

solid, m.p. 331°, separated. The m.p. was not depressed on admixture with XIVc.

Action of Alkali on 4,5-Dibromo-*exo-cis*-3,6-endomethylenehexahydrophthalic Acid.—A mixture of 2.1 g. of the acid^{34a} and 25 cc. of water was brought to a phenolphthalein end-point with aqueous sodium hydroxide. (A portion of the clear solution immediately gave a positive test for halogen with silver nitrate.) After two hours, a crystalline precipitate appeared. The mixture was acidified with 6 *N* nitric acid, the product was collected at the pump and dried at 100° for 48 hours to give 1.2 g. of the bromolactonic acid XXVII, m.p. 157.5–159°, reported^{34a} m.p. 157°. The mother liquors gave 1.13 g. of silver bromide when treated with excess silver nitrate. Alder and co-workers^{34a} also report a "bromohydrin," m.p. 116°, which upon drying in the solid state gives the 157° bromolactonic acid. It seems unreasonable to suppose that the 116° material is a bromohydrin since we find it is reformed from the 157° lactone upon simple recrystallization of the latter from water. The low-melting modification is undoubtedly a crystal hydrate.

Conversion of 4,5-dibromo-*exo-cis*-3,6-endomethylenehexahydrophthalic acid to the anhydride XXII was accomplished by heating the dibromoacid with an excess of acetic anhydride at 100° for five minutes. The anhydride had m.p. 205° alone or mixed with a sample of XXII prepared by brominating XX in chloroform.³³

Bromination of *endo-cis*-3,6-Endomethylene- Δ^4 -tetrahydrophthalic Anhydride (XX). A. Ethyl Acetate.—A solution of 122.7 g. of XX in 500 cc. of ethyl acetate was treated with 41 cc. of bromine in 100 cc. of ethyl acetate during one and one-third hours. The temperature of the reaction mixture was kept below 5° and vigorous stirring was used. The clear solution was allowed to come to room temperature whereupon the bromine color faded and a crystalline product

separated. This material weighed 55.1 g. and was identified as crude XXII, m.p. 203–205°. The mother liquor was concentrated to a volume of 150 cc. and diluted to 300 cc. with carbon tetrachloride whereupon a further quantity (23.2 g.) of XXII separated, m.p. 192.5–201°.

The residual mother liquor was evaporated to dryness leaving 175 g. of a pale orange glass. Sixty-eight and one-half grams of this material was heated for five hours at reflux with 100 cc. of methanol and 5 cc. of 30% fuming sulfuric acid. After standing an additional fourteen hours at room temperature, the reaction mixture was poured into 250 cc. of cold water, extracted with chloroform and the chloroform extracts washed with potassium bicarbonate and then with water. The chloroform solution was dried with sodium sulfate and evaporated to leave a thick, pale-yellow oil. The oil was distilled through a small Vigreux column to give the following fractions (bath at 220–240°): 1, b.p. 170° (2 mm.), 1.5 g., n_D^{25} 1.5205; 2, b.p. 170° (2.5 mm.), 12.1 g., n_D^{25} 1.5305; 3, b.p. 170° (2 mm.), 27.1 g., n_D^{25} 1.5308; 4, b.p. 171–173.5° (2 mm.), 9.6 g., very viscous oil, n_D^{25} 1.5338. Fraction 4 was triturated with cold methanol whereupon a sticky, partially crystalline material separated. Recrystallization from Skellysolve B gave 1.1 g. of colorless needles, m.p. 118–119°.

Anal. Calcd. for $C_{11}H_{14}O_4Br_2$: C, 35.70; H, 3.81. Found: C, 35.78; H, 3.75.

