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263. Synthesis of Benzo-Homotriasterenedione[1])[2])

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(10. X. 74)

Zusammenfassung. Kondensation von 6,8-dimethoxycarbonyl-benzocycloheptan-7-on (4,5-Benzo-tropon-2,7-dicarbonsäure-dimethylester) (**4**)[4]) mit Aceton-dicarbonsäuredimethylester ergab 68% 1,5-Hydroxy, methoxy-2,4,6,8-tetramethoxycarbonyl-10,10a-benzo-9-oxa-10a-homo-adamant-10-en (**6**) und 17% des bekannten 3,7-Dihydroxy-4,8,2β,6β-tetramethoxycarbonyl-9,10-benzo-bicyclo[3.3.2]dec-3,7,9-triens (**7**). Hydrolyse und Decarboxylierung überführte den Tetraester **6** (wie schon für **7** beschrieben) in 9,10-Benzo-bicyclo[3.3.2]dec-9-en-3,7-dion (**9**). Aus den durch Spinsimulierung bestimmten ^{1}H-NMR.-Parametern wurde für **9** die Bevorzugung des Sessel-Sessel-Konformers **9cc** abgeleitet.

Bromierung des Diketons **9** mit vier Äquivalenten Brom lieferte 74% 1,5-Dihydroxy-2β,4β-6β,8β-tetrabrom-10,10a-benzo-9-oxa-10a-homoadamant-10-en (**10**). Die homoadamantoide Struktur von **10** war – wie schon früher bei ähnlichen Systemen – durch hydratisierende Cyclisierung des primär gebildeten Tetrabrom-diketons entstanden; sie offenbarte sich in der Abwesenheit

[1]) Some of these results have been communicated in a preliminary note [2], where a different numbering system and correspondingly different names have been used.

von Carbonylbanden im IR.-Spektrum, sowie im ^{1}H-NMR.-Spektrum, das auch die β-Konfiguration aller vier Bromatome zeigte (C_{2v}-Symmetrie).

Bromierung des Dieketons **9** mit vier Äquivalenten Phenyl-trimethyl-ammonium-tribromid lieferte nur 11% **10**, dafür aber 20% eines Äthoxy-dibromderivates (Verbindung **A**), aus dessen spektroskopischen Daten ein Argument für seine Struktur als $2\beta,10\beta$-Dibrom-6-äthoxy-9,9a-benzo-5-oxa-9a-homo-isotwist-9-en-3-on (**14**) abgeleitet wurde.

Durch Dehydrobromierung des Tetrabromids **10** mit Natriumäthylat in Äthanol oder mit Triäthylamin entstand (80 und 30%) $2\beta,8\beta$-Dibrom-10,10a-benzo-5-oxa-10a-homotwist-10-en-3,7-dion (**15**). Seine Struktur ergab sich aus den Spektraleigenschaften, insbesondere aus dem ^{1}H-NMR.-Spektrum, welches die C_2-Symmetrie und ein Argument für die β-Konfiguration der zwei Bromatome aufdeckte. Dieses Dehydrobromierungsverhalten des Tetrabromids **10** unter-

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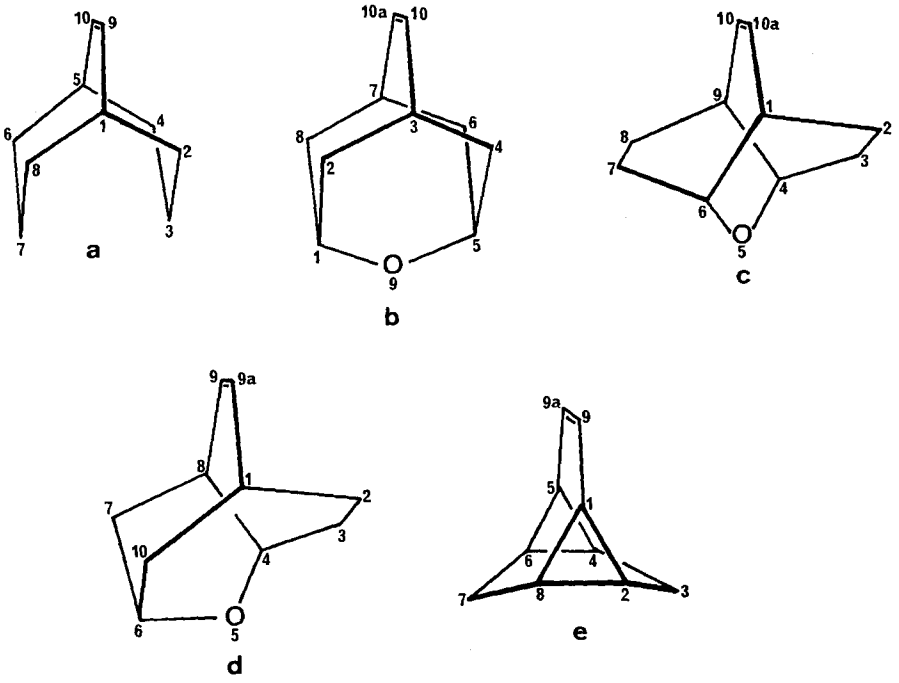
[2]) The tri- and tetra-cyclic compounds encountered in this work are derivatives of homologues of well known ring systems, namely of adamantane, twistane, isotwistane and triasterane. They are named on the basis of the trivial names preceded by the prefix 'homo' [1a] and are numbered accordingly [1b] as follows:



For each formula (**a** to **e**) the trivial name used in this paper is given below, together with the systematic name in the polycyclo-nomenclature [1c], for which the numbering is self-evident.

a: bicyclo[3.3.2]dec-9-ene

b: 9-oxa-10a-homoadamant-10-ene ≡ 7-oxa-tricyclo[4.3.1.1^{4,8}]undec-2-ene

c: 5-oxa-10a-homotwist-10-ene ≡ 8-oxa-tricyclo[5.4.0.0^{4,9}]undec-2-ene

d: 5-oxa-9a-homo-isotwist-9-ene ≡ 2-oxa-tricyclo[4.4.1.0^{3,9}]undec-7-ene

e: 9a-homotriaster-9-ene ≡ tetracyclo[3.3.2.0^{2,8}.0^{4,6}]dec-9-ene

[3]) Post-doctoral fellow 1972–1974.

[4]) The name in brackets is not correct and only mentioned for correlation with earlier related publications, particularly [5] [6].

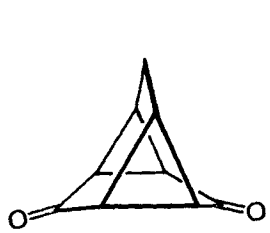
scheidet sich von demjenigen ähnlicher Tetrabromide, welche nur einen Kohlenstoff in der kleinsten Brücke des bicyclischen Systems tragen und welche unter solchen Bedingungen in Triasteranderivate überführt werden.

Ein Mechanismus, welcher nach Quaternisierung der Carbonylkohlenstoffatome in bicyclischen Systemen dieser Art besonders leichte intramolekulare S_N2-Reaktionen postuliert, kann zur Erklärung der Bildung von **14** (*Schema 1*) und auch von **15** (*Schema 2*) zugezogen werden.

Das Ziel, ein Homotriasteransystem zu bilden, wurde schliesslich durch Erhitzen des Tetrabromids **10** mit Kupferpulver (Debromierung) erreicht. Es entstand 40% von 9,9a-Benzo-9a-homotriaster-9-en-3,7-dion (**5**), neben (erstaunlicherweise auch unter diesen Bedingungen) 12% des Dibrom-oxa-homotwisten-Derivates **15**.

1. Introduction. – Recent work [3] [4] on the synthesis of triasteranedione (**1**) and triasteranetrione (**2**) has stimulated our interest in homotriasterane[2]) (**3**). The readily available 6,8-dimethoxycarbonyl-benzocycloheptan-7-one (4,5-benzo-tropone-2,7-dicarboxylic acid dimethyl ester) (**4**)[4]) [5] (*cf.* [6]) seemed to offer a synthetic pathway for benzo-homotriasterenedione (**5**) similar to that used [4] for the synthesis of **2**. The present paper describes our experience in the preparation of **5**, including the isolation of certain derivatives of benzo-oxa-homoadamantane, benzo-oxa-homotwistene and benzo-oxa-homo-isotwistene[2]).

2. Synthesis of 9,10-benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione (9). – Treatment of 4,5-benzo-tropone-2,7-dicarboxylic acid dimethyl ester (**4**), [5] [6] with one mol-equivalent of acetone-dicarboxylic acid dimethyl ester and a catalytic amount of sodium methoxide in methanol yielded 68% of 1,5-hydroxy, methoxy-2,4,6,8-tetramethoxycarbonyl-10,10a-benzo-9-oxa-10a-homoadamant-10-ene[2]) (**6**), mp. 156°,



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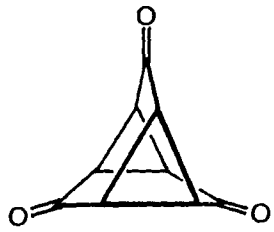

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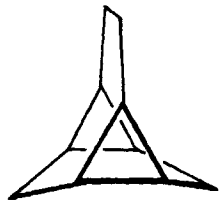

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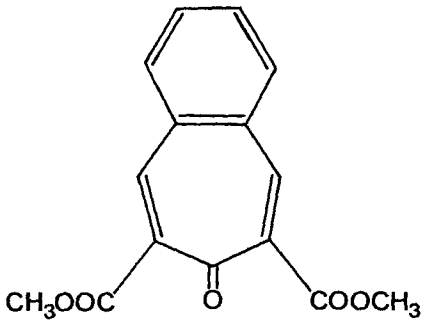

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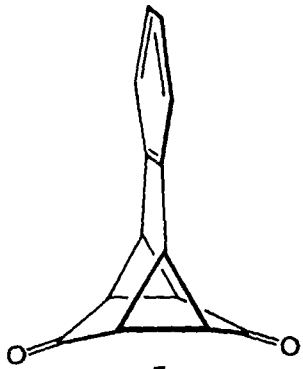

