

saturated ammonium chloride solution was added, the layers were separated, the aqueous layer was extracted twice with 100-ml. portions of chloroform, and the combined organic layers were dried over magnesium sulfate. Evaporation of the solvents left 9.5 g. (94%) of phenylethylene glycol, m.p. 60.0–64.5°, $[\alpha]_{D}^{20} +13.7^{\circ}$ (95% ethanol, c 3.91, l 2). The infrared spectrum was identical with that of an authentic sample of the racemate.

Reduction of Phenylidihydrothebaine Phenylglyoxylate.
A. With Lithium Aluminum Hydride.—A solution of the free base was prepared by shaking 17.5 g. of phenylidihydrothebaine phenylglyoxylate perchlorate⁵ with ether and concentrated ammonia water. The ether solution was dried over calcium sulfate in the dark in a nitrogen atmosphere, filtered, and added during 40 minutes to a stirred solution of 2.0 g. of lithium aluminum hydride in 250 ml. of anhydrous ether. After an additional hour, saturated ammonium chloride solution and then 50 ml. of 15% hydrochloric acid were added. The layers were separated, the aqueous layer was extracted with chloroform, and the combined organic layers were extracted with 15% hydrochloric acid, washed with water and dried over calcium sulfate. Evaporation of the neutral fraction gave an oil the infrared spectrum of which indicated it to be essentially pure phenylethylene glycol. This material was chromatographed on alumina in chloroform. After a trace of yellow impurity had been washed off the column with chloroform, elution with methanol gave 1.7 g. (45%) of colorless phenylethylene glycol, m.p. 53–57°, $[\alpha]_{D} +28.0^{\circ}$ (95% ethanol, c 2.02, l 2), 48% optically pure, infrared spectrum identical with that of the racemate.

The basic fraction (hydrochloric acid extracts and washings) was neutralized with bicarbonate and extracted with ether. After having been dried over calcium sulfate, the ether solution was evaporated to give an oil which was taken up in 95% ethanol and treated with 72% perchloric acid until no further precipitation was noted. The colorless, crystalline product was dried to give 7.1 g. (50%) of phenylidihydrothebaine perchlorate, m.p. 241–244°.

B. With Sodium Borohydride.—A solution of 2.5 g. of sodium borohydride in 200 ml. of dry diethylene glycol diethyl ether was prepared at 100° and cooled to room temperature, whereupon only a slight turbidity developed. It was treated with a solution of phenylidihydrothebaine phenylglyoxylate (from 3.0 g. of perchlorate) in 50 ml. of diethylene glycol diethyl ether. After 5 minutes, the solution was poured into 500 ml. of 10% hydrochloric acid, extracted with chloroform, dried, and evaporated to give 0.45 g. of phenylethylene glycol, m.p. 62–65°, $[\alpha]_{D}^{20} +5.8^{\circ}$ (95% ethanol, c 2.55, l 2), 10% optically pure, infrared spectrum identical with that of the racemate.

From the acid-soluble fraction, there were obtained 1.55 g. (66%) of phenylidihydrothebaine perchlorate, m.p. 244–246° (dec.), $[\alpha]_{D} +33.8^{\circ}$ (95% ethanol).

From a reaction run at 100° for 5 minutes in diethylene glycol diethyl ether, there were obtained 0.57 g. (71%) of phenylethylene glycol, m.p. 64–67°, $[\alpha]_{D} +2.1^{\circ}$ (95% ethanol), and 1.65 g. (70%) of phenylidihydrothebaine perchlorate, m.p. 244–246° dec.

Reductions run in methanol, dioxane and *t*-butyl alcohol gave phenylidihydrothebaine perchlorate and carbonyl-free neutral material.

Borohydride Reduction of Ethyl Phenylglyoxylate.—A solution of 2.28 g. of sodium borohydride in 150 ml. of dioxane was heated at 100°, stirred and treated with a solution of 5.34 g. of ethyl phenylglyoxylate in 50 ml. of dioxane during 5 minutes. After an additional 10 minutes, dilute hydrochloric acid was added, the mixture was concentrated to a small volume, diluted with chloroform, dried over calcium sulfate and filtered. This solution showed only weak carbonyl absorption and gave a faint positive Brady test. Cooling deposited 2.65 g. (64%) of phenylethylene glycol, m.p. 65–67°, infrared spectrum identical with that of the racemate.