B. Methylene Chloride.—A solution of 12.5 g. of XX in 150 cc. of methylene chloride was treated with 4.5 cc. of bromine. A precipitate appeared after one hour. After 12 hours, the crystalline precipitate was collected to give 20.9 g. of dibromide, m.p. 204–205.5°, reported³³ m.p. 206°.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF SOUTHERN CALIFORNIA]

The Structure and Stereochemistry of Bicyclic Derivatives. V.¹ Pyrolysis of *endo-cis*-3,6-Endomethylene-*exo-cis*-4,5-dibromohexahydrophthalic Acid

BY JEROME A. BERSON

RECEIVED NOVEMBER 27, 1953

The anhydride obtained from the pyrolysis reaction of the title is shown to be a *meso* compound. This finding requires the rejection of the formula proposed by Kwart and Kaplan on the basis of dipole moment studies and confirms the unarranged "all-*exo*" structure.

In an investigation of methods of converting the *endo*-cyclopentadiene-maleic anhydride adduct (I) to its *exo*-isomer (II), Alder and Stein² discovered that the isomerization could be effected circuitously via a sequence involving bromination of I to a dibromide, m.p. 209° (now known to be III^{1c,3}), hydrolysis of III to the corresponding dibasic acid IV, pyrolysis of IV at 215° to give a mixture of a bromolactonic acid V and a new dibromoanhydride VI, m.p. 249°, and debromination of VI with zinc to give II. Bromination of II gave not VI but a new dibromoanhydride VII, m.p. 184°. It is the structure of VI with which we are concerned here.

Kwart and Kaplan,⁵ on the basis of a study of dipole moments, assigned the structure VIa to the anhydride VI of m.p. 249°. These authors also

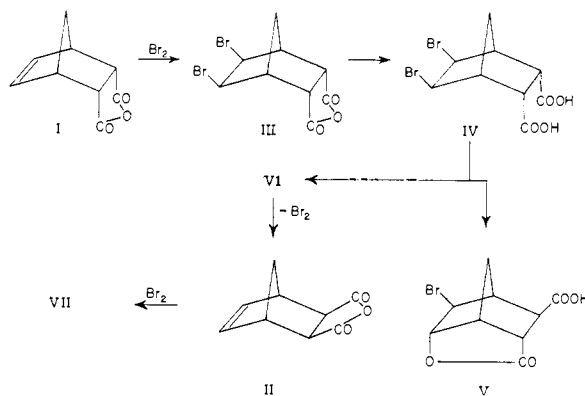
(1) For previous papers in this series see (a) *THIS JOURNAL*, **75**, 1721 (1953); (b) **75**, 4366 (1953); (c) **76**, 4057 (1954); (d) **76**, 4060 (1954).

(2) (a) K. Alder and G. Stein, *Ann.*, **504**, 247 (1933). (b) The experiments of the German authors have been repeated in detail by P. D. Bartlett and A. Schneider, *THIS JOURNAL*, **68**, 6 (1946).

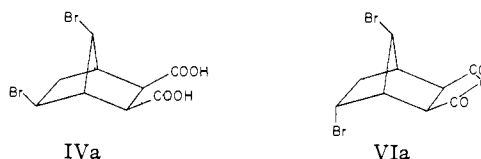
(3) cf. H. Kwart and L. Kaplan, *ibid.*, **76**, 4072 (1954).

(4) D. Craig, *ibid.*, **73**, 4889 (1951).

(5) H. Kwart and L. Kaplan, *ibid.*, **75**, 3356 (1953).

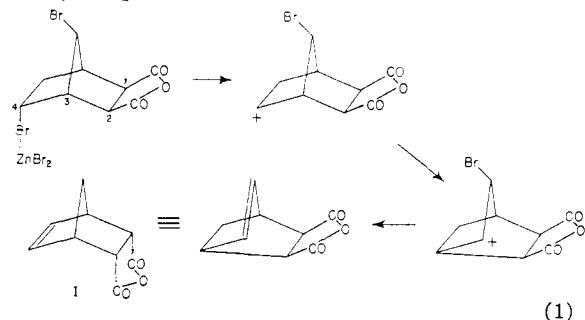


suggested a mechanism for the formation of VIa by the pyrolysis of the dibasic acid which they believed to be IVa.