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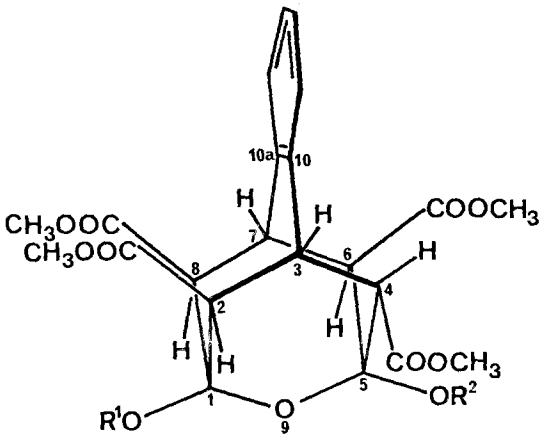
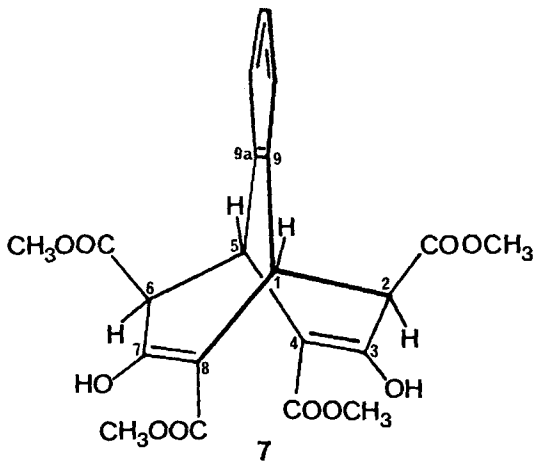


6

R^1, R^2 = H, CH_3



7

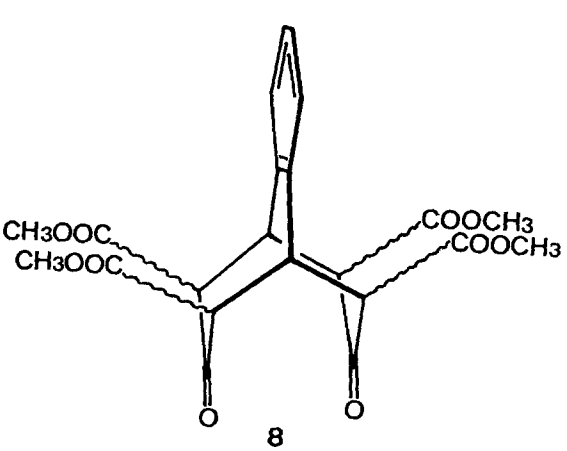
and 17% of 3,7-dihydroxy-4,8,2β,6β-tetramethoxycarbonyl-9,10-benzo-bicyclo-[3.3.2]dec-3,7,9-triene (**7**)[5], mp. 170°, which were separated by fractional crystallisation. The latter compound **7** was found to be identical, by spectral properties and melting point, with a product recently reported [7] to have been formed in about 50% yield directly from *o*-phthaldialdehyde and 2 equivalents of acetone-dicarboxylic acid dimethyl ester with diethylamine in ethanol. In addition to the reported properties, elemental analysis and the mass spectrum (M^+ 446 m/e) indicate a molecular formula of $C_{22}H_{22}O_{10}$. The IR.-spectrum shows absorptions for two ester carbonyl groups (1755 and 1745 cm^{-1}) and one for the two enolised β-keto ester groups (1650 cm^{-1}). The ^{1}H-NMR.-spectrum [7] shows the C_2-symmetry, since it contains only two singlets for the four methoxycarbonyl groups and only two doublets for H–C(1)/H–C(5) and H–C(2)/H–C(6). The two methoxycarbonyl groups at C(2) and C(6) have, therefore, the same configuration. We suggest that it is the β-configuration because the coupling between the two doublets is 4.5 Hz, which corresponds to the value expected from the dihedral angle in a stereomodel if H–C(2) and H–C(6) are each in the α-configuration.

The structure of the major product mentioned above, the oxa-homoadamantane derivative **6**, was deduced from its properties as follows: Elemental analysis and the mass spectrum (M^+ 478 m/e) correspond to a molecular formula of $C_{23}H_{26}O_{11}$, which contains the elements of methanol in excess of the expected 2,4,6,8-tetramethoxycarbonyl-9,10-benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione (**8**). (Compound **8** has been shown [7] to exist predominantly in the enol form **7** and this dienol **7** is, in fact, the other product isolated from the present reaction.) That methanol has been added is evident from the ^{1}H-NMR.-spectrum, which contains five methoxy signals (δ = 3.88, 3.78, 3.54, 3.50 and 3.42 ppm), one in excess of the expected number for four methoxy-

[5] For the tri- and tetra-cyclic compounds encountered in this work, we shall call that side of the eight-membered ring which lies *cis* to the bridge carrying the benzene ring, the β-side and that *trans* to this bridge the α-side.

carbonyl groups in different environments. The IR.-spectrum (Nujol) indicates the presence of two different types of carbonyl group (1743 and 1722 cm^{-1}) and a hydroxy group (3570, 3500 and 3180 cm^{-1}) but the absence of a double bond. The ^{1}H-NMR.-spectrum also exhibits three one-proton signals ($\delta = 4.14$, 4.02 and 3.65 ppm), which can be attributed to H–C^4 [6]) in benzylic or vicinal-to-carbonyl positions. (The presence of other signals under the strong methoxy absorptions at $\delta = 3.88$–3.42 ppm cannot be excluded.) The evidence suggests that an addition of methanol has occurred by a cycloketalisation across the two carbonyl groups of **8** to give the benzo-oxa-homoadamantane skeleton **6**. This is not surprising in view of the proximity of the two carbonyl groups. In fact, oxa-adamantanes have been obtained under similar conditions in the course of triasterane-3,7-dione (**1**) synthesis [3] (*cf.* also ref. in footnote 7). A possible interpretation of the ^{1}H-NMR.-spectrum corresponds to the parameters expected for the 2β,4α,6β,8β-tetramethoxycarbonyl stereomer[5]) of **6**, in which case the three visible H–C^4 signals may be assigned as follows: $\delta = 4.14$ (H–C(4) or H–C(7)); 4.02 (H–C(2) or H–C(8)) and 3.65 ppm (H–C(8) or H–C(2)); the other three H–C^4 signals are then assumed to be hidden under the strong methoxy signals.

When the above mentioned *Michael* reaction was performed in ethanol as solvent (*cf.* [7]) 3,7-dihydroxy-4,8,2β,6β-tetramethoxycarbonyl-9,10-benzo-bicyclo[3.3.2]-dec-3,7,9-triene (**7**) was the only product obtained (76% yield). The failure of the ethoxy group to initiate the cycloketalisation to the benzo-oxa-homoadamantene system might be due to its greater bulk, as compared to the methoxy group.



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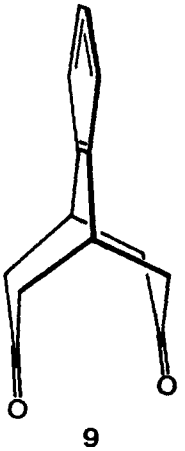


9

The hydrolysis and decarboxylation of the triene **7** to 9,10-benzo-bicyclo[3.3.2]-dec-9-ene-3,7-dione (**9**) was carried out according to the procedure of *Föhlisch et al.* [7]. Treatment of 1,5-hydroxy,methoxy-2,4,6,8-tetramethoxycarbonyl-10,10a-benzo-9-oxa-10a-homoadament-10-ene (**6**) in an acetic acid/hydrochloric acid mixture also gave the same product **9** in a yield of 80%. In addition to the properties already

[6]) We use the symbol C^4 for quadriligant carbon atoms.

reported [7] the mass spectrum (M^+ 214 m/e) and elemental analysis indicate a molecular formula of $C_{14}H_{14}O_2$[7]).

The 100 MHz-^{1}H-NMR.-spectrum of **9** contains a singlet at $\delta = 7.30$, a multiplet at 3.5–3.2 and another multiplet at 3.1–2.5 ppm, the three signal groups in the intensity ratio of 2:1:4. The two latter signal groups, in the 3.5–2.5 ppm range (*cf.* fig. 1), can be interpreted fully as an A_2B_2M-system. The following parameters permitted the simulation of this spin system: $\nu(A) = 274.8$, $\nu(B) = 288.2$, $\nu(M) = 335.4$ Hz and $J(AB) = 15.4$, $J(AM) = 4.6$, $J(BM) = 4.2$ Hz. The excellent agreement of the simulated spectrum with that observed are shown in fig. 1.

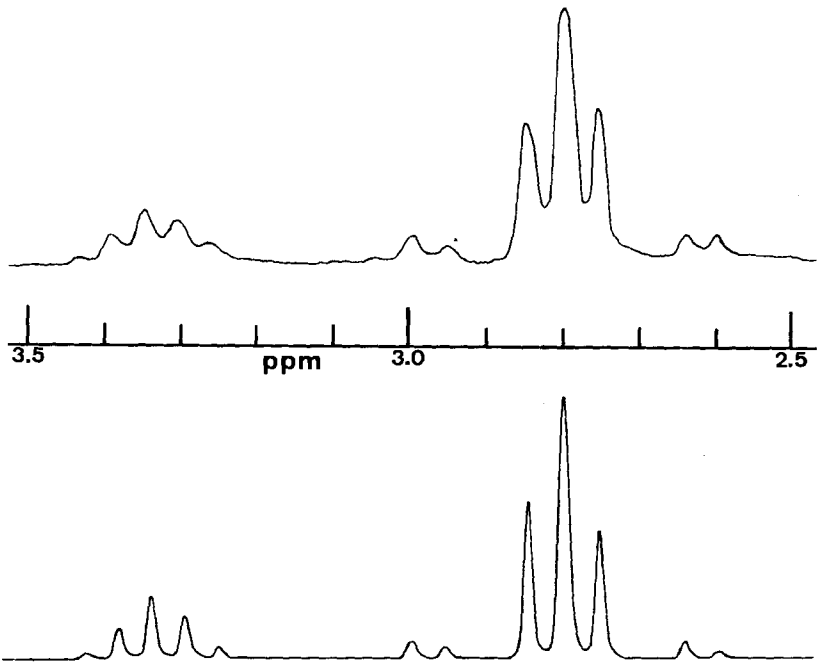


Fig. 1. Top: *100 MHz-^{1}H-NMR.-spectrum of 9,10-benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione* (**9**) *in* $CDCl_3$. Bottom: *Spin-simulated spectrum of the* A_2B_2M-*system*

