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Diisophorone and Related Compounds. Part 11[1]. A Partial Aromatisation of Diisophorone

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Hydrochloric acid in boiling glacial acetic acid converts 8-bromodiisophor-2(7)-en-1-ol-3-one or its 4-bromo-isomer into 6-methyl-5-nordiisophora-2(7)-3,5-triene-1,3-diol by aromatisation of ring A. Subsequent bromination occurs successively in the phenolic C-4 and the bridgehead C-1 positions, resulting finally in 1,4-dibromo-6-methyl-5-nordiisophora-2(7)3,5-trien-3-ol, the structure of which is confirmed by an X-ray analysis. The crystals of this dibromo-derivative are monoclinic, $a = 16.874(2)$, $b = 8.7342(11)$, $c = 11.7364(11)$ Å, $\beta = 96.418°$, $Z = 4$, space group $P2_1/n$. The structure was solved by *Patterson* and *Fourier* syntheses and was refined by full matrix least squares procedures to $R = 0.031$ and $R_w = 0.036$ for 1 598 observed reflections. The structure of the 6-methyl-5-nordiisophora-2(7),3,5-trien-3-ols thus established provides a basis for amending certain structural assignments recorded in the literature.

(Keywords: Diisophorones; 8-Bromodiisophorone, aromatisation of; Diisophorone, aromatised dibromo-derivative, X-ray analysis thereof; Tricyclo[7.3.1.0^{2,7}]tridecanes; 5,9-Methanobenzocyclooctene)

Diisophoron und verwandte Verbindungen, 11. Mitt.: Eine teilweise Aromatisierung von Diisophoron

8-Bromdiisophor-2(7)-en-1-ol-3-on und dessen 4-Brom-Isomer werden von kochender Salzsäure in Eisessig unter Aromatisierung des Rings A in 6-Methyl-5-nordiisophora-2(7),3,5-trien-1,3-diol umgewandelt. Weitere Bromierung erfolgt stufenweise in der C-4- und C-1-Stellung; die Konstitution des Endproduktes [1,4-Dibrom-6-methyl-5-nordiisophora-2(7),3,5-trien-3-ol] wurde durch eine Röntgen-Strukturanalyse gesichert. Die Kristalle der Dibrom-Verbindung sind monoklin, Raumgruppe $P2_1/n$, $a = 16{,}874(2)$, $b = 8{,}7342(11)$, $c = 11{,}7364(11)$ Å, $\beta = 96{,}418°$, $Z = 4$. Das Phasenproblem wurde mittels *Patterson*- und *Fourier*-Synthese bestimmt, und die Struktur nach der Methode der kleinsten Quadrate im Vollmatrix-Verfahren bis zu einem kristallographi-

schen R-Faktor von $R = 0{,}031$ und $R_w = 0{,}036$ für 1 598 Reflektionen verfeinert. Die so bewiesene Konstitution der 6-Methyl-5-nordiisophora-2(7),3,5-trien-3-ole bildet die Grundlage für die Berichtigung einiger früher von anderer Seite veröffentlichten Struktur-Zuteilungen.

Introduction

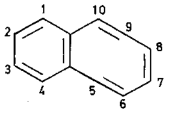
The halogenation of diisophorone (**1**) introduces reactive centres into this ring-system, at which further reactions may be studied. Bromination of **1** yields successively the 8-monobromo-[2,3], 4,8-dibromo-[4], and 4,6,8-tribromo-derivatives[3] (**2**–**4**), but the substitution pattern becomes progressively less uniform as halogenation proceeds. The readily accessible 8-bromodiisophor-2(7)-en-1-ol-3-one (**2**)[5], produced both by molecular bromine[2,3], and by N-bromosuccinimide[2], has served in studying nucleophilic replacements at the 8-position of the diisophorone framework[6]; instead of the expected 8-substitution products, the reaction gives the corresponding 4-isomers (**6**), involving an apparent migration, the nature of which has been discussed[6].

With the object of further testing the mobility of the 8-bromo-substituent, the action of mineral acid (on **2**) was examined under conditions that promote the intramolecular transfer of halogen in α-chloro- or α-bromoketones (e.g. alkyl α-bromoacetoacetate[7], α,α-dihalogenoketones $RCX_2CO \cdot CH_2R'$[8], 1,1-dichloro-4,4-dimethylcyclohexa-2,6-dione[9]). In 8-bromodiisophorone (**2**), the halogen might thus similarly migrate into the 4-position, i.e. to the methylene activated by the 3-keto-group. In the event, the reaction that occurred was a dehydrobromination, resulting in the aromatisation of ring A of the diisophorone structure.

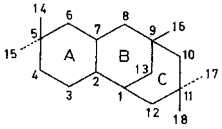
Results and Discussion

Aromatisation

Treatment of 8-bromodiisophor-2(7)-en-1-ol-3-one (**2**) with concentrated hydrochloric acid in boiling glacial acetic acid gave good yields of a bromine-free product which is formulated, on the basis of its composition, spectral and chemical properties, as 6-methyl-5-nordiisophora-2(7),3,5-triene-1,3-diol (**5**). The same product was



