought below 2 by addition of hydrochloric acid, the hydrogenation took a different course and 4-oxooctanedioic acid (IX) was formed in 72% yield. The melting point of



this acid agrees with those reported in the literature,⁴ but that of its semicarbazone does not, although it has the correct composition. This keto acid was surprisingly stable toward further hydrogenation over platinum or nickel.

Although at 100–150° *trans*-bifurandione (I) was hydrogenated over ruthenium to a mixture of γ,γ' -bibutyrolactone (III) and γ -(γ -carboxypropyl)-butyrolactone (IV), this catalyst at 200° promoted partial hydrogenolysis of I to γ -(δ -hydroxybutyl)-butyrolactone (X). The yield of hydroxy lactone in an experiment utilizing 1% catalyst was 37%. When this amount of catalyst was increased to 10%, some of the hydroxy lactone was further hydrogenated to 1,4,8-octane-triol⁵ (XI), m.p. 89.5°, in 8% conversion from bifurandione. This triol also was obtained, in a less pure state, by hydrogenation of the hydroxy lactone X over copper chromite catalyst at 225°.



trans-Bifurandione (I) was hydrogenated over Raney nickel at 80–100° to mixtures of bibutyrolactone (III) and carboxypropylbutyrolactone (IV), but if the hydrogenation was carried out in ethyl alcohol or ethyl acetate at 235–275°, the solvent participated in the reaction and the product was a mixture of γ -(γ -ethoxycarbonylpropyl)-butyrolactone (XII) and 2-(3-ethoxycarbonylpropyl)-tetrahydrofuran (XIII). The best yields of the two esters at 250° with ethyl acetate as solvent were 27 and 18%, respectively. The properties of the lactone ester XII were identical with those of a sample prepared by esterification of the lactone acid IV. Hydrogenation of the lactone ester XII over copper chromite catalyst gave 1,4,8-octanetriol (XI).

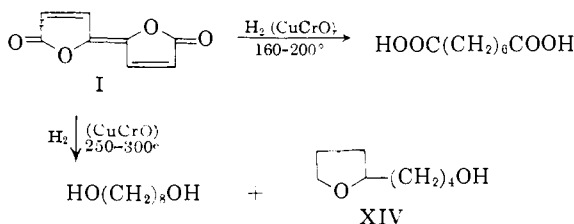
(4) (a) A. C. Cope and W. R. Schmitz, *THIS JOURNAL*, **72**, 3056 (1950); (b) N. J. Leonard and W. E. Goode, *ibid.*, **72**, 5404 (1950); (c) R. M. Dodson and P. Sollman, *ibid.*, **73**, 4197 (1951); (d) N. Choudhuri and P. C. Mukharji, *J. Indian Chem. Soc.*, **29**, 336 (1952); (e) H. Stetter and W. Dierricks, *Chem. Ber.*, **85**, 61 (1952).

(5) A. C. Cope and G. W. Wood, *THIS JOURNAL*, **79**, 3885 (1957).

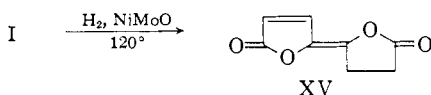
The methyl ester corresponding to XII was prepared in 7% yield together with bibutyrolactone (III) by hydrogenation of bifurandione in methanol at 10° using 10% palladium-on-carbon as catalyst.

Bifurandione has a tendency to cleave to four-carbon fragments when treated with strongly basic reagents at high temperatures. Thus, hydrogenation of bifurandione over nickel in anhydrous ammonia at 100° gave a 5% yield of succinimide. Similarly, hydrogenation over nickel of aqueous alkaline solutions of I resulted in low conversion to succinic acid and γ,γ' -bibutyrolactone (III).

1,8-Octanediol resulted in 61% yield from the copper chromite-catalyzed hydrogenation of *trans*-bifurandione at 250–300°. An additional product of the reaction, formed in 12% yield, was 2-(4-hydroxybutyl)-tetrahydrofuran (XIV), a new compound. When bifurandione was hydrogenated over copper chromite at 160–200°, suberic acid was the product in 30% yield.



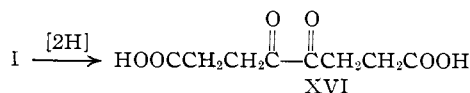
The hydrogenation of *trans*-bifurandione over nickel molybdate⁶ at 80–120° gave the unsymmetrical dihydrobifurandione XV, m.p. 153–156°.