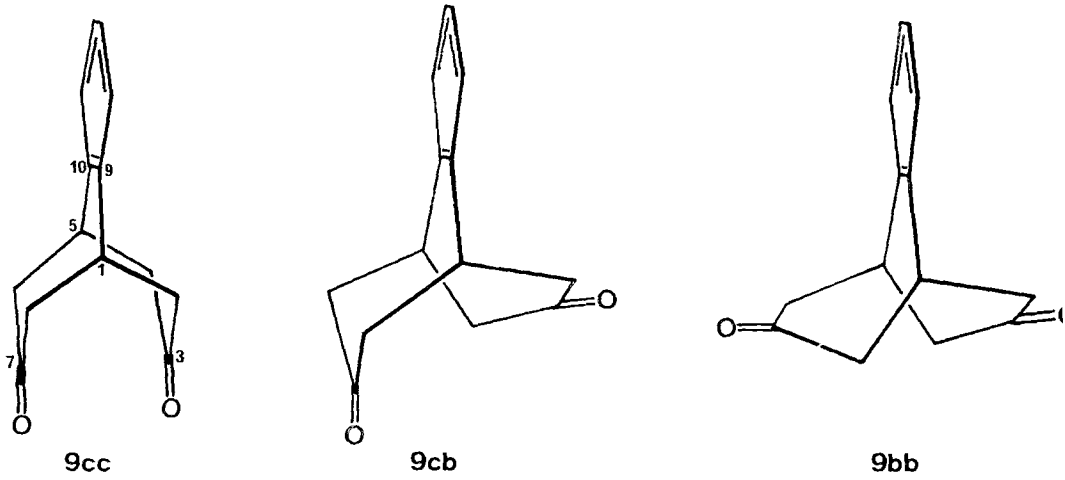
This analysis of the ^{1}H-NMR.-spectrum confirms the constitution of **9** as follows: The four hydrogen atoms on the aromatic ring produce the singlet at $\delta = 7.30$ ppm and the aliphatic hydrogen atoms (there are 10 in the molecule) give rise to two identical five-proton (A_2B_2M)-systems, which are isolated from each other by the two carbonyl groups and the phenylene bridge. The M-signal is due to the two benzylic hydrogen atoms (H(benzyl)), the A-signal comes from one type of the methylene hydrogen atoms vicinal to the carbonyl groups and the B-signal from the other type. Which type of methylene hydrogen atom, H(α) or H(β), is responsible

[7]) Since the completion of this work more details on the diketone **9** have been reported, see *B. Föhlisch, V. Dukek, I. Graessle, B. Novotny, E. Schupp, G. Schwaiger & E. Widmann,* Liebigs Ann. Chem. *1973,* 1839.

for which signal of the A,B-pair cannot be deduced from the chemical shifts nor from the coupling constants, since both are very similar.

The above features of the ^{1}H-NMR.-spectrum are consistent with a C_{2v}-symmetry of **9**, which makes the front and the back (twice A_2B_2M-system) as well as the two sides (A_2 and B_2) of the molecule (at least dynamically) equivalent. The ^{1}H-NMR.-spectrum was found to remain essentially unchanged over a temperature range from $-60°$ (in $CDCl_3$) to 160° (in $C_6H_5NO_2$). Care should be taken to exclude water from the NMR.-sample tube as this was found to produce the hydrate of the diketone **9** (*cf.* ref. in footnote 7).

3. Conformation of 9,10-benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione (9). – The above NMR.-observations also permit the deduction of the preferred conformation of the bicyclic ring-system **9**. Three conformers, free of angle strain, can be populated by molecules of **9**, the fairly rigid chair-chair-(**9cc**) and chair-boat-(**9cb**) conformers as well as the boat-boat-(**9bb**) conformer family.



9cc **9cb** **9bb**

The independence of the magnetic effects over a 220° temperature range is consistent with the molecules of **9** either very strongly preferring a single conformer or their moving very rapidly between several conformers; the symmetry aspects (C_{2v}) require the single conformer to be the chair-chair-conformer (**9cc**) or that the several conformers be either the boat-boat-family (**9bb**) or all three conformers (**9cc**, **9cb** and **9bb** family).

The chemical shifts of the two types of methylene hydrogen atoms (H(α) and H(β)[5]) vicinal to carbonyl give no information on the preferred conformation, since the hydrogen atoms in these two sites (α and β) are different in any case so that the observed closeness of their chemical shifts ($\Delta\delta = 0.13$ ppm) must be due to an accidental (and at present hardly predictable) similarity of their magnetic sites.

However, the similarity of the coupling constants ($J = 4.2$ and 4.6 Hz) of H(α) and of H(β) with H(benzyl) permits an interpretation in favour of the preference of the chair-chair-conformer (**9cc**), because the range of torsional angles of H(benzyl) with H(α) and with H(β) in a family of conformers which includes a boat form of

the seven-membered rings (**9cb** and **9bb**) cannot possibly be such as to lead to almost equal coupling constants. In the chair-chair-conformer, on the other hand, the torsional angles of H(benzyl) with H(α) and with H(β) are almost equal ($\sim$60°) if the seven-membered rings are slightly flattened by intra-annular bond angle expansion[8]). It is concluded, therefore, that the molecules of **9** exist primarily as the chair-chair conformer (**9cc**)[9]).

Recent evidence for the conformational preferences of the bicyclo[3.3.2]decane system include: 1) Molecular strain calculations [8] predict for the hydrocarbon a slightly greater stability of the chair-boat-conformer over the chair-chair-conformer ($\Delta\Delta H$ = 0.5 kcal/mol) and a lesser stability of the boat-boat-conformer by about 2.5 kcal/mol. 2) The same calculations [8] suggest that the chair-chair-conformer must be slightly twisted to avoid the close proximity of H(*endo*)–C(3) to H(*endo*)–C(7) in the conformation with C_{2v}-symmetry. 3) High frequency C–H bands in the hydrocarbon and some simple derivatives are interpreted [9] in terms of a preferred chair-chair- or (according to point 1 less likely) boat-boat-conformer. 4) NMR.-data show [10] the 3 *exo*-hydroxy-derivative to exist as the chair-chair-conformer. 5) ESR.-hyperfine splitting constants of the 9,10-semidione fit [11] for the chair-boat-conformer. All this information is rationalised [9] by postulating that the intrinsically more stable chair-chair-conformer is destabilised by any forced eclipsing of the C(1),C(9)- and C(5),C(10)-bonds, which causes a resistance to the twisting away from the C_{2v}-structure, so that the repulsive interaction between the *endo*-substituents at C(3) and C(7) suffices to flip one ring over to the boat form.

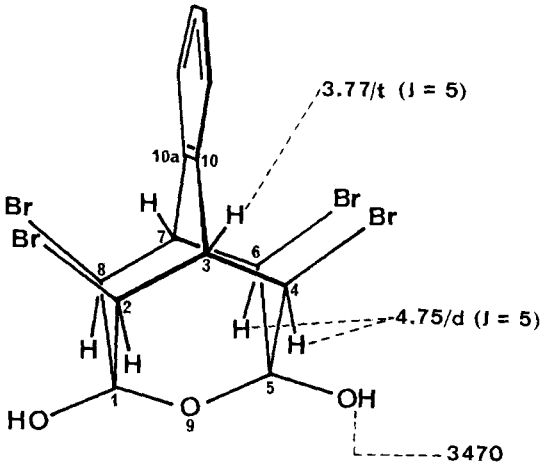
In our bicyclo[3.3.2]decane derivative **9** the forced eclipsing of the C(1),C(9)- and the C(5),C(10)-bonds is also present; but it does not induce a preference for the chair-boat-conformer, presumably because of the absence of the chair-chair destabilizing interaction around C(3) and C(7), which in this case are only triligant.

4. Brominations of 9,10-benzo-bicyclo[3.2.2]dec-9-ene-3,7-dione (9). – The bromination of **9** with four equivalents of bromine in acetic acid yielded 74% of 1,5-dihydroxy-2β,4β,6β,8β-tetrabromo-10,10a-benzo-9-oxa-10a-homoadamant-10-ene[2])[5]) (**10**), m.p. 233° dec. The product is a tetrabromide of composition $C_{14}H_{12}Br_4O_3$ as shown by elemental analysis and mass spectrum (M^+ 552/550/548/546/544 m/e), *i.e.* it contains the elements of water in excess of the expected product of simple tetrabromination of **9**. The IR.-spectrum exhibits no carbonyl absorption, but a strong hydroxy band (3470 cm^{-1}). That each methylene carbon atom of **9** (C(2), C(4), C(6) and C(8)) has been attacked by one bromine atom and that all four bromine atoms possess the same configuration (C_{2v}-symmetry) can be seen in the ^{1}H-NMR.-spectrum where four hydrogen atoms give rise to a single doublet (J = 5 Hz) at a field (δ = 4.75 ppm) characteristic for hydrogen atoms geminal to bromine atoms. The two benzylic hydrogen atoms (H–C(3) and H–C(7)) appear as a triplet (J = 5 Hz) at δ = 3.77 ppm. The β-configuration[5]) is assigned to the four bromine atoms because of the similarity of the ^{1}H-NMR.-data for H–C(Br) (δ = 4.75 ppm, J with H(benzyl) =

[8]) This is the same ring flattening which was held responsible for the *difference* in the coupling constants of H(angular) with H(α) and with H(β) in two bicyclo[3.3.1]nona-3,7-dione systems [3] [4].

[9]) This conclusion is in contrast to that drawn in the paper mentioned in footnote 7, where the argument is based on the chemical shifts of H(α) and H(β).