Application of the above reduction conditions to 5.40 g. of ethyl mandelate, extraction with chloroform, and distillation gave 4.85 g. (90%) of ethyl mandelate, b.p. 155–156° (35 mm.), n_{D}^{20} 1.5101, infrared spectrum identical with that of the starting material, which had b.p. 156–157° (35 mm.), n_{D}^{20} 1.5106.

Borohydride Reduction of Ethyl Pyruvate.—A sample of 5.8 g. of ethyl pyruvate was reduced with 5.56 g. of sodium borohydride according to the above procedure. Extraction with chloroform and distillation gave 4.2 g. (71%) of ethyl lactate, b.p. 152–153°, n_{D}^{20} 1.4136, infrared spectrum identical with that of an authentic sample.

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[CONTRIBUTION FROM THE MCPHERSON CHEMICAL LABORATORY OF THE OHIO STATE UNIVERSITY]

Condensed Cyclobutane Aromatic Compounds. VIII. The Mechanism of Formation of 1,2-Dibromobenzocyclobutene; A New Diels–Alder Synthesis

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RECEIVED MAY 20, 1959

The conversion of $\alpha,\alpha,\alpha',\alpha'$ -tetrabromo-*o*-xylene to 1,2-dibromobenzocyclobutene by iodide ion proceeds *via* a transient *o*-quinodimethane derivative. The *o*-quinodimethane intermediate can be trapped by maleic anhydride or *N*-phenylmaleimide to give the expected 2,3-disubstituted naphthalenes. *p*-Benzoquinone and 1,4-naphthoquinone can be employed also as dienophiles, giving simple syntheses of 1,4-anthraquinone and 5,12-naphthacenequinone, respectively.

Two mechanisms have been suggested for the conversion of $\alpha,\alpha,\alpha',\alpha'$ -tetrabromo-*o*-xylene (I) to 1,2-dibromobenzocyclobutene (II). The first of these¹ involves a concerted elimination reaction giving rise to a highly reactive *o*-quinodimethane derivative (III) which then cyclizes spontaneously to the observed dibromide II. Reactions analogous to each of the two steps of this proposed mechanism have already been reported. Formation of a polymer of *o*-quinodimethane (IV) occurs readily² when attempts are made to convert the chloroether V into a Grignard reagent, but cyclization of IV to benzocyclobutene can be observed under different conditions, particularly in the gas phase.³ The second mechanism suggested for the

formation of 1,2-dibromobenzocyclobutene⁴ assumes the generation of the intermediate carbanion VI, which displaces a bromide ion from the opposite and very close carbon atom.⁵

Since it was possible to trap *o*-quinodimethane itself as a Diels–Alder adduct with *N*-phenylmaleimide,³ it appeared that this dienophile should be capable also of trapping the dibromo-*o*-quinodimethane III, if this molecule actually is an intermediate in the conversion of tetrabromide I to dibromide II. This expectation was indeed realized. When $\alpha,\alpha,\alpha',\alpha'$ -tetrabromo-*o*-xylene (I) and sodium iodide are warmed in dimethylformamide at 60–70° for twenty-four hours in the pres-

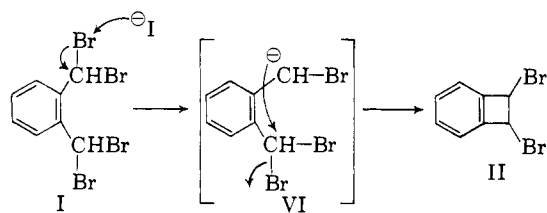
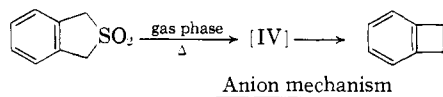
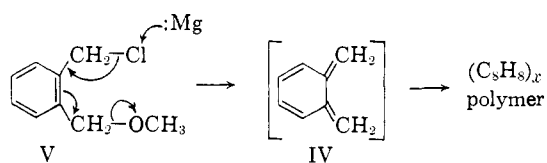
(4) F. R. Jensen and W. E. Coleman, *J. Org. Chem.*, **23**, 869 (1958).