The best yield was 49% obtained at 120°. At higher temperatures, the yield decreases sharply. The new dilactone also was obtained in 12% yield by stopping the palladium-catalyzed reduction of *trans*-bifurandione after just one mole of hydrogen had been absorbed. The unsymmetrical structure of XV was assigned on the basis of its infrared spectrum which exhibits a carbonyl band split into a doublet by virtue of the two kinds of lactone rings present.

Succinic acid in 10% yield was the product of reduction of bifurandione at 150° with nickel molybdate catalyst.

The controlled potential electrolytic reduction⁷ of *trans*-bifurandione (I) in concentrated sulfuric acid resulted in a 58% yield of 4,5-dioxooctanedioic acid (XVI). The process is a two-electron hydro-



genation and may be considered to be a 1,6-addition to the conjugated double bond system of 4,5-dihydroxy-2,4,6-octatrienedioic acid, the theoretical hydrolysis product of bifurandione, followed

(6) H. R. Arnold and J. E. Carnahan, U. S. Patent 2,572,300 (1951).

(7) The authors are indebted to Dr. E. A. Abrahamson and Miss Lucille Williams for carrying out this reduction.

by ketonization of the resulting bis-enol. The new, bright yellow acid was further characterized as an α -diketone by preparation of a quinoxaline derivative.

Experimental

Preparations of γ,γ' -Bibutyrolactone (III).⁸—1. *trans*-Bifurandione (I, 2.15 g.) and dioxane (300 ml.) were shaken at room temperature with hydrogen at 3 atm. and 1% palladium-on-calcium carbonate (1.2 g.) until absorption ceased (106 minutes). The oily product was distilled at 178–184° (2 mm.) to give 1.5 g. of a liquid–solid mixture. The solid was recrystallized from chloroform–petroleum ether to give white needles of γ,γ' -bibutyrolactone (III), m.p. 104°.

Anal. Calcd. for $\text{C}_8\text{H}_{10}\text{O}_4$: C, 56.56; H, 5.92. Found: C, 56.66; H, 6.02.

2. A slurry of *cis*-bifurandione (II, 11.0 g.) in acetic acid (350 ml.) was shaken with 1.5 g. of 10% palladium-on-charcoal and hydrogen (repressured to 3 atm.) at room temperature. The hydrogenation was completed in 40 minutes. The filtered solution was concentrated under reduced pressure until white crystals appeared. The first two crops of III weighed 5.2 g., m.p. 104–106° after recrystallization from chloroform–petroleum ether.

3. *trans*-Bifurandione (I, 60 g.), dioxane (300 ml.) and 0.5% palladium-on-alumina (10 g.) were shaken with hydrogen at room temperature and a maximum pressure of 3 atm. until absorption ceased (about 5 hours). The solution was combined with those from three similar runs (total bifurandione 236 g.), filtered, and concentrated under reduced pressure to leave a thick, light-colored oil from which 136.4 g. (56%) of III crystallized, m.p. 55–65°.

4. *trans*-Bifurandione (I, 90 g.), dioxane (700 ml.) and 5% palladium-on-carbon (4.5 g.) were shaken with hydrogen at 115 atm. and 32–46°. The product was freed of solvent by distillation under reduced pressure, neutralized to pH 7.2 with dilute sodium bicarbonate, and cooled to 0–10°. Crystallization of the mixture of stereoisomers of III (64.5 g., 83%, m.p. 68–70°) occurred rapidly.

Quantitative Analysis of Mixtures of III and IV.—Mixtures of γ,γ' -bibutyrolactone (III) and γ -(γ -carboxypropyl)-butyrolactone (IV) obtained from the reduction of bifurandione were quantitatively analyzed: A weighed sample of the reduction mixture dissolved in water was cooled in an ice-bath and titrated with 0.1 N sodium hydroxide to a phenolphthalein end-point. The amount of III was calculated from the amount of alkali consumed, assuming no lactone rings to be hydrolyzed. A measured amount of 0.1 N sodium hydroxide then was added and the mixture heated on the steam-bath for one hour. Excess alkali was titrated with 0.1 N hydrochloric acid and the quantity of IV calculated, assuming complete hydrolysis of all lactone rings. The validity of this determination was demonstrated by analysis of similar synthetic mixtures of known composition, and by the good agreement of analytical results with yields of isolated products.