5 Hz) with the corresponding values found previously [3] for $2\beta,4\alpha,6\beta,8\beta$-tetrabromo-3,7-dihydroxy-10-oxa-adamantane where H–C(2) and H–C(8) also have the α-configuration and are *syn*-diaxial on an oxane ring (δ = 4.76 and 4.52 ppm, J with H(benzyl) = 2 and 1.7 Hz). The larger coupling (5 Hz) in the present case (homo-adamantane system, **10**) as compared to the adamantane system (~2 Hz) is due to the extra atom (C(10a)) in the bridge which causes flattening of both oxane rings with a consequent decrease of the torsional angle and increase in coupling between Hα–C(Br) and H(benzyl) (*cf.* discussion in section 3). The spectral data and their interpretations are summarised on the following formula for **10**.



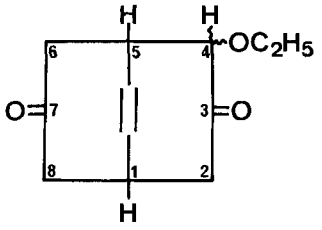
10

It is of interest that the parent diketone **9** can be isolated under the same conditions as **10** without having undergone hydration (*cf.* ref. in footnote 7). The presence of the bromine atoms on both sides of both carbonyl groups may sufficiently enhance the electronegativity of the latter in the intermediate tetrabromo-diketone **9** as to facilitate the formation of the hydrated form, which cyclises spontaneously to the oxa-homoadamantene system **10**. This phenomenon was also experienced in the intermediate bromination products during the synthesis of triasterane-3,7-dione (**1**) [3].

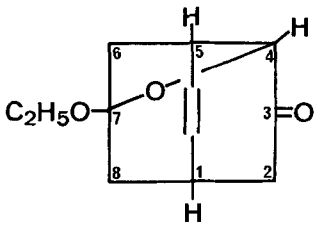
When, on the other hand, the bromination of **9** was performed with 4.5 equivalents of phenyl-trimethyl-ammonium tribromide (PTT) in methylene chloride, followed by aqueous working up, only 11% of the tetrabromide **10** was isolated from the crude reaction product. Chromatography of the rest yielded colourless plates, m.p. 206° (20%), consisting of a product **A** which persistently retained a minor impurity. The impurity manifested itself by extremely weak peaks in the mass spectrum at M^+ 498/496/494/492 m/e (1:2:2:1) and by slightly high bromine- and low carbon-hydrogen-analyses (see experimental). This impurity must, therefore, be a tribromoderivative of **9**; it is present to the extent of less than 5% since the ^{1}H-NMR.-spectrum showed no signals except those interpretable as belonging to the major product **A**, next described.

The strong M^+ peak in the mass spectrum at 418/416/414 m/e (1:2:1) and the elemental analysis showed *compound* **A** to be a dibromide of molecular formula

$C_{16}H_{16}Br_2O_3$. The structure assigned is based on the following: Compound **A** contains an ethoxy group as shown by the ^{1}H-NMR.-spectrum with its triplet at $\delta = 1.30$ and quartet at 3.75 ppm (both $J = 7$ Hz), the latter being mixed with another signal (see below). The ethoxy group must be due to a reaction with ethanol contained in the chloroform used in the chromatography on neutral alumina. To obtain the molecular formula of **A** one must envisage tribromination of **9** followed by replacement of one of the bromine atoms by an ethoxy group. The replacement could occur in one of two ways: a) by direct substitution leading to a structure of type **11** or b) by attack of the ethoxy group at one of the carbonyl groups and intramolecular substitution of one of the bromine atoms by C_2H_5O–C–O$^-$ leading to a structure of type **12**.



11

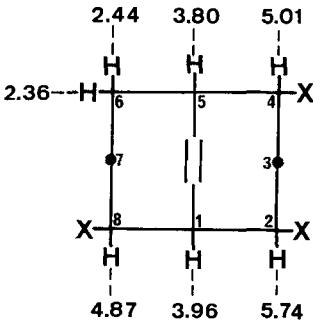


12

With H_2, HBr, HBr at any of the positions 2, 6 and 8 (To facilitate comparison the numbering of **12** follows that of **11**)

In a first approximation the ^{1}H-NMR.-spectrum of compound **A** accords with both constitutions **11** and **12** as follows: Aside from the above mentioned signals for the ethoxy-hydrogen atoms, there is a four-proton multiplet ($\delta = 7.4$–7.0 ppm) of the aromatic hydrogen atoms, two one-proton signals ($\delta = 3.96$ and 3.80 ppm) of the benzylic hydrogen atoms (the latter superimposed on, but separable from, the ethoxy-CH_2 signal), a two proton AB-signal ($\delta = 2.44$ and 2.36 ppm, $J = 12$ Hz) of non-equivalent geminal hydrogen atoms and three one-proton signals ($\delta = 5.74$, 5.01 and 4.87 ppm) of hydrogen atoms geminal to oxygen or bromine atoms.

This information is expressed in the partial formula **13**, which represents both ring systems **11** and **12** (in the case of **11**, any of the three X could be ethoxy, in the

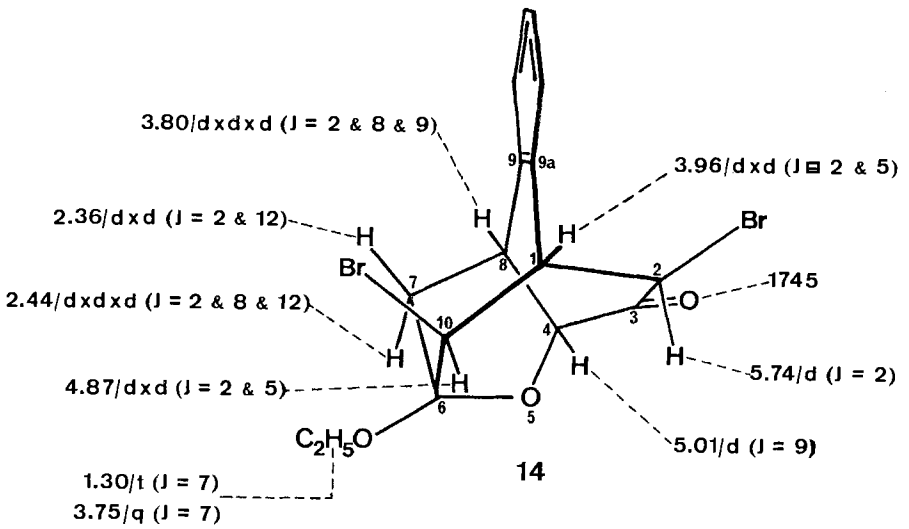


13

3 X = 2 Br and 1 OR

case of **12**, X–C(2) or X–C(4) would be an ether bridge to C(7)). Since the $\delta = 3.96$ ppm signal shows only two couplings ($J = 2$ and 5 Hz) it is assigned to the benzylic hydrogen atom H–C(1), which has only two neighbours, namely H–C(2) with $\delta = 5.74$ ppm ($J = 2$ Hz) and H–C(8) with $\delta = 4.87$ ppm ($J = 5$ Hz). This leaves the $\delta = 3.80$ ppm signal with its three couplings ($J = 2$, 8 and 9 Hz) for the other benzylic hydrogen atom H–C(5), which indeed has three neighbours, namely H–C(4) with $\delta = 5.01$ ppm ($J = 9$ Hz) on one side, and the two geminal ($J = 12$ Hz) hydrogen atoms H_2–C(6) with $\delta = 2.36$ ($J = 2$) and 2.44 ppm ($J = 8$ Hz) on the other. The hydrogen atoms which give rise to the $\delta = 4.87$ ppm and the $\delta = 2.44$ ppm signals are placed on the same side of the ring system (in **13** on the left) because there is a coupling of 2 Hz between them, which is interpreted as a W-coupling. A W-arrangement is only possible between H–C(8) and one of the hydrogen atoms at C(6) ($\delta = 2.44$ ppm) if both of them are in the α-configuration (see also later).

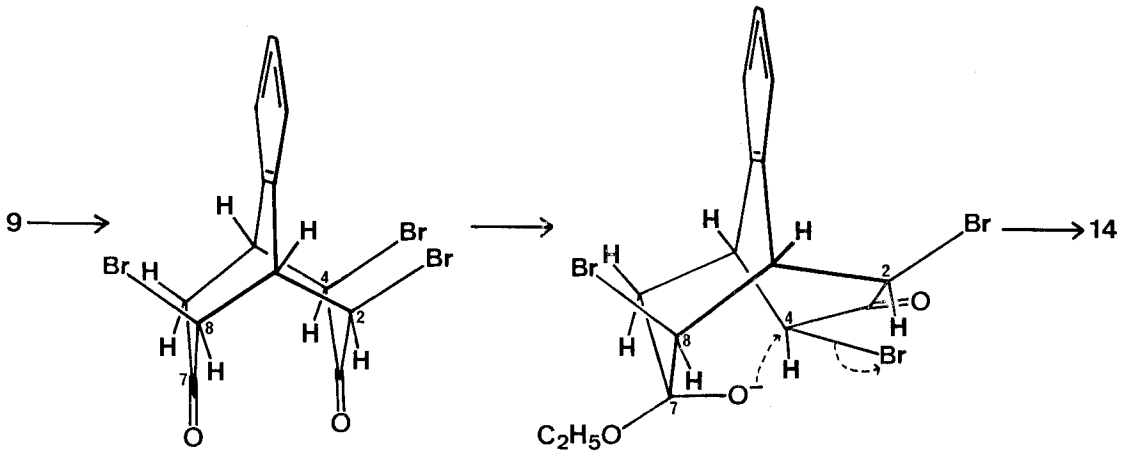
A choice between the two constitutions **11** and **12**, in favour of the latter (**12**), is made possible by focussing attention on the following structural differences: Constitution **11** is that of the 4-ethoxy derivative of 9,10-benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione (**9**); it has two different carbonyl groups and the couplings at its two benzylic hydrogen atoms with their vicinal neighbours (whatever their configurations) would be expected to be similar to those in **9**, namely about 4–5 Hz. Constitution **12**, on the other hand, has only one carbonyl group and encompasses a rigid five-membered ring with three *cis*-located vicinal hydrogen atoms (H–C(4), H–C(5) and Hα–C(6)), for which two relatively large couplings would be expected. The pertinent observations are that compound **A** exhibits: a) a single relatively sharp and not very strong C=O absorption in the *IR.*-spectrum and b) two relatively large couplings ($J = 9$ and 8 Hz) seen in the $\delta = 5.01/3.80$ and the 3.80/2.44 ppm signal pairs. Both these observations support the **12**-version of formula **13**. Combination with formula **13** fixes the two bromine atoms at C(2) and C(8) of **12**. Both must have the β-configuration, since H–C(8) has already been shown to be in the α-con-



figuration, and the coupling of 2 Hz between H–C(2) and H–C(1) also fits best for the α-configuration of H–C(2). Compound **A** is, therefore, concluded to be 2β,10β-dibromo-6-ethoxy-9,9a-benzo-5-oxa-9a-homo-isotwist-9-ene-3-one (**14**). Its spectroscopic data are summarised in the formula (p. 2430).