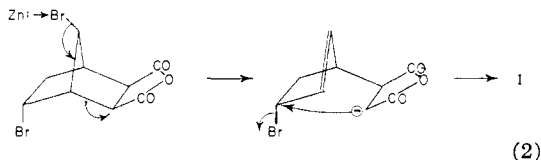


The establishment of the structure IV instead of IVa for the dibasic acid^{1c,3} makes the question of the mechanism of the change IVa \rightarrow VIa irrelevant but requires a reinvestigation of the structure of VI. *A priori*, two experimental facts seriously imperil VIa: (i) Lactonization in aqueous solution of the dibasic acid of VIa and of the dimethyl ester in alcoholic silver nitrate is to be expected.^{1c} Neither reaction occurs.

(ii) The zinc debromination of VIa to a 3,6-endomethylenetetrahydrophthalic anhydride requires a formal Wagner-Meerwein change. This might conceivably be accomplished by a zinc bromide-catalyzed process (1)



or by a process involving attack of zinc metal on the bridge bromine in concert with *trans*-elimination of the group $\ominus\text{CH}-\text{CO}$ followed by displacement of bromide ion (2)

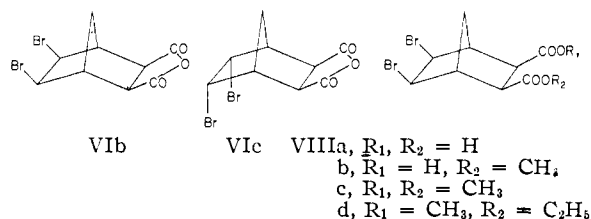


Both processes are inherently improbable because of the unfavorable geometry of the bromine atom at C₄, but even if this objection is ignored, a more serious one arises from the fact that *both* (1) and (2) generate the *endo*-isomer (I) rather than the observed² product, the *exo*-isomer (II). Also, since I is stable under the debromination conditions (*cf.* its formation in the debromination of III²), it cannot be an intermediate in the formation of II. Therefore, no mechanism is apparent for the change VIa \rightarrow II.

Structure VIa is definitely eliminated by the demonstration that the 249° anhydride VI is a *meso* compound. Preliminary attempts to resolve the corresponding dibasic acid with quinine and with quinidine were unsuccessful. However, the monomethyl ester was smoothly resolvable with these alkaloids. Fractionation of the quinine salt gave (-)-monomethyl ester, $[\alpha]_D -6.7^\circ$, regenerated from the head fraction, and (+)-monomethyl ester, $[\alpha]_D +1.8^\circ$, from the tail fraction. (The resolution was not carried to completion.) The intermediate fractions gave samples of ester of low activity, but further resolution of these with quinidine gave dextrorotatory material, $[\alpha]_D +3.6^\circ$, from the head fraction. Both (+)- and (-)-monomethyl esters gave *optically inactive dimethyl ester* with diazomethane. The (+)-monomethyl ester gave (+)-methyl ethyl ester with diazoethane. Pyrolysis of (+)-monomethyl ester above the melting point

resulted in loss of methanol and quantitative conversion to *optically inactive* anhydride VI.

The *meso* character of VI and its debromination to the *exo*-anhydride (II) allow only two formulas, VIb and VIc.



It seems most reasonable to assume that the change IV \rightarrow VI involves a simple double epimerization and dehydration to VIb rather than the more drastic changes leading to VIc. Accordingly, VI is formulated as VIb and the corresponding acid and its derivatives as VIIIa-d.