Pure high-melting γ,γ' -bibutyrolactone (III) was heated in 10% sodium hydroxide on a steam-bath for one hour, followed by acidification to give a mixture whose melting point (64–100°), analysis and infrared spectrum corresponded closely to the mixture of isomers isolated directly from some bifurandione reductions carried out with palladium catalysts.

Derivatives of γ,γ' -Bibutyrolactone (III). 1,4,5,8-Octanetetrol (V) and Acetate.⁹—A solution of 4.36 g. of high-melting III in 200 ml. of dioxane was hydrogenated over 1 g. of copper–barium chromite at 225° and 200 atm. for 3 hours. The filtered product was concentrated by distillation under reduced pressure. Crystals of V (1.35 g., 29%) formed in the concentrate, m.p. 104–106°, insoluble in chloroform, sparingly soluble in ethyl acetate, and soluble in ethyl alcohol. After two recrystallizations from ethyl acetate–ethyl alcohol, the tetrol melted at 111.5°.

Anal. Calcd. for $\text{C}_8\text{H}_{18}\text{O}_4$: C, 53.91; H, 10.18. Found: C, 53.41, 53.53; H, 10.18, 10.36.

A 0.50-g. sample of V was heated with acetic anhydride (15 ml.) for two days. The excess anhydride was removed by conservative addition and evaporation to dryness of

(8) J. C. Sauer, U. S. Patent 2,840,570 (1958).

(9) H. E. Holmquist, U. S. Patent 2,835,710 (1958).

TABLE I
 PROPERTIES OF AMIDES FROM γ,γ' -BIBUTYROLACTONE

Reactant	Solvent	Tempera- ture	Product	M.p., °C.	Analyses, %	
					Calcd.	Found
1 $n\text{-C}_4\text{H}_9\text{NH}_2$	Toluene or dioxane	Reflux	VII (R = C_4H_9)	161	C 60.73	C 60.49
					H 10.10	H 10.43
					N 8.86	N 8.78, 8.78
2 $\text{N}_2\text{H}_4\cdot\text{H}_2\text{O}$	None	Room	VII (R = NH_2)	187-188	C 41.00	C 41.26
					H 7.74	H 8.02
					N 23.91	N 23.38, 23.34
3 NH_4OH	None	Room	VII (R = H)	162	...	Infrared: 2.95, 3.12 (OH and/or NH_2), 6.07 (amide carbonyl), 6.13 μ (NH_2 shoulder)

 TABLE II
 PROPERTIES OF AMIDES FROM MIXTURES OF γ,γ' -BIBUTYROLACTONE AND γ -(γ -CARBOXYPROPYL)-BUTYROLACTONE

Reactant	Solvent	Temp., °C.	Products	M.p., °C.	Analyses, %	
					Calcd.	Found
1 Aniline	None	150	a VIII (Ar = Ph)	168-171	C 63.86	C 63.82
					H 6.51	H 6.57
					N 5.32	N 5.56, 5.27
			b IX (Ar = Ph)	107	C 67.99	C 67.89
					H 6.93	H 7.16
					N 5.66	N 5.62
2 <i>p</i> -Toluidine	Tetralin	Reflux	a VIII (Ar = <i>p</i> -tolyl)	172-173	C 64.96	C 65.38
					H 6.91	H 7.00
					N 5.05	N 5.37, 5.50
			b IX (Ar = <i>p</i> -tolyl)	115-116	C 68.94	C 68.02
					H 7.33	H 7.37
					N 5.30	N 5.59

two 25-ml. portions of ethyl alcohol. The residue crystallized on standing to the tetraacetate (0.97 g., 100%), m.p. 50-51° after recrystallization from ethyl acetate-petroleum ether.

Anal. Calcd. for $\text{C}_{16}\text{H}_{26}\text{O}_5$: C, 55.48; H, 7.57; mol. wt., 346. Found: C, 55.64; H, 7.61; mol. wt., 368, 364.

Bis-(S-benzylisothiuronium) 4,5-Dihydroxyoctanedioate.—A small sample of γ,γ' -bibutyrolactone (III) was carefully saponified with the stoichiometric amount of sodium hydroxide. To the solution was added S-benzylisothioureahydrochloride. The resulting salt melted at 97-105° after two recrystallizations from ethyl alcohol-dioxane.