A



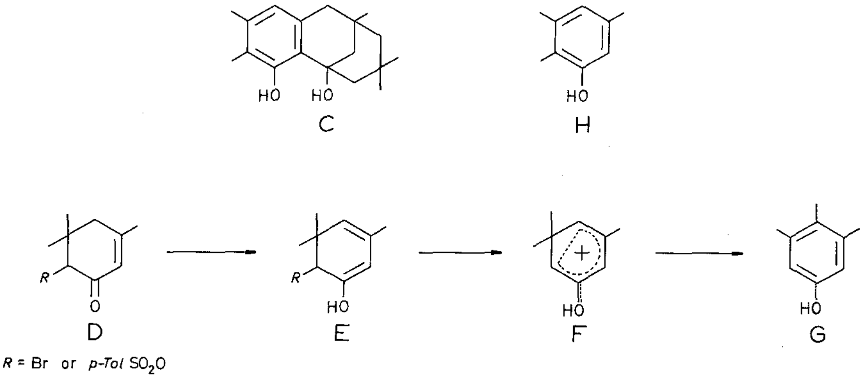
B

obtained even more readily under these conditions from the 4-bromo-isomer (**8**) of **2**, an observation that is of significance in connection with the mechanism of the aromatisation of ring A (see below).

Nomenclature. According to the IUPAC rules, the systematic name of **5**, derived from its fully *unsaturated* parent hydrocarbon[10,11] (i.e. benzocyclooctene, **A**) is 4,5-dihydroxy-1,2,7,7,9-pentamethyl-5,6,7,8,9,10-hexahydro-5,9-methanobenzocyclooctene. This nomenclature, though cumbersome, is essential for indexing purposes, but the simplified system originally adopted[5] for ordinary use, in which the name "diisophorane" is assigned to the parent hydrocarbon (**B**), is applicable with adequate precision to the present dehydrogenation products (**5**, etc.).

The presence of one or more hydroxy-groups in the reaction product ($C_{18}H_{26}O_2$, **5**) was indicated by a broad intense absorption band at 3 350 cm^{-1} in its IR spectrum. Aromaticity was suggested by its characteristic absorption in both the UV (λ_{max} 214 and 287 nm) and IR range (3 080, 1 620 and 1 585 cm^{-1}) and was shown conclusively by the appearance of the characteristic low-field signals in its ^{13}C-NMR spectrum (see below). Being phenolic, the compound gave a positive colour test with ferric chloride, was slightly alkali-soluble and reprecipitated by acid, and gave a *p*-nitrobenzyl ether (**7**).

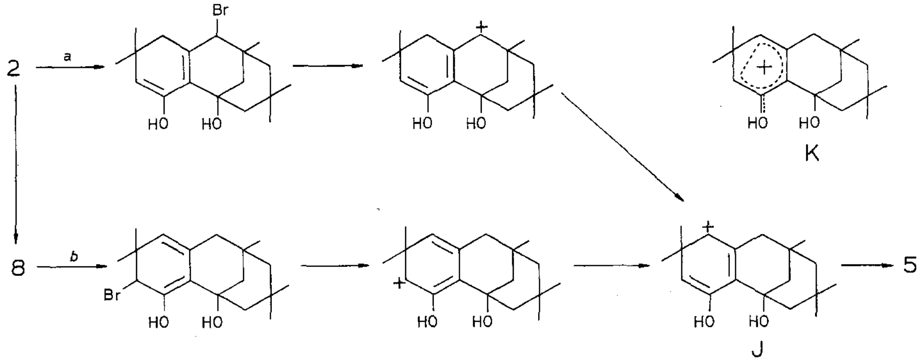
Scheme 1



Since the presence of the bridgehead substituent precludes aromatisation of rings B and C in diisophorones (**1**, **2**, etc.), the change occurs clearly in ring A and is necessarily attended by the migration of one of the geminal 5-methyl groups. Of the possible 4,5- (**C**) or 5,6-dimethyl-structures (**5**) of the resulting product, the latter is favoured by the established course of comparable aromatisations of isophorone derivatives[12]: Thus, acidic reagents convert 6-bromo- or 6-tosyloxyisophorone (**D**) into 3,4,5-trimethylphenol (**G**) by a mechanism thought to involve preliminary enolisation (to **E**) and formation of the delocalised carbonium ion (**F**)[12]. The fact that the isomeric 2,3,5-trimethylphenol (**H**) is not produced supports the formulation of the diisophorone analogue as the 5,6-dimethyl-compound (**5**); see Scheme 1.

In conformity with this precedent[12], the mechanism of the present aromatisations (**2** or **8** → **5**) is thought to involve as its principal steps the production of a carbonium ion, an enolisation, and migration of one of the 5-methyl groups by a *Wagner-Meerwein* rearrangement[13]. Of several possible variants of this mechanism, a sequence for both the 8-bromo- (pathway *a*) and 4-bromo-isomer (pathway *b*) is outlined in Scheme 2. The fact that the latter (**8**) yields the same product (**5**) even more readily than does **2** provides some support for the view, that aromatisation of the 8-bromo-compound (**2**) is preceded by its isomerisation to **8**, leading to a mechanism common to both reactions. However, nucleophilic replacement of the 8-bromo-atom in **2**, with formation of 4-substitution products (**6**) can be accounted for in terms of a SN2″-mechanism[6], that does not require the preliminary migration of 8-halogen to C-4; the occurrence of isomerisation (**2** → **8**) in the present reaction (**2** → **5**) is therefore undecided. The function as intermediates of classical carbonium ions, leading by mesomeric changes to the penultimate stage (**J**), is in better accord with the observed formation of the sole product **5** than is the intermediacy of delocalised ions (e.g. **K**); the analogous interpretation of the aromatisation of the 6-substituted isophorones (**D**)[12] might be preferable for the same reason.

Scheme 2