The experimental dipole moment of the 249° anhydride VI, as determined by Kwart and Kaplan,⁵ is 3.2 *D*. This value agrees well with the theoretical value of 3.0 *D* calculated by these authors for the incorrect structure VIa, but is in poor agreement with their calculated values for VIb and VIc (both 4.4 *D*). Indeed, of the ten formulas (including VIb and VIc) which they considered in assigning structures to the three known dibromo compounds (III, VI and VII) of the endomethylenehexahydrophthalic anhydride series, *none* (except VIa) has a theoretical dipole moment, according to their calculations, which is closer to 3.2 *D* than the claimed maximum discrepancy of ± 0.4 *D*. We have no quantitative explanation for the failure of the observed dipole moment to correspond to that calculated. However, several factors might contribute to the effect. Although the details of the calculations were not given by Kwart and Kaplan, we assume they were made using normal bond angles. It would not be surprising if the non-bonded repulsive interaction of the *cis* bromines of VIb produced a slight spreading of the C-C-Br angles. Such distortions have been noted in X-ray and electron diffraction studies of halogenated cyclohexanes.⁶ However, on the basis of calculations applied to VIb, we have found that although the effect is in the right direction, the distortion would have to be considerably more than the values of 5°-10° observed⁶ in order to cause any appreciable reduction of the discrepancy. Another possible source of error, as Kwart and Kaplan point out, is in the neglect of mutual polarizability and of field interaction effects.

Experimental⁷

Pyrolysis of *endo-cis*-3,6-endomethylene-*exo-cis*-4,5-dibromohexahydrophthalic acid (IV) was carried out accord-

(6) (a) O. Bastiansen and O. Hassel, *Acta Chem. Scand.*, **5**, 1404 (1951); (b) O. Bastiansen, O. Ellefsen and O. Hassel, *ibid.*, **3**, 918 (1949); (c) O. Hassel and E. W. Lund, *ibid.*, **3**, 203 (1949); (d) J. N. Bijvoet, *Rec. trav. chim.*, **67**, 777 (1948).

(7) Melting points are corrected. The optical rotations were taken at room temperature with a Rudolf polarimeter reading directly to 0.001°. The reproducibility of readings with colorless solutions at thermal equilibrium was usually ± 0.002 -0.006°. The infrared spectra were determined with a Perkin-Elmer model 13 instrument equipped for double beam operation. The microanalyses were performed by Mr. W. J. Schenck.

ing to the directions of Alder and Stein^{2a} and of Bartlett and Schneider.^{2b} We found the reaction to be sensitive to the length of time taken for the addition of IV and to the time of heating. From a run in which the addition of IV to a flask heated at 210–220° required ten minutes and in which the additional time of heating was seven minutes, the neutral pyrolysis product was mostly the anhydride III corresponding to IV. However, when the addition was carried out during three minutes and the additional time of heating was 15–20 minutes, VIb was obtained in about the same yield as reported.² This anhydride melted at 257–258° (246–247° uncor.), reported^{2b} m.p. 244–245° (uncor.), reported^{2a} m.p. 249°.

Hydrolysis of the anhydride with boiling 50% acetonitrile gave shimmering, micaceous platelets of the dibromo acid VIIIA, m.p. 257–258° (246–247° uncor.), reported^{2a} m.p. 248°.

Stability of the Salt of VIIIA.—A solution of 0.20 g. of VIIIA in sufficient 5% sodium hydroxide to impart a definite pink color to phenolphthalein was allowed to stand at room temperature for three and one-quarter hours, and then heated on the steam-bath for one-half hour. The solution was cooled and acidified with hydrochloric acid to give 0.19 g. (95%) of the starting material, m.p. and mixed m.p. 253–255°.

Attempted Resolution of the Dibasic Acid VIIIA. A. With Quinine.—A hot, filtered solution of 6.85 g. of quinine trihydrate in 150 cc. of acetone was treated with a hot solution of 6.20 g. of VIIIA in 100 cc. of acetone. The salt separated immediately as a granular solid. The mixture was digested on the steam-bath for ten minutes, cooled and filtered to give 12.0 g. of quinine salt. This material was very sparingly soluble in hot water, methanol, ethanol, acetone or acetonitrile. It was recrystallized from 100 cc. of boiling dimethylformamide to give 4.7 g. (after washing with methanol and drying at 70°) of felted, laminate needles. The recrystallized salt was decomposed with 6 *N* hydrochloric acid and the resulting solid washed with water and dissolved in aqueous potassium carbonate. The aqueous solution was washed with chloroform and ether, acidified with concentrated hydrochloric acid and the resulting precipitate filtered and recrystallized from dilute acetonitrile to give 1.60 g. of the acid, m.p. 257–258°. This material was optically inactive (*c* 3.85 in acetone, *l* 4).