Structure **14** must have arisen from a 2β,4β,8β-tribromodiketone by the above mentioned intramolecular S_N2 replacement of the 4β-bromine atom by C_2H_5O–C(7)–$O^{\ominus}$ from the α-side (see *Scheme 1*). The β-configuration of all three bromine atoms in the intermediate PTT-tribromination product correlates with the observation that all four bromine atoms in the bromine-tetrabromination product **10** are in a β-configuration.

Scheme 1



5. Dehydrobromination of 1,5-dihydroxy-2β,4β,6β,8β-tetrabromo-10,10a-benzo-9-oxa-10a-homoadamant-10-ene (10). – Treatment of **10** with sodium ethoxide in ethanol gave 2β,8β-dibromo-10,10a-benzo-5-oxa-10a-homotwist-10-ene-3,7-dione (**15**) in 80% yield, as colourless prisms m.p. 236°. This same product was obtained in 31% yield when the tetrabromide **10** was treated with triethylamine in tetrahydrofuran. Its structure was derived from its properties as follows:

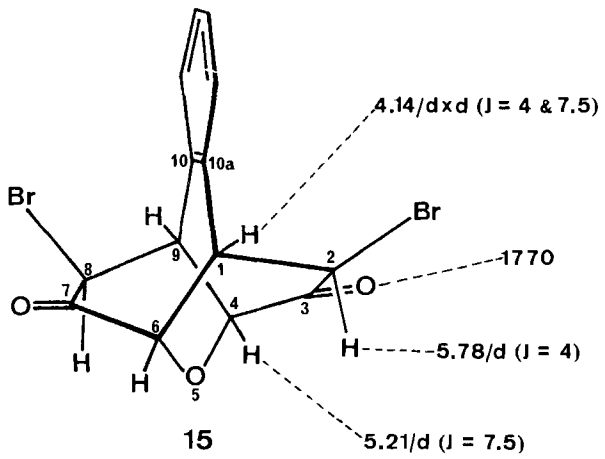
Elemental analysis and the mass spectrum (M^+ 338/336/334 m/e) indicate a dibromide of molecular formula $C_{14}H_{10}Br_2O_3$. The IR.-spectrum shows a carbonyl absorption at 1770 cm^{-1} ($CHCl_3$). The presence of an acid or ester can be ruled out from the ^{1}H-NMR.-spectrum (no –OH or $-OC_2H_5$ signals), leaving as possible functions for the three oxygens: a) two ketones and an ether, b) a lactone and a ketone, c) a lactone and an ether or d) an anhydride. Since there is only one carbonyl absorption in the IR.-spectrum, since the mass spectrum shows fragment peaks $M^+ - Br - CO$ and $M^+ - Br - 2 \times CO$, and since the ^{1}H-NMR.-spectrum reflects structural symmetry (see below), the product **15** must have two keto-groups and an ether-function. The relatively high frequency of the carbonyl absorption in the IR.-spectrum will be rationalised further below.

The ^{1}H-NMR.-spectrum brings to light the two-fold symmetry (C_2) in **15**: The signal of the four aromatic protons appears at $\delta = 7.22$ ppm as a singlet and each of

the three remaining signal groups represent two protons each. The low field doublet (δ = 5.78 ppm, J = 4 Hz) is assigned to the hydrogen atoms geminal-to-bromine, namely H–C(2) and H–C(8). This chemical shift is similar to the one which had been observed [4] for axial hydrogen atoms vicinal to a carbonyl oxygen, geminal to a bromine and also close to an ether oxygen atom. The doublet at δ = 5.21 ppm (J = 7.5 Hz) is attributed to the two hydrogen atoms (H–C(4) and H–C(6)) which are vicinal to a carbonyl oxygen and geminal to the ether oxygen atom. The remaining signal at 4.14 ppm (double doublet, J = 4 and 7.5 Hz) must belong to the two benzylic hydrogen atoms, H–C(1) and H–C(9). From a stereomodel of **15** it is possible to estimate a torsional angle of ~60° between H–C(1) and H–C(2) or H–C(9) and H–C(8), whatever the configurations of the bromine atoms at C(2) and C(8), (Fig. 2a) and one of ~23° between H–C(1) and H–C(6) or H–C(9) and H–C(4) (Fig. 2b). The

Fig. 2. *View along the C(1), C(2)- or C(9), C(8)-bond (a) and the C(1), C(6)- or C(9), C(4)-bond (b) of 2β,8β-dibromo-10,10a-benzo-5-oxa-10a-homotwist-10-ene-3,7-dione* (**15**)

expected couplings of 3–4 Hz and of 7–9 Hz are in fair agreement with those found in the signals of H–C(2)/H–C(8) and of H–C(4)/H–C(6). Since the former value does not give any information concerning the configuration of the bromine atoms another argument is presented further below. The ^{1}H-NMR.-parameters of **15** are interpreted on the following structure:

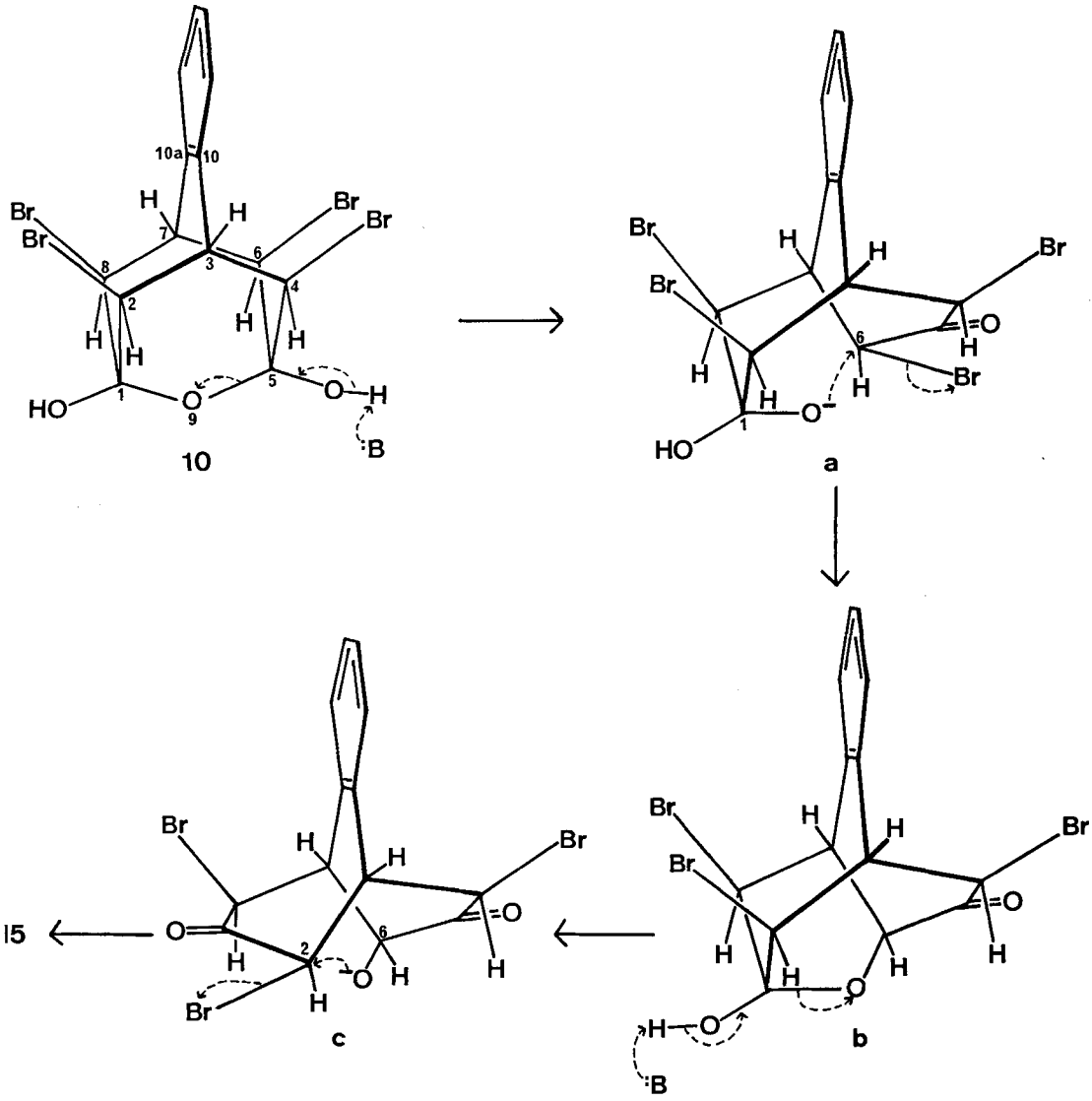


15

The assignment of structure **15** to our product on the basis of the evidence presented receives support from the plausibility of a proposed mechanism illustrated in *Scheme 2*. Molecular models indicate that the intermediates and transition states, shown there, are not highly strained. The base abstracts a proton from a hemiketal hydroxy group (*e.g.* HO–C(5)) thus opening the dihydroxy-oxa-homoadamantene system **10** and permitting the *gem.*-diolate anion at C(1) to closely approach the rear side of the C(6)–Br bond by flipping the cycloheptenone ring into a twist boat con-

Scheme 2

(for convenience all intermediates numbered as in **10**)



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formation (**a**). S_N2 reaction (**b**) followed by a similar hemiketal opening of the hydroxy-oxa-homo-isotwistene system, flipping of the other cycloheptenone ring into a twist boat conformation (**c**) and transannular S_N2 reaction of the again favourably located C(6)-oxide anion with the C(2)–Br bond leads to **15**.