(5) The conversion of I to II *via* VI would seem to be an almost concerted process; otherwise, a considerable amount of VI would be lost by proton abstraction from the solvent (ethanol).

(1) M. P. Cava and D. R. Napier, *THIS JOURNAL*, **79**, 1701 (1957).

(2) F. G. Mann and F. H. C. Stewart, *J. Chem. Soc.*, 2826 (1954).

(3) M. P. Cava and A. A. Deana, *THIS JOURNAL*, **81**, 4266 (1959).



Quinodimethane mechanism

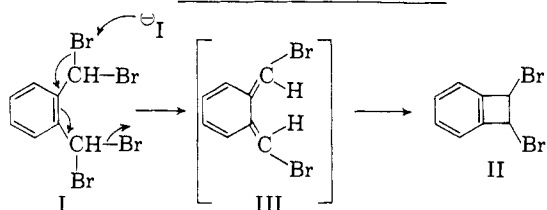


CHART I

ence of *N*-phenylmaleimide, none of II (or the corresponding diiodides) is formed. The sole reaction product isolated, in 65% yield, was *N*-phenyl-2,3-naphthalimide (VII). The formation of VII from the quinodimethane intermediate III must involve first the production of an initial adduct VIII, which then aromatizes readily by the loss of two moles of hydrogen bromide. Maleic anhydride could be substituted for *N*-phenylmaleimide as the dienophile. The reaction product, isolated in 74% yield, was naphthalene-2,3-dicarboxylic acid (IX). This reaction represents a simple and convenient synthesis of IX.

It was found possible to extend the synthetic utility of intermediate III as a diene by generating it in the presence of quinone dienophiles. In this manner, 5,12-naphthacenequinone (X) was obtained easily in 68% yield from 1,4-naphthoquinone and the tetrabromide I. Similarly, 1,4-benzoquinone and III gave, in 43% yield, the difficultly accessible^{6,7} 1,4-anthraquinone (XI). As a by-product in the latter reaction, a small amount (7%) of 6,13-pentacenequinone (XII) was formed from XI by addition of the quinoid intermediate III.

A more detailed examination of the maleic anhydride trapping reaction was carried out in order to obtain a rough idea of the rate of conversion of the tetrabromide I to the dibromide II, assuming the formation of the unstable quinodimethane III to be the rate-controlling step of the process. Under the conditions employed (see Table I) the yield of Diels-Alder product did not increase materially after six hours. Only after short reaction periods, however, did the product consist largely of the originally formed anhydride XIII; with longer

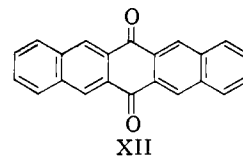
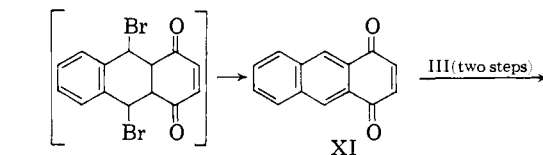
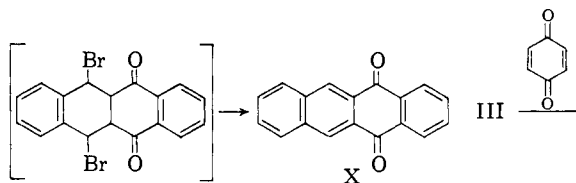
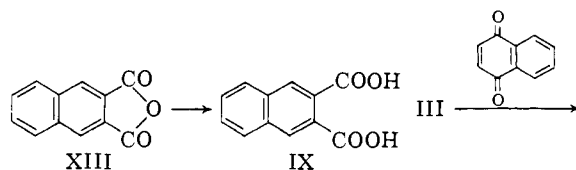
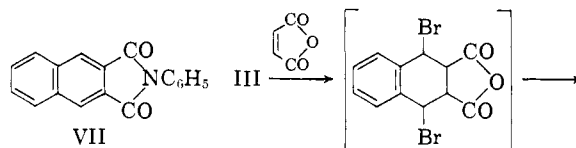
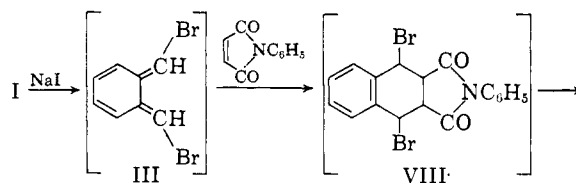
(6) H. Diel, *Ber.*, **39**, 926 (1906).(7) K. Lagodzinski, *ibid.*, **39**, 1717 (1906).