B. With Quinidine.—A hot solution of 1.54 g. of VIIIA in 20 cc. of acetone was treated with a hot solution of 1.46 g. of quinidine in 30 cc. of acetone. After a few minutes, a precipitate of tightly packed, hemispherical aggregates appeared. After 12 hours at room temperature, the yield of salt was 3.0 g. This material was recrystallized from a mixture of 120 cc. of 70% ethanol and a few cc. of methanol to give 1.46 g. of quinidine salt. Decomposition of the salt and isolation of the acid gave 0.60 g. of VIIIA, optically inactive (*c* 3.90 in acetone, *l* 4).

Racemic Monomethyl Ester VIIIb.—A mixture of 2.1 g. of the anhydride VIb and 25 cc. of methanol was heated at reflux for 135 minutes. The solvent was removed by distillation to give 2.23 g. of the half-ester. This material melted at 170–172° with evolution of gas, then resolidified as the temperature was raised and finally remelted at 250–253°. It was recrystallized from acetone–Skellysolve B.

Anal. Calcd. for C₁₀H₁₂O₄Br₂: C, 33.73; H, 3.40. Found: C, 33.88; H, 3.42.

Resolution of the Monomethyl Ester.—A hot solution of 5.40 g. of VIIIb in 50 cc. of acetone was treated with a hot solution of 5.75 g. of quinine trihydrate in 100 cc. of acetone. The solution was filtered while still hot and concentrated to a volume of 50 cc. After being allowed to cool to room temperature, the solution was placed in the refrigerator for two hours, after which time 1.50 g. (A) of a chalky, granular solid had separated. A second crop (B) of 8.0 g. and a third crop (C) of 1.55 g. were also obtained by successive concentration of the mother liquors. Crops A and B were combined and dissolved in 250 cc. of boiling acetone. The solution was filtered hot, concentrated to a volume of 75 cc. and allowed to cool to give 1.30 g. of quinine salt. This was triturated with 6 *N* hydrochloric acid, the resulting gummy precipitate was extracted with chloroform, the chloroform solution extracted with aqueous potassium carbonate, and the aqueous layer, after being washed with fresh chloroform, acidified with concentrated hydrochloric acid. The precipitated solid was recrystallized from dilute acetic acid and

then from dilute acetone to give 0.25 g. of the (–)-monomethyl ester as tiny, glistening needles, melting at about 150°, evolving gas at 165–170°, resolidifying and then remelting at 251–254°. This material showed $[\alpha]_D -6.7^\circ$ (*c* 1.85 in acetone, *l* 4).

Anal. Calcd. for C₁₀H₁₂O₄Br₂: C, 33.73; H, 3.40; neut. equiv., 356. Found: C, 33.44; H, 3.74; neut. equiv., 356.

The infrared spectrum (Nujol mull) was very similar to that of racemic VIIIb, although the slight differences to be expected between a racemate and an enantiomer¹⁶ were noted.

Crop C from the original formation of the quinine salt was worked up by decomposition with hydrochloric acid, extraction with chloroform, extraction with carbonate and regeneration with hydrochloric acid to give 0.84 g. of (+)-VIIIb, $[\alpha]_D +1.8^\circ$ (*c* 4.30 in acetone, *l* 4).

The acetone mother liquor from the recrystallization of crops A and B was concentrated by evaporation until the onset of crystallization, then cooled, the solid collected and recrystallized from acetone to give 1.7 g. of salt. This was decomposed in the usual manner to give 0.68 g. of monomethyl ester of very low optical activity. Further concentration of the mother liquors gave two further crops of quinine salt which yielded monomethyl ester of very low rotation. These samples of ester were combined (2.4 g.), dissolved in 15 cc. of hot acetone and the solution added to a hot solution of 2.2 g. of quinidine in 40 cc. of acetone. The mixture was concentrated to 20 cc. and allowed to cool to give 1.25 g. of quinidine salt. This was decomposed with 6 *N* hydrochloric acid, the resulting solid filtered, washed with water and dissolved in potassium carbonate solution. This solution was washed with ether, acidified with concentrated hydrochloric acid and the precipitated solid filtered, washed with water and dried to give 0.56 g. of (+)-monomethyl ester, $[\alpha]_D +3.6^\circ$ (*c* 5.6 in acetone, *l* = 4). This substance melted at 145–150°, resolidified at about 170–175° and remelted at 251–253°.