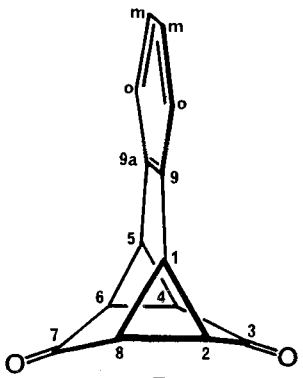
Providing no isomerisation has taken place, this mechanism leaves the remaining two bromine atoms in the original β-configuration. Such an isomerisation either did not occur at all or must have proceeded to completion at both H–C(2) and H–C(8) since both bromine atoms in **15** evidently have the same configuration (C_2-symmetry of the molecule). The former possibility is more likely, especially since the β-sites of **15** appear to offer more room for the bromine atoms. Only in the β-configuration is the bromine bond nearly coplanar with the carbonyl bond, which correlates with the above mentioned high frequency of the carbonyl absorption in the IR.-spectrum.

It is of interest that the reaction of triethylamine with the tetrabromo-diketone **10** proceeds in a way differing from that experienced previously [3] [4] with similar tetrabromo-diketones (2,4,6,8-tetrabromo-bicyclo[3.3.1]nona-3,7-diones), where it produced double cyclopropanisations to give triasterane systems.

6. 9,9a-Benzo-9a-homotriaster-9-ene-3,7-dione (5). – Treatment of 1,5-dihydroxy-2β,4β,6β,8β-tetrabromo-10,10a-benzo-9-oxa-10a-homoadamant-10-ene (**10**) with excess copper powder at 150° under reduced pressure brought about sublimation of two compounds. One of these (12% yield) was identified as 2β,8β-dibromo-10,10a-benzo-5-oxa-10a-homotwist-10-ene-3,7-dione (**15**) by comparison of its spectroscopic data with those of the sample discussed in section 5. It is perhaps surprising that a dehydrobromination leading to **15** should occur under these conditions, which previously [3] [4] [12] have been found to produce only debrominative cyclopropanisation. It should be noted, however, that the mechanism proposed for the formation of **15**, in *Scheme 2*, does not require any external reagent except a *Lewis* base.

The second product, m.p. 238°, 30–40% yield, was shown to possess the composition $C_{14}H_{10}O_2$ by elemental analysis and mass spectrum (M^+ 210 m/e). In the MS.-fragmentation the loss of CO followed by that of a second CO can be seen. The IR.-spectrum suggests the presence of cyclopropane C–H (3050 cm^{-1}) and a carbonyl group (1685 cm^{-1}) (*cf.* [3]). The ^{1}H-NMR.-spectrum in $CDCl_3$ shows only two absorptions in the ratio 2:3. The multiplet at $\delta = 7.6$–7.2 ppm evidently belongs to the four aromatic hydrogen atoms, so that the high field singlet at $\delta = 2.92$ ppm must be due to six isochronous protons. With Eu(fod)$_3$ shift reagent, this spectrum is resolved into four signal groups with relative intensities of 1:1:2:1. This, together with the composition (10H) suggests a four fold symmetry. The two signals at $\delta =$ 8.0–7.8 and 7.6–7.4 ppm, which appear as an $AA'XX'$ system, are assigned to the aromatic hydrogen atoms. The doublet at $\delta = 5.15$ ppm ($J = 9$ Hz) belongs to the four hydrogen atoms vicinal to a carbonyl oxygen (H–C(2), H–C(4), H–C(6), H–C(8)) and the triplet at $\delta = 3.98$ ($J = 9$ Hz) is due to the benzylic hydrogen atoms (H–C(1), H–C(5)). The assignment of the 9,9a-benzo-9a-homotriaster-9-ene-3,7-dione structure (**5**) to this product, on the basis of the evidence presented, receives strong confirmation from the ^{13}C-NMR.-spectrum: The lowest field signal ($\delta = 195.7$/s) corresponds to the two carbonyl carbon atoms namely C(3) and C(7). The three signals in

the middle field group (δ = 133.1/*s*, 131.9/*d* × *d* and 128.1/*d* × *d*) correspond to the six aromatic carbon atoms (C(9) together with C(9a), 2 × C(*o*), 2 × C(*m*) respectively). The weak intensity of the δ = 133.1 ppm signal is due to the long relaxation time of carbon atoms which carry no hydrogen (C(9), C(9a)). The two signals in the high field group (δ = 39.1/*d* and 32.9/*d*) correspond to the six quadriligant carbon atoms (δ = 39.1 for C(2), C(4), C(6), C(8) and δ = 32.9 for C(1), C(5)) in the cyclopropane rings. The proton couplings shown in these two signals (39.1 ppm – J = 175.7 Hz,



5

32.9 ppm – J = 170 Hz) are also indicative of cyclopropane rings [13]. Although care must be exercised in basing assignments on the intensities of ^{13}C-NMR.-signals, it is worth noting that the three signals due to the non-aromatic carbon atoms (δ = 195.7, 39.1 and 32.9 ppm) have relative intensities of 1:2:1, which corresponds to the distribution expected for the C_{2v}-symmetry of **5**.

This work was supported by the *Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung* and by *Sandoz AG* Basel. We thank the members of our research team for interesting discussions on this problem and also Dr. *J. Tabony* for calculating the spin-simulation spectrum.

Experimental Part

General. – The indications given in [4] were adhered to apart from the following modifications or additions: *Working up.* The unqualified term 'dried' refers to the use of anhydrous magnesium sulfate, and 'petrol' refers to the fraction b.p. 40–60°. All compounds were examined for purity on thin layer chromatography (TLC.) plates prepared by *Macherey-Nagel* from silica gel N–HR/UV_{254}. For preparative layer chromatography (PLC.) *Merck* Kieselgel 60 F 254 plates were used. The medium used for column chromatography was *Woelm*'s aluminium oxide.

IR.-spectra as in [4]; *MS.-spectra* as in [4]; with the exception of the ions for which an interpretation can be offered, only the peaks above m/e = 90 with intensities higher than 5% or sometimes 15% are recorded. *^{1}H–NMR.-spectra* as in [4]. Unless described otherwise the spectra were subjected to first order analysis. The *spin-simulation spectrum* was obtained with a Varian 620 L computer. *^{13}C–NMR.-spectra* were measured on a *Varian* XL 100 instrument with *Fourier transform*, and are recorded as follows: (frequency and solvent): chemical shifts in ppm on the δ scale (TMS internal = 0)/multiplicity with *s* = singlet, *d* = doublet (splitting J in Hz), (interpretation). The carbon numbering corresponds to the formulae in the text.

We thank the MS.-laboratory (direction Prof. *M. Hesse*) for the mass spectra, the microlaboratory (direction *H. Frohofer*) for the elemental analyses and the IR.-spectra, and the NMR.-laboratory (direction Prof. *W. v. Philipsborn*) as well as Mr. *M. Karpf* for the NMR.-spectra.

Reaction of 6,8-dimethoxycarbonyl-bonzocycloheptan-7-one (**4**) *with acetone-dicarboxylic acid dimethylester.* – To a solution of 0.4275 g (1.57 mmol) of **4** [6], in 60 ml methanol, 0.0036 g (0.157 mmol) sodium metal was added. When the sodium had dissolved, a solution of 0.2734 g (1.57 mmol) acetone-dicarboxylic acid dimethyl ester in 10 ml methanol was added with stirring. After 60 h at room temperature a few ml of water were added and most of the methanol was removed under vacuum. The residual mixture was diluted with water, acidified with hydrochloric acid and extracted with chloroform. The combined extracts were washed with water, dried and evaporated leaving a solid residue. Fractional recrystallisation from chloroform/petrol permitted the separation of two products.

The less soluble fraction consisted of 0.511 g (68%) of *1,5-hydroxy, methoxy-2,4,6,8-tetramethoxycarbonyl-10,10a-benzo-9-oxa-10a-homoadamant-10-ene* (one isomer shown in **6**) as small colourless needles, m.p. 152–156°. – *IR.* (Nujol): 3570 w; 3500 w; 3180 w; 1743 s; 1722 s; 1210 s; 1200 m; 1180 s. (KBr): 3570 w; 3500 w; 3200 w; 2855 w; 1740 s; 1720 s; 1440 m; 1385 m; 1342 m; 1325 m; 1210 s; 1175 s; 1010 m; 980 m. – *MS.* (70 ev): 478 (9, M^+); 446 (44, $M^+ - CH_3OH$); 415 (24); 414 (29, $M^+ - 2 \times CH_3OH$); 387 (18); 386 (15); 354 (15); 346 (15); 345 (23); 315 (36); 314 (29); 313 (22); 287 (24); 281 (15); 274 (21); 273 (100); 255 (22); 244 (17); 242 (18); 241 (97); 225 (17); 223 (18); 213 (69); 202 (23); 186 (20); 183 (29); 173 (37); 171 (17); 155 (38); 152 (20); 143 (24); 142 (21); 141 (26); 140 (15); 139 (27); 129 (16); 128 (51); 127 (50); 126 (19); 115 (38); 101 (44). – ^1H*–NMR.* (100 MHz, $CDCl_3$): $\delta = 7.3$–$6.9/m$, 4 pr (aromatic H′ s); 5.64/broad *s*, 1 pr (OH); 4.14/*d* ($J = 6$), 1 pr; 4.02/*d* × *d* ($J = 2$ & 6), 1 pr; 3.88/*s*, 3 pr (OCH_3); 3.78/*s*, 3 pr (OCH_3); 3.65/*d* × *d* ($J = 2$ & 6), 1 pr; 3.54/*s*, 3 pr (OCH_3); 3.50/*s*, 3 pr (OCH_3); 3.42/*s*, 3 pr (OCH_3). One possible interpretation of this spectrum is that it belongs to the 2β,4α,6β,8β-tetramethoxycarbonyl stereomer **6**, in which case some of the H–$C^{4\,6}$) signals could be assigned as follows: $\delta = 4.14$/d ($J = 6$), 1 pr (H–C(4) or H–C(7)); 4.02/d × *d* ($J = 2$ & 6), 1 pr (H–C(2) or H–C(8)); 3.65/*d* × *d* ($J = 2$ & 6), 1 pr (H–C(8) or H–C(2)). The other three H–C^4 signals may be masked by the methoxy signals.