CHART II

reaction times its hydrolysis product, diacid IX, was the major substance isolated.⁸ The possibility that dibromobenzocyclobutene (II) was produced first and then reacted directly or indirectly (by reversion to III) with the dienophile was easily excluded. Substitution of the dibromide II for the tetrabromide I in the maleic anhydride reaction for six hours led to the formation of not a trace of the diacid IX or its anhydride.

The knowledge of the approximate rate of reaction of tetrabromide I with sodium iodide was applied to the practical preparation of dibromide II. Under the conditions of the above rate study, but in the absence of maleic anhydride, the formation of II (in 65% yield) was essentially complete in the short period of six hours. By employing this reaction time, the dibromide II was readily obtained free of any diiodide, from which it can be separated only with very great difficulty.¹

(8) No attempt was made to ascertain the cause of the slow hydrolysis of XIII to IX during these reaction runs. Traces of moisture in the reagents would seem to be the simplest explanation; however, a more devious mechanism involving hydrogen bromide and the solvent cannot be entirely discounted at present.

TABLE I

PERCENTAGE YIELDS OF NAPHTHALENE-2,3-DICARBOXYLIC ACID (IX) AND ITS ANHYDRIDE XIII FROM TETRABROMIDE I (0.010 *M*), MALEIC ANHYDRIDE (0.015 *M*) AND NaI (0.066 *M*) IN DIMETHYLFORMAMIDE AT 65°

Hours	Yield of XIII, %	Yield of IX + XIII, %
1	19	22
2	27	57
4	23	72
6	21	76
9	14	78
11	7	76

Acknowledgment.—We should like to thank the National Science Foundation for a grant in support of a portion of this work.

Experimental⁹

N-Phenyl-2,3-naphthalimide (VII). (a) From Naphthalene-2,3-dicarboxylic Acid (IX).—A mixture of diacid IX (1.12 g.) and aniline (5 ml.) was refluxed 20 minutes. The cooled reaction mixture was triturated with excess dilute hydrochloric acid and the imide extracted into chloroform. The dried extract, after treatment with charcoal, was concentrated and diluted slowly with petroleum ether (30–60°) to give the imide VII as white plates (1.20 g., 85%), m.p. 284–285° (reported¹⁰ 277–278°).

(b) From $\alpha,\alpha,\alpha',\alpha'$ -Tetrabromo-*o*-xylene (I).—A mixture of tetrabromide I (4.22 g.), sodium iodide (10.0 g.), N-phenylmaleimide (4.00 g.) and dry dimethylformamide (30 ml.) was stirred at 60–70° for 24 hours. The reaction mixture was poured into cold water (350 ml.) containing sodium bisulfite (5.0 g.). The brown precipitate was crystallized from chloroform–petroleum ether to give, in two crops, 1.35 g. of white plates, m.p. 283–285°. A third crop of material (0.90 g.) was purified by recrystallization, followed by chromatography in methylene chloride solution on neutral alumina (Grade II). The total yield of pure imide VII, m.p. 283–285°, was 1.78 g. (65%). The melting point was not depressed by admixture with material prepared from naphthalene-2,3-dicarboxylic acid, and the infrared spectra of both samples were identical.

Naphthalene-2,3-dicarboxylic Acid (IX).—A mixture of tetrabromide I (4.22 g.), sodium iodide (10.0 g.), maleic anhydride (3.0 g.) and dry dimethylformamide (35 ml.) was stirred at 60–70° for 24 hours. The reaction mixture was poured into water (350 ml.) containing sodium bisulfite (5.0 g.). The yellow precipitate was dissolved in dilute sodium hydroxide, the solution decolorized by charcoal, filtered and the filtrate acidified with sulfuric acid. The white precipitate of diacid IX was washed well with cold water and dried. The product, m.p. 238–239° (1.59 g., 74%), was quite pure without further treatment; its melting point and infrared spectrum were identical with those of material obtained by controlled oxidation of 2,3-dimethylnaphthalene.¹¹