Methylation of the Active Monomethyl Esters to Inactive (*meso*) Dimethyl Ester.—A solution of 0.18 g. of VIIIb, $[\alpha]_D -6.7^\circ$, in 20 cc. of methanol was added to a solution of excess diazomethane in 100 cc. of ether. Nitrogen was evolved briskly. After 90 minutes, the excess diazomethane was decomposed with a few drops of acetic acid, the solution was washed with a little water, dried over sodium sulfate and evaporated. The crystalline residue was made up accurately to a volume of 10 cc. in acetone. The observed optical rotation of this solution was nil ($\alpha +0.001 \pm 0.005^\circ$). Evaporation of 8.5 cc. of the polarimetry solution gave 0.15 g. (94%) of the dimethyl ester VIIIc, m.p. 171.5–173.5° alone or mixed with a sample prepared from VIb and boiling acidulated methanol.

The same procedure was used for methylation of 0.40 g. of the (+)-monomethyl ester, $[\alpha]_D +1.8^\circ$. An acetone solution of the total product was optically inactive ($\alpha = -0.002 \pm 0.007^\circ$, *l* 4). The polarimetry solution was evaporated and the product recrystallized from ethyl acetate to give transparent wedges of the dimethyl ester VIIIc, m.p. 173.5–174.5° alone or mixed with samples prepared as above.

Anal. Calcd. for C₁₁H₁₄O₄Br₂: C, 35.70; H, 3.81. Found: C, 35.50; H, 3.86.

The dimethyl ester was recovered unchanged after eight days at reflux with methanolic silver nitrate. No silver bromide was formed.

Racemic Methyl Ethyl Ester VIIIId.—A solution of 0.52 g. of the racemic monomethyl ester VIIIb in 15 cc. of methanol was added to an excess of diazoethane in 100 cc. of ether. Nitrogen was evolved immediately. After one hour, the excess diazoethane was decomposed with acetic acid and the solution evaporated to give 0.56 g. (quantitative yield) of bold, transparent laths of the methyl ethyl ester. After recrystallization from carbon tetrachloride–Skellysolve B, the ester melted at 100.5–101.5°.

Anal. Calcd. for C₁₂H₁₆O₄Br₂: C, 37.52; H, 4.20. Found: C, 37.47; H, 4.30.

Active Methyl Ethyl Ester.—The same procedure was applied to 0.56 g. of the (+)-monomethyl ester, $[\alpha]_D +3.6^\circ$. The product (0.53 g.) was recrystallized from carbon tetrachloride–Skellysolve B to give 0.35 g. of clusters of transparent flat laths, m.p. 106.5–107.5°, $[\alpha]_D +2.1^\circ$ (*c* 2.8 in

acetone, 14). The infrared spectra (chloroform solutions) of the active and racemic methyl ethyl esters were precisely superimposable.

Anal. Calcd. for $C_{12}H_{16}O_2Br_2$: C, 37.52; H, 4.20. Found: C, 37.74; H, 4.26.