Anal. Calcd. for $\text{C}_{24}\text{H}_{34}\text{O}_6\text{S}_2\text{N}_4$: C, 53.50; H, 6.36; N, 10.40. Found: C, 53.63; H, 6.75; N, 10.24.

Hexamethylenediammonium 4,5-Dihydroxyoctanedioate.—To a 500-ml. flask equipped with a stirrer, reflux condenser and nitrogen inlet were added 25.5 g. (0.15 mole) of γ,γ' -bibutyrolactone (III), 50 ml. of water and two drops of phenolphthalein indicator solution. The flask was flushed with nitrogen and a slow flow of nitrogen maintained throughout the time of the reaction. The solution was heated to reflux and a freshly filtered solution of barium hydroxide (25.6 g., 0.15 mole) in 200 ml. of water was added slowly with stirring to the phenolphthalein end-point. The solution then was refluxed for an additional hour. Hexamethylenediammonium sulfate, prepared by titrating 17.46 g. (0.15 mole) of hexamethylenediamine dissolved in 50 ml. of water with approximately 20% sulfuric acid to a bromthymol blue end-point, was added slowly and the mixture refluxed for one hour. The mixture was cooled and filtered and the filtrate evaporated to dryness at room temperature and 1 mm. pressure to give 45.7 g. (100% yield) of a white crystalline material which was purified by dissolving in 200 ml. of absolute alcohol and 85 ml. of water and then precipitation with 350 ml. of absolute alcohol; m.p. 166-168°.

Anal. Calcd. for $\text{C}_{14}\text{H}_{30}\text{O}_6\text{N}_2$: C, 52.15; H, 9.38; N, 8.69. Found: C, 51.50; H, 9.23; N, 8.74.

Diamides and Dihydrazone from Bibutyrolactone (III).—Excess *n*-butylamine, hydrazine hydrate and aminonium

hydroxide reacted with III to form products of type VI as summarized in Table I.

Monoamides from the Reaction Mixture of III and IV.—*N*-Aryl amides of types VII and VIII were obtained directly from the action of excess aromatic amine on the liquid hydrogenation product of bifurandione comprising a mixture of III and IV. The amides were separated by fractional crystallization from the reaction mixture and are described in Table II.

Preparation of γ -(γ -Carboxypropyl)-butyrolactone (IV).—A mixture of *trans*-bifurandione (90 g.), dioxane (700 ml.) and 10% palladium-on-carbon (4.5 g.) was hydrogenated at 110 atm. and 25-40° until hydrogen absorption ceased. The resulting solution was filtered and the dioxane removed at 1 mm. to give 94 g. of a colorless, viscous oil. Analysis (see above) of this oil gave: III, 31.01, 31.17%; IV, 71.19, 71.54%. This oil was separated by extraction with dilute sodium bicarbonate into 22 g. (31%) of a mixture of isomeric γ,γ' -bibutyrolactones (III) and 48.8 g. (69%) of γ -(γ -carboxypropyl)-butyrolactone (IV), b.p. 184-186° (1 mm.), 175° (0.2 mm.), n_{20}^D 1.4740.

Anal. Calcd. for $\text{C}_8\text{H}_{12}\text{O}_4$: C, 55.82; H, 7.03; neut. equiv., 172.2; sapon. equiv., 86.1. Found: C, 56.34; H, 7.46; neut. equiv., 176.0; sapon. equiv., 82.8, 82.5.

Derivatives of γ -(γ -Carboxypropyl)-butyrolactone (IV). Benzylammonium Salt of IV.—Benzylamine (0.77 g.) dissolved in 2 ml. of dioxane was added to 1.24 g. of the oily reduction mixture of III and IV dissolved in 4 ml. of dioxane. Addition of ether caused the precipitation of a white, crystalline product, 1.12 g. (56% yield). Two recrystallizations from dioxane gave a product melting at 101-102°.

Anal. Calcd. for $\text{C}_{15}\text{H}_{21}\text{O}_4\text{N}$: C, 64.49; H, 7.58; N, 5.02. Found: C, 64.62; H, 7.58; N, 4.94.

Hexamethylenediammonium Salt of IV.—To a 100-ml. flask equipped with a nitrogen inlet, stirrer, dropping funnel and drying tube was added 17.2 g. of γ -(γ -carboxypropyl)-butyrolactone dissolved in 60 ml. of methanol. The solution was cooled to 0° with stirring and 5.81 g. of hexamethylenediamine dissolved in 10 ml. of methanol was added slowly. The mixture was stirred at 0° for one-half hour and then poured into an excess of anhydrous ether at 10°. White crystals separated, which after two recrystallizations from an

absolute alcohol-ether mixture gave 18.1 g. of salt melting at 117–118°.