5,12-Naphthacenequinone (X).—A mixture of tetrabromide I (4.22 g.), sodium iodide (10.0 g.), 1,4-naphthoquinone (2.50 g.) and dry dimethylformamide (35 ml.) was stirred at 60–70° for 24 hours. The cooled mixture was poured into water (350 ml.) and aqueous sodium bisulfite was added dropwise until the color of iodine was just dis-

charged. The brown precipitate (2.90 g.) was dissolved in warm *sym*-tetrachloroethane and chromatographed on neutral alumina (Grade III), the column being eluted with the same solvent. Evaporation of the eluate left a residue which was triturated with cold methylene chloride to remove a purple impurity. The insoluble yellow-orange quinone (1.84 g.) was obtained pure by chromatographing it once more in *sym*-tetrachloroethane solution on neutral alumina (Grade III). Removal of the solvent left pale yellow needles of quinone X (1.76 g., 68%), m.p. 290–292° (reported¹² 280°, 284–285°¹³).

Anal. Calcd. for C₁₈H₁₀O₂: C, 83.71; H, 3.90. Found: C, 83.98; H, 4.02.

1,4-Anthraquinone (XI).—A mixture of tetrabromide I (4.22 g.), sodium iodide (10.0 g.), 1,4-benzoquinone (2.50 g.) and dry dimethylformamide (35 ml.) was stirred at 60–70° for 24 hours. After pouring into cold water (350 ml.) the iodine color was just discharged by the gradual addition of aqueous sodium bisulfite. The brown precipitate (1.9 g.) was air-dried and then sublimed at 140–150° (2 mm.). The orange sublimate (0.97 g.) was chromatographed on neutral alumina (Grade III) in chloroform solution. Concentration of the eluate and gradual addition of petroleum ether afforded yellow plates of quinone XI (0.89 g., 43%), m.p. 219–223° dec., with previous darkening at about 210° (reported¹⁴ 218° dec., darkening at 210°).

Anal. Calcd. for C₁₄H₈O₂: C, 80.76; H, 3.87. Found: C, 80.68; H, 3.74.

Continued sublimation of the residual crude reaction product at 2 mm. (heating with a free flame) afforded an orange sublimate (0.30 g.). Chromatography of this product on neutral alumina (Grade III) in *sym*-tetrachloroethane solution gave, after removal of the eluate solvent, pale yellow needles of quinone XII (0.11 g., 7%), m.p. 395–398° (cor.) (reported¹⁵ 385–387°).

Anal. Calcd. for C₂₇H₁₂O₂: C, 85.70; H, 3.92. Found: C, 85.75; H, 4.07.

Rate of Formation of Quinodimethane Intermediate III.—A mixture of tetrabromide I (4.22 g.), sodium iodide (10.0 g.), maleic anhydride (1.50 g.) and dry dimethylformamide (35 ml.) was heated with stirring at 65° for a certain period of time. The cooled reaction mixture was poured into water (300 ml.) and sodium bisulfite solution added until the free iodine was reduced. The precipitate was filtered and the diacid IX which it contained was extracted with cold aqueous sodium bicarbonate and further isolated in the usual manner. The anhydride XIII present in the insoluble residue could be recrystallized and identified by direct comparison (melting point and infrared spectrum) with authentic material; for quantitative results the crude anhydride from a run was dissolved in dilute warm sodium hydroxide, then isolated as diacid IX. The results of a number of runs are given in Table I.

***trans*-1,2-Dibromobenzocyclobutene (II).**—A 6-hour run was carried out exactly as described above, except that no maleic anhydride was introduced. The reaction mixture was poured into water (300 ml.) and the iodine present was reduced by the addition of 10% aqueous sodium bisulfite. The dibromide II was extracted into Skellysolve F and purified by chromatography on Woelm neutral alumina (Grade I). The product obtained (1.50 g., 65%), m.p. 50–51° (reported¹ 52.4–52.8°), was practically pure dibromide. (The product did not contain enough of the corresponding *trans*-diiodide to be detected by infrared analysis.¹)

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(11) Private communication from L. Friedman, D. L. Fishel and H. Shechter.