Pyrolysis of the Active Monomethyl Ester to the meso-Anhydride.—A sample (0.225 g.) of (+)-VIIIb, $[\alpha]_D +1.5^\circ$, was heated at 185–190° for five minutes. The pyrolysis residue was cooled, made up accurately to a volume

of 10 cc. in acetone, treated with a pinch of Norit A and finally freed of charcoal by centrifugation. The solution was optically inactive, $\alpha +0.006 \pm 0.016^\circ$. (The precision of the readings was lower than usual in this case because the solution was faintly colored.) From 7.3 cc. of the polarimetry solution there was obtained 0.140 g. (94%) of the anhydride (VIb), m.p. 252–255°, alone or mixed with an authentic specimen.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF DELAWARE]

Isomerism in the Diels–Alder Reaction. III. The Bromination of the Diels–Alder Adduct, Norbornylene¹

BY HAROLD KWART AND LLOYD KAPLAN

RECEIVED NOVEMBER 13, 1953

The bromination of norbornylene yields two distinct dibromides, whose structures have been elucidated by dipole moment measurement and characterization of their dehydrobromination products. Some consideration is given to the path of reaction by which these structures are formed. The dehydrobromination reaction and the isomerization under the influence of electrophilic reagents also are discussed.

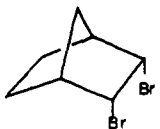
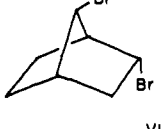
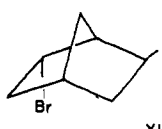
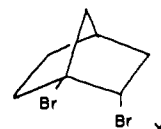
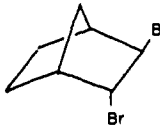
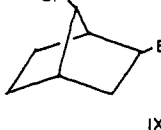
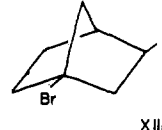
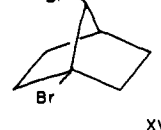
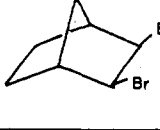
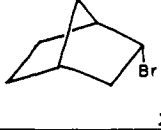
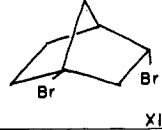
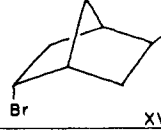
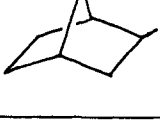
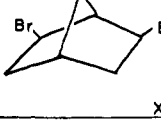
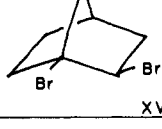
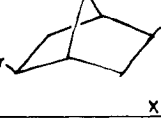
Introduction.—Previous studies² on the bromination of norbornylene, I (bicyclo[2.2.1]heptene-2), have shown that a complex mixture of products is obtainable, among which *exo*-norbornyl bromide II and 3-bromonorbornene III could be identified. The constitution of the dibromide products was not determined. We undertook to separate the components of the dibromide fraction and determine their structures in order to further our studies³ of the stereochemical course of addition reactions of the

double bond of bicyclic Diels–Alder adducts. We are reporting here the isolation of two pure dibromide products of this reaction and the structural assignments we have made thereto based on dipole moment measurements and chemical reactivity studies.

Discussion of Results

Designating the two dibromides as compounds A and B, respectively, Table I contains a summary of the dipole moment results as well as the calcu-

TABLE I. DIPOLE MOMENTS OF DIBROMONORCAMPHANES

Structure	μ calc'd.	Structure	μ calc'd.	Structure	μ calc'd.	Structure	μ calc'd.
	3.7 D		2.1 D		2.3 D		3.3 D
	2.0 D		2.0 D		2.3 D		2.8 D
	3.8 D		2.1 D		2.2 D		1.9 D
	3.9 D		2.3 D		3.3 D		1.9 D

Compound Observed Alternative configurations consistent with these moments
 A 2.3 D V, VIII, IX, X, XI, XII, XIII, XIV, XVIII, XIX
 B 3.5 D IV, VI, VII, XV, XVI

A C–Br bond moment of 2.0 D was used in calculating the above dipole moments (see reference 1b).

(1) The research work being reported here has been supported by the Office of Naval Research under contract N-onr-567(00).

(2) J. D. Roberts, E. R. Trumbull, Jr., W. Bennett and R. Armstrong, *THIS JOURNAL*, **72**, 3116 (1950).

(3) For the previous paper in this series see *ibid.*, **75**, 3356 (1953).

lated moments of all possible structures for comparison. On this basis a preliminary screening of the possible structures that could be assigned to A and B was obtained.