Anal. Calcd. for $C_{22}H_{40}O_8N_2$: C, 57.32; H, 8.76; N, 6.08. Found: C, 57.13; H, 8.86; N, 6.06, 6.07.

Anilide (VIII) of IV.—To a 50-ml. flask equipped with a condenser and drying tube was added IV (1.7 g., 0.01 mole) and oxalyl chloride (3.96 g., 0.03 mole). (The equivalent quantity of thionyl chloride could also be used.) After the initial reaction had subsided, the mixture was heated on a steam-bath for 20 minutes and the excess oxalyl chloride removed under reduced pressure at 75–100°. Addition of aniline (4.64 g.) dissolved in 10 ml. of dry benzene gave on cooling 1.6 g. (45% yield) of white crystals. Recrystallization from aqueous ethyl alcohol gave the anilide, m.p. 107–108°.

Anal. Calcd. for $C_{14}H_{17}O_8N$: C, 67.96; H, 6.93; N, 5.67. Found: C, 67.95; H, 6.87; N, 5.58.

A mixed melting point with the anilide VIII (Ar = C_6H_5) of γ -(γ -carboxypropyl)-butyrolactone prepared by reaction of aniline with a mixture of III and IV was not depressed.

4-Oxoöctanedioic Acid (IX).^{10,11}—*trans*-Bifurandione (25 g.), acetic acid (270 ml.), concentrated hydrochloric acid (30 ml.) and 10% palladium-on-carbon catalyst (1.6 g.) were shaken with hydrogen at room temperature at a maximum pressure of 3 atm. until absorption ceased. The solution was filtered and evaporated to dryness to give IX (13.4 g.) in crystalline form and an additional 7.3 g. as a tacky solid, total yield 72%. After recrystallization from ethyl acetate, chloroform or water it melted at 132–133°.

Anal. Calcd. for $C_8H_{10}O_6$: C, 51.05; H, 6.43; neut. equiv., 94. Found: C, 51.06; H, 6.43; neut. equiv., 98.6, 98.3.

A semicarbazone was obtained from 4-oxoöctanedioic acid (0.90 g.), semicarbazide hydrochloride (0.54 g.), sodium acetate (0.75 g.) and water (10 ml.). It weighed 0.91 g. and melted at 146° after two recrystallizations from ethyl alcohol. The compound has the correct composition, although the melting point reported in the literature is 160–163°.^{4c}

Anal. Calcd. for $C_9H_{15}O_5N_3$: C, 44.07; H, 6.30; N, 17.14. Found: C, 43.82; H, 6.35; N, 17.02, 17.10.

γ -(δ -Hydroxybutyl)-butyrolactone (X).—Bifurandione (23.0 g., 0.14 mole), dioxane (200 ml.) and ruthenium dioxide (0.23 g.) and water (10 ml.) were shaken with hydrogen (70–200 atm.) at 200° for 4.5 hours. The product was distilled to give a fraction at 155° (1 mm.), 8.1 g. (37% yield), and a residue, 2.9 g. The first fraction was redistilled to give two fractions, (1) b.p. 140–142° (0.5 mm.), n_D^{25} 1.4650, and (2) b.p. 142° (0.5 mm.), n_D^{25} 1.4715; infrared spectrum: 2.95 (strongly bonded-OH), 3.4 (saturated CH), 5.65 μ (lactone carbonyl).

Anal. Calcd. for $C_9H_{14}O_5$: sapon. equiv., 158; hydroxyl number, 354. Found (fraction 1): sapon. equiv., 158; hydroxyl number, 378.

1,4,8-Octanetriol (XI).—Three identical runs were made, each employing 25 g. of *trans*-bifurandione, 2.5 g. of ruthenium dioxide and 200 ml. of dioxane at 200° and hydrogen at 170–200 atm. for 4 hours. The first group of fractions (18.1 g.) from the combined runs boiled at 67–77° (1.8–2.0 mm.) and had n_D^{25} 1.4372 to 1.4377. The central cut XI (b.p. 71° at 1.8 mm.) solidified (2 g.) and after several recrystallizations from ethyl acetate-petroleum ether and chloroform-petroleum ether melted at 89.5°; infrared spectrum: 3.0 (–OH), 3.35 and 3.45 μ (–CH).