$C_{23}H_{26}O_{11}$ (478.438) Calc. C 57.74 H 5.48% Found C 57.46 H 5.72%

The more soluble fraction consisted of 0.1204 g (17%) of *3,7-dihydroxy-4,8,2β,6β-tetramethoxycarbonyl-9,10-benzo-bicyclo[3.3.2]dec-3,7,9-triene* (**7**) as colourless prisms, mp. 158–170.5° (identical with Lit. [7]). – *IR.* (Nujol): 1755 s; 1745 s; 1650 s; 1265 s; 1235 s; 1005 m; 870 m; 835 m; 730 m. – *MS.* (70 ev): 446 (14, M^+); 404 (19); 281 (16); 273 (75); 244 (15); 241 (60); 223 (25); 213 (70); 195 (25); 183 (40); 181 (18); 173 (18); 170 (15); 169 (15); 168 (25); 167 (23); 155 (45); 153 (23); 152 (50); 151 (27); 143 (30); 142 (32); 141 (22); 140 (28); 139 (80); 128 (45); 127 (100); 126 (47); 125 (25); 115 (55); 114 (33); 113 (23); 102 (24); 101 (80). – The NMR., identical with that reported in [7], can be interpreted to mean that it belongs to the 4,8,2β,6β-tetramethoxycarbonyl stereomer **7**, namely: $\delta = 4.48$ for H–C(1) and H–C(5), which couple with H–C(2) and H–C(6) ($\delta = 3.67$) with $J = 4.5$, and thus must be situated in α-positions. Furthermore the high field absorption of two carbomethoxy protons ($\delta = 3.25$) could be due to a shielding influence of the benzene ring on the β-side.

$C_{22}H_{22}O_{10}$ (446.396) Calc. C 59.21 H 4.97% Found C 58.89 H 4.69%

When the reaction was performed in ethanol only 3,7-dihydroxy-4,8,2β,6β-tetramethoxycarbonyl-9,10-benzo-bicyclo[3.3.2]dec-3,7,9-triene (**7**) was obtained, in 76% yield.

9,10-Benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione (**9**). – A solution of 1.00 g (2.09 mmol) of **6** (above) in 22 ml acetic acid and 6 ml concentrated hydrochloric acid was heated under reflux for 12 h. The solvent was removed under reduced pressure and the residue was trituated with water. Sublimation of the residue yielded 0.358 g (80%) of **9**, m.p. 188–194°; recrystallisation from acetonepetrol raised the m.p. to 196–199° (Lit. [7]) m.p. 199°, *IR.* identical as far as reported). – *MS.* (70 ev): 214 (59, M^+); 186 (25, $M^+ - CO$); 172 (33); 171 (22); 158 (16, $M^+ - 2 \times CO$); 157 (63); 144 (44); 143 (15); 141 (24); 130 (35); 129 (94); 128 (100); 127 (28); 116 (28); 115 (66); 102 (20); 91 (21). – ^1H*–NMR.* (100 MHz, $CDCl_3$): $\delta = 7.30/s$, 4 pr (aromatic H′ s); A_2B_2M system with the *M* part at $\delta = 3.5$–3.2 ($J_{AM} = 4$, $J_{BM} = 5$), 2 pr (H–C(1), H–C(5)); the B_2 part at $\delta = 3.1$–2.8 ($J_{BM} = 5$, $J_{AB} = 15$), 4 pr (Hβ–C(2), Hβ–C(4), Hβ–C(6), Hβ–C(8)); the A_2 part at $\delta = 2.8$–2.5 ($J_{AM} = 4$, $J_{AB} = 15$), 4 pr (Hα–C(2), Hα–C(4), Hα–C(6), Hα–C(8)).

This spectrum of **9** in $CDCl_3$ remained essentially unchanged when recorded down to $-60°$. *^1H—NMR.* (100 MHz, $C_6H_5NO_2$): The spectrum was the same as in $CDCl_3$ with only very slight changes in chemical shifts; it remained essentially unchanged when recorded up to $+160°$.

Additional signals, assigned to the hydrate of **9** (see ref. in footnote [7]), were observed when the NMR.-spectrum of **9** was measured in $CDCl_3$ without precautions to exclude moisture. These signals were: $\delta = 7.15/s$; 3.39–3.19/*m* (partly masked by the *M* part of diketone **9**); 2.19–1.76/*m*. These two multiplets resemble a MB_2A_2 system.

$C_{14}H_{14}O_2$ (214.252) Calc. C 78.48 H 6.59% Found C 78.60 H 6.79%

This diketone (**9**), m.p. 196–199°, was also prepared in 82% yield from **7** (above) by the method of *Föhlisch et al.* [7]. The product was shown by m.p., IR.-, MS.- and ^{1}H—NMR.-spectra to be identical with the sample described above.

1,5-Dihydroxy-2β,4β,6β,8β-tetrabromo-10,10a-benzo-9-oxa-10a-homoadamant-10-ene (**10**)[5]. To a stirred solution of 0.155 g (0.724 mmol) of **9** (above) in 10 ml glacial acetic acid a solution of 0.4636 g (2.896 mmol) bromine in 10 ml glacial acetic acid was added over 20 min. After 4 h the solvent was removed under reduced pressure to give 0.388 g of a yellow solid which, by recrystallisation from acetone and heating at 100° under vacuum to remove the acetone of crystallisation, afforded 0.292 g (74%) of **10** as a white powder, m.p. 231–233° (dec.). – *IR.* (KBr): 3550 w; 3470 s (broad); 3430 w; 1335 m; 1302 m; 1225 m; 1175 s; 1118 s; 988 m; 935 s; 838 s; 830 s; 740 s; 643 s. – *MS.* (70 ev): 552/550/548/546/544 (0.1/0.2/0.25/0.2/0.1, M^+); 534/532/530/528/526 (0.2/1.2/2/1.2/0.2, $M^+ - H_2O$); 389/387/385 (2.5/4/2, $M^+ - Br - HBr$); 371/369/367 (2.5/3/1, $M^+ - Br - HBr - H_2O$); 181 (25); 169 (20); 157 (18); 153 (35); 152 (40); 141 (80); 140 (20); 139 (42); 129 (38); 128 (100); 127 (42); 126 (19); 116 (15); 115 (92); 102 (23). – *H′—NMR.* (100 MHz, d_6-DMSO): $\delta = 7.76$ broad *s*, 2 pr (2 × OH); *AA′XX′* system at $\delta = 7.5$–7.0, 4 pr (aromatic H′ s); 4.75/*d* (*J* = 5), 4 pr (H—C(2), H—C(4), H—C(6), H—C(8)); 3.77/*t* (*J* = 5), 2 pr (H—C(3), H—C(7)).

$C_{14}H_{12}Br_4O_3$ (547.900) Calc. C 30.70 H 2.21 Br 58.33% Found C 30.75 H 2.19 Br 58.58%

Bromination of 9,10-benzo-bicyclo[3.3.2]dec-9-ene-3,7-dione (**9**) *with phenyl-trimethyl-ammonium tribromide.* To a stirred slurry of 2.4 g (6.38 mmol) PTT, in 10 ml methylene chloride, 0.3 g (1.42 mmol) of **9** was added. Stirring was continued for 90 min, water was added and the solution decolourised by shaking with an aliquot of aqueous sodium bisulphite. The organic layer was separated, washed with water, dried and evaporated to leave 0.617 g of a partially crystalline residue. Crystallisation from acetone afforded 0.08 g (11%) of **10**, m.p. 220–222°, identical in its spectroscopic properties with the sample obtained above. The residue from the concentrated mother liquor was dissolved in a small amount of hot chloroform and added to a column of 20 g aluminium oxide packed in benzene-chloroform (1:1). Elution with this solvent mixture gave a partially crystalline product, which was recrystallised from chloroform/petrol to give 0.12 g (20%) of *2β,10β-dibromo-6-ethoxy-9,9a-benzo-5-oxa-9a-homo-isotwist-9-ene-3-one* (**14**), m.p. 203–205.5°, which contained traces of an unknown tribromide. – *IR.* (KBr): 1745 s; 1342 m; 1208 m; 1150 m; 1128 s; 1062 s; 1050 s; 1020 m; 950 m; 825 m; 810 m; 765 m. ($CHCl_3$): 1750 s. – *MS.* (70 ev): (M_1 refers to impurity, M_2 to the major component) 498/496/494/492 (0.5/2.5/2.5/0.5, M_1^+); 418/416/414 (50/100/50, M_2^+); 406/404/402 (0.5/0.8/0.5); 392/391/390/389/388/387 (0.5/0.6/1.4/1.4/0.6/0.5); 374/372/370 (0.5/0.7/0.5); 361/359/357 (0.5/0.7/0.5); 337/335 (30/29, $M_2^+ - Br$); 309/307 (16/16, $M_2^+ - Br - CO$); 227 (20); 199 (19); 181 (23); 157 (20); 155 (20); 154 (18); 153 (22); 142 (22); 141 (82); 129 (50); 128 (64); 127 (20); 115 (46). – *^1H—NMR.* (100 MHz, $CDCl_3$): $\delta = 7.4$–7.0/*m*, 4 pr (aromatic H′ s); 5.74/*d* (*J* = 2), 1 pr (H—C(2)); 5.01/*d* (*J* = 9), 1 pr (H—C(4)); 4.87/*d* × *d* (*J* = 2 & 5), 1 pr (H—C(10)); 3.96/*d* × *d* (*J* = 2 & 5), 1 pr (H—C(1)); 3.80/*d* × *d* × *d* (*J* = 2 & 8 & 9), 1 pr (H—C(8)); 3.75/*q* (*J* = 7), 2 pr (CH_2 of ethoxy); *AB*-system with the *B* part at $\delta = 2.44/d \times d \times d$ (*J* = 2 & 8 & 12), 1 pr (H(α)—C(7)); the *A* part at $\delta = 2.36/d \times d$ (*J* = 2 & 12), 1 pr (H(β)—C(7)); 1.30/*t* (*J* = 7), 3 pr (CH_3 of ethoxy). – *Spin decoupling*: Irradiation at $\delta = 5.74$ (H—C(2)) converted the signal at $\delta = 3.96$ (H—C(1)) to *d* (*J* = 5); irradiation at $\delta = 5.01$ (H—C(4)) converted the signal at $\delta = 3.80$ (H—C(8)) to *d* × *d* (*J* = 2 & 8); irradiation at $\delta = 4.87$ (H—C(10)) converted the signal at $\delta = 3.96$ (H—C(1)) to *d* (*J* = 2) and the signal at $\delta = 2.44$ (H(α)—C(7)) to *d* × *d* (*J* = 8 & 12); irradiation at $\delta = 2.44$ H(α)—C(7)) converted the signal at $\delta = 3.80$