Anal. Calcd. for $C_8H_{18}O_3$: C, 59.23; H, 11.18; mol. wt., 162. Found: C, 58.95, 59.68, 59.69; H, 11.43, 11.62, 11.49; mol. wt., 143, 156.

Compound XI also was obtained by hydrogenation of γ -(δ -hydroxybutyl)-butyrolactone (X) in dioxane over copper barium chromite at 225° and 200 atm. as a non-crystallizable oil.

γ -(γ -Ethoxycarbonylpropyl)-butyrolactone (XII) and 2-(3-Ethoxycarbonylpropyl)-tetrahydrofuran (XIII).¹²—Bifurandione (25 g.) in ethyl acetate (200 ml.) was hydrogenated with 5 g. of Raney nickel at 250° and 200 atm. for 4 hours.

(10) R. J. Crawford, V. A. Engelhardt and H. E. Holmquist, U. S. Patent 2,840,608 (1958).

(11) This reaction was first carried out by Dr. R. J. Crawford, to whom the authors are indebted.

(12) H. E. Holmquist, U. S. Patent 2,849,457 (1958).

The product was distilled to give XIII (less dense than water), 2.8 g., b.p. 66–70° (0.9 mm.), n_D^{25} 1.4438; an intermediate cut (2.5 g.); and XII (denser than water), b.p. 134° (1.8 mm.), or 122° (0.6 mm.), n_D^{25} 1.4539. Fraction I (XIII) was redistilled at 65° (0.8 mm.), n_D^{25} 1.4424.

Anal. Calcd. for $C_{10}H_{18}O_5$: C, 64.49; H, 9.74; mol. wt., 186. Found: C, 64.63; H, 9.74; mol. wt., 182, 181.

A small amount of XIII was saponified to the corresponding acid, b.p. 104–106° (2.5 mm.), n_D^{25} 1.4590; reported¹³ b.p. 145° (5 mm.), n_D^{25} 1.4572. A sample of the XII fraction was redistilled at 127° (0.7 mm.), n_D^{25} 1.4540.

Anal. Calcd. for $C_{10}H_{18}O_4$: C, 59.98; H, 8.05; mol. wt., 200; sapon. equiv., 100. Found: C, 60.17, 60.29; H, 8.13, 8.36; mol. wt., 200, 200; sapon. equiv., 103, 103.

In an alternative method, bifurandione (15.5 g., 0.095 mole), absolute ethyl alcohol (200 ml.) and Raney nickel (2–3 g.) were shaken with hydrogen (200 atm.) at 235° for 4 hours. The products were XII and XIII but in reduced yields.

Compound XII was hydrogenated over copper barium chromite in dioxane at 225° and 200 atm. to give the triol XI in less pure state than that reported above.

γ -(γ -Methoxycarbonylpropyl)-butyrolactone.¹¹—A slurry of 50 g. of *trans*-bifurandione and 10 g. of 10% palladium-on-charcoal catalyst in 500 ml. of methanol was cooled to 10°. A stream of hydrogen gas was bubbled into the solution until the bifurandione was dissolved completely. After filtration and removal of the solvent by evaporation the product was fractionated to give the methyl ester, 4.0 g. (b.p. 117–119° at 2 mm.); infrared spectrum: 5.65 (lactone carbonyl), 5.80 μ (ester carbonyl).

Anal. Calcd. for $C_9H_{14}O_4$: C, 58.65; H, 7.62. Found: C, 58.13; H, 7.73.

The remainder of the product was a mixture of III and IV.

4-Hydroxyoctanediamide.—A solution of 2.8 g. of γ -(γ -methoxycarbonylpropyl)-butyrolactone in 25 ml. of concentrated ammonium hydroxide was heated overnight on a steam-bath. The thick, brown residue solidified when triturated with hot methyl ethyl ketone. The tan powder (0.6 g.) was recrystallized twice from ethyl alcohol to give a pure sample of the diamide, m.p. 151°.

Anal. Calcd. for $C_8H_{16}O_5N_2$: C, 51.05; H, 8.57; N, 14.88. Found: C, 51.27; H, 8.77; N, 14.37.

Succinimide and Succinic Acid from Bifurandione.—A solution of *trans*-bifurandione (5 g.) in dioxane (200 ml.) was hydrogenated in the presence of ammonia (20 g.) over Raney nickel at 100° and 200 atm. for 3.5 hours to give 0.4 g. of succinimide, identified by mixed m.p. with an authentic sample.

A solution of *trans*-bifurandione (32 g., 0.2 mole) in dilute sodium hydroxide (0.6 mole in 200 ml. of water) was hydrogenated at 200° and 910–990 atm. with 5 g. of Raney nickel for 16 hours. The almost colorless solution was filtered, acidified and extracted with methyl ethyl ketone. The extract was dried and concentrated to give 19.2 g. of an oil, from which γ , γ' -bibutyrolactone (III) and succinic acid identified by mixed m.p., were isolated.

Suberic Acid.—A solution of 19.8 g. (0.12 mole) of *trans*-bifurandione (I) in 200 ml. of dioxane was hydrogenated at 190° and 140–200 atm. for 3.5 hours with 5 g. of copper-barium chromite. The absorption of hydrogen was 0.5 mole. The blue solution was filtered and concentrated under reduced pressure to leave a moist residue (21.1 g.), which was dissolved in chloroform-petroleum ether and chilled to give 5.3 g. of crude suberic acid, m.p. 124–128° (m.p. 141° after several recrystallizations from chloroform).

Anal. Calcd. for $C_8H_{14}O_4$: C, 55.16; H, 8.10; mol. wt., 174. Found: C, 54.71, 54.61; H, 7.88, 8.13; mol. wt., 186, 188.

After removal of the solvents, the remainder of the product was distilled at 1.8 mm. to give a forerun (0.8 g.) at 110–170°, a distillate at 175–178° from which was crystallized another 1.0 g. of suberic acid (total yield 6.3 g., 30%); and a liquid fraction (1.5 g.) at 180–190° (1 mm.).

1,8-Octanediol and 2-(4-Hydroxybutyl)-tetrahydrofuran (XIV).—A solution of 18.9 g. (0.115 mole) of *trans*-bifurandione (I) in 200 ml. of dioxane was hydrogenated at 290° and

(13) H. Gilman and A. P. Hewlett, *Rec. trav. chim.*, **51**, 93 (1931).

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 (reported¹⁴ 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 C₈H₁₆O₂: 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, reported¹⁴ 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 C₈H₁₆O₂: 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 C₁₀H₁₈O₄N₂: N, 12.17. Found: N, 11.92.

Dihydrobifurandione (XV).¹⁵—*trans*-Bifurandione (25 g.), dioxane (200 ml.) and reduced nickel molybdate catalyst⁵ (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 C₈H₈O₄: 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 electrolytically⁷ 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: $k_{2570 \text{ \AA}}$ = 0.73; infrared absorption: 3.4 (saturated CH) and 5.8 μ (carbonyl and carboxyl).

Anal. Calcd. for C₈H₁₀O₆: 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 C₁₄H₁₄O₄N₂: 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).

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Bifurandione. III. Addition and Ring-opening Reactions

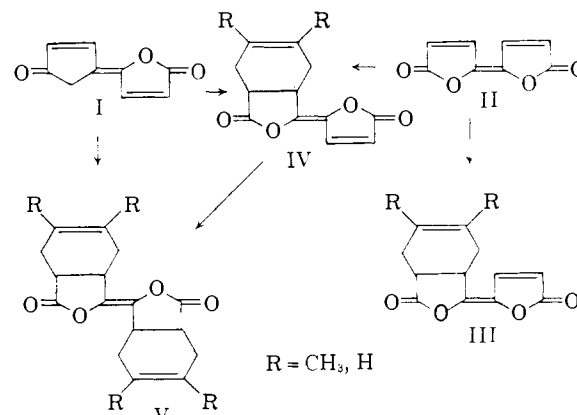
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$\Delta^{2,2'}$ (⁶H,^{5'}H)-Bifuran-5,5'-dione (bifurandione) added either one or two molecules of a diene in the Diels–Alder reaction. Oxidation of the dilactone with nitric acid gave 2,2'-dihydroxy-2,2'-bifuran-5,5'-(2H,2'H)-dione, which was hydrogenated 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*- $\Delta^{2,2'}$ (⁶H,^{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 reactions² 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



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

(2) Paper 11, H. E. Holmquist, et al. *ibid.*, **81**, 3681 (1959).

only as a dienophile under the conditions tried. Thus, either isomer of the dilactone reacted readily