(H—C(8)) to $d \times d$ (J = 2 & 9); irradiation at δ = 1.30 (CH_3) converted the signal at δ = 3.75 (CH_2) to *s*.

$C_{16}H_{15}Br_3O_3$ (495.03) Calc. C 38.83 H 3.06 Br 48.43%
$C_{16}H_{16}Br_2O_3$ (416.13) Calc. C 46.18 H 3.88 Br 38.41%
Found C 44.11 H 3.10 Br 40.80%

Dehydrobromination of 1,5-dihydroxy-2β,4β,6β,8β-tetrabromo-10,10a-benzo-9-oxa-10a-homo-adamant-10-ene (**10**), *a) with sodium ethoxide in ethanol.* To a stirred solution of 0.40 g (0.72 mmol) of **10**, in 20 ml ethanol, 0.02 g sodium metal was added. After 12 h the solution was diluted with 200 ml water, acidified with aqueous hydrochloric acid and extracted with chloroform. The combined extracts were washed with water, dried and evaporated leaving a solid residue. Fractional crystallisation from chloroform/petrol gave 0.23 g (80%) of *2β,8β-dibromo-10,10a-benzo-5-oxa-10a-homotwist-10-ene-3,7-dione* (**15**), as colourless prisms m.p. 235–236°. – *IR.* (KBr): 1760 s; 1290 m; 1128 m; 1100 m; 1080 s; 878 m; 818 s; 765 s. ($CHCl_3$): 1770 s. – *MS.* (70 ev): 388/386/384 (28/60/30, M^+); 361/359/357 (0.4/1/0.4); 333/331/329 (0.4/1/0.4); 308 (10); 307/305 (27/23, M^+ – Br); 279/277 (20/20, M^+ – Br – CO); 261/259 (3/4); 251/249 (5/5, M^+ – Br – 2×CO); 220 (7); 219 (8); 218 (7); 217 (6); 211 (9); 209 (12); 198 (11), 197 (23), 185 (9), 171 (6); 170 (26, M^+ – 2×Br – 2×CO); 169 (42); 168 (6); 157 (18); 152 (6); 143 (7); 142 (30); 141 (100); 140 (10); 139 (20); 129 (38); 128 (56); 127 (18); 126 (6); 116 (8); 115 (48); 102 (9). – ^1H*—NMR.* (100 MHz, d_6-acetone): δ = 7.22/*s*, 4 pr (aromatic H′ s); 5.78/*d* (J = 4), 2 pr (H—C(2), H—C(8)); 5.21/*d* (J = 7.5), 2 pr (H—C(4), H—C(6)); 4.14/$d \times d$ (J = 4 & 7.5), 2 pr (H—C(1), H—C(9)).

$C_{14}H_{10}Br_2O_3$ (386.052) Calc. C 43.56 H 2.61 Br 41.39% Found C 43.78 H 2.57 Br 41.34%

b) with triethylamine. To a stirred solution of 0.50 g (0.92 mmol) of **10** in 10 ml tetrahydrofuran a solution of 1.5 g (15 mmol) triethylamine in 10 ml tetrahydrofuran was added over a period of 5 min. After 24 h the mixture was evaporated under reduced pressure and the residue dissolved in chloroform. The resulting solution was washed with water, dried and evaporated to give 0.31 g of an oil. Purification by PLC. (silica gel/chloroform) and crystallisation from chloroform/petrol gave 0.11 g (31%) of **15**, shown by its m.p. and spectral properties to be identical with the sample described in a) above.

Debromination of 1,5-dihydroxy-2β,4β,6β,8β-tetrabromo-10,10a-benzo-9-oxa-10a-homoadamant-10-ene (**10**) *with copper powder.* – An intimate mixture of 0.50 g (0.91 mmol) of **10** with 1.50 g (23.8 mmol) copper powder (grease-free, commercial grade) was heated in a sublimation apparatus first under nitrogen at 50° for 15 min and then under reduced pressure at 150°. The product sublimed on to the cold finger and was purified by PLC. (silica gel/chloroform) to give 0.099 g of a brown oil (see below) and 0.065 g (34%) of *9,9a-benzo-9a-homotriaster-9-ene-3,7-dione* (**5**) which was recrystallised from chloroform/petrol as colourless plates, m.p. 236–238°. – *IR.* (KBr): 3050 m; 1685 s; 1275 m; 1225 m; 1075 m; 885 s; 848 m; 760 s. – *MS.* (70 ev): 210 (96, M^+) 183 (8); 182 (56, M^+ – CO); 181 (100); 165 (10); 155 (6); 154 (34, M^+ – 2×CO); 153 (88); 152 (44); 151 (12); 141 (14); 139 (6); 129 (10); 128 (72); 127 (16); 126 (9); 116 (17); 103 (8); 96 (7); 92 (5). – ^1H*—NMR.* (100 MHz, $CDCl_3$): δ = 7.6–7.2/*m*, 4 pr (aromatic H′ s); 2.92/*s*, 6 pr (accidently equivalent cyclopropyl H′ s). – 100 MHz NMR.-measurement in the presence of $Eu(fod)_3$. Four signal groups with relative intensities of 1:1:2:1 became separated as follows: δ = 8.0–7.8 and 7.6–7.4/*AA′XX′* system, 4 pr (aromatic H′ s); 5.15/*d* (J = 9), 4 pr (H—C(2), H—C(4), H—C(6), H—C(8)); 3.98/*t* (J = 9), 2 pr (H—C(1), H—C(5)). – ^{13}C*—NMR.* (25.2 MHz, $CDCl_3$): δ = 195.7/*s* (C(3), C(7)); 133.1/*s* (C(9), C(9a)); 131.9/*d* with fine splitting (J = 160), (aromatic C(*m*)), 128.1/*d* with fine splitting (J = 163) (aromatic C(*o*)); 39.1/*d* (J = 175.7), (C(2), C(4), C(6), C(8)); 32.9/*d* (J = 170), (C(1), C(5)).

$C_{14}H_{10}O_2$ (210.220) Calc. C 79.98 H 4.79% Found C 80.28 H 4.58%

Crystallisation of the above mentioned 0.099 g brown oil in chloroform/petrol yielded 0.044 g (12%) of *2β,8β-dibromo-10,10a-benzo-5-oxa-10a-homotwist-10-ene-3,7-dione* (**15**) shown by m.p., IR.- and ^{1}H—NMR.-spectra to be identical with the sample of **15** isolated in the preceding experiment.

When the reaction was performed in the same way on 1.0 g (1.82 mmol) of **10** with 3.0 g (47.6 mmol) of activated [14], instead of commercial, copper powder 0.163 g (43%) of *9,9a-benzo-*

9a-homotriaster-9-ene-3,7-dione (**5**) was obtained (for spectra, see section 6) together with 0.109 g of a brown oil from which 0.029 g of a white solid was separated, consisting – according to its ^{1}H–NMR.-spectrum – of about 50% of **15**.

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264. Über die säurekatalysierte Umlagerung von β-Jonon-5,6-epoxid

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(19. IX. 74)

Summary. β-Ionone-5,6-epoxide (**1**) undergoes acid-catalyzed ring contraction and enlargement, concurrently, by [1,2]-alkyl shifts, to give the isomeric cyclopentane derivative **6** and the cycloheptafurane derivative **7**. Spectroscopic and chemical evidence for the structures of **6** and **7** is presented.

Die durch *Karrer* [1] begründete Chemie des β-Jonon-5,6-epoxids (**1**) hat in den letzten Jahren eine Renaissance erfahren. Dies nicht zuletzt wegen der Bedeutung von **1** als Glied in der Kette des Carotinoid Metabolismus. So wurde das Epoxid **1** in verschiedenen Naturprodukten[1]) nachgewiesen oder zur Synthese von Naturstoffen[2]), teils unter biomimetischen Aspekten, eingesetzt.

Epoxid **1** geht in Gegenwart verdünnter, alkoholischer Mineralsäuren bekanntlich in die Hydroxyderivate **2**, **3** und **4** über [1] [7] [9]. Zu einem überraschend unterschiedlichen Ergebnis gelangt man jedoch bei der Einwirkung von Säuren auf **1** im wasserfreien Medium. Es wurde nämlich gefunden, dass **1** beim Erhitzen in Chloroform unter Rückfluss in Gegenwart von *p*-Toluolsulfonsäure neben den Allylalkoholen **3** und **4** (18%), 3,4-Dehydro-β-jonon (**5**, 14%), ein Diketon **6** (3%) und das

[1]) Z.B. in Tomaten [2], Karotten [3], in der Himbeere [4], im Schwarztee [5] und im Tabak [6].
[2]) Z.B. zur Synthese von Abscisinsäure [7] und Theaspiron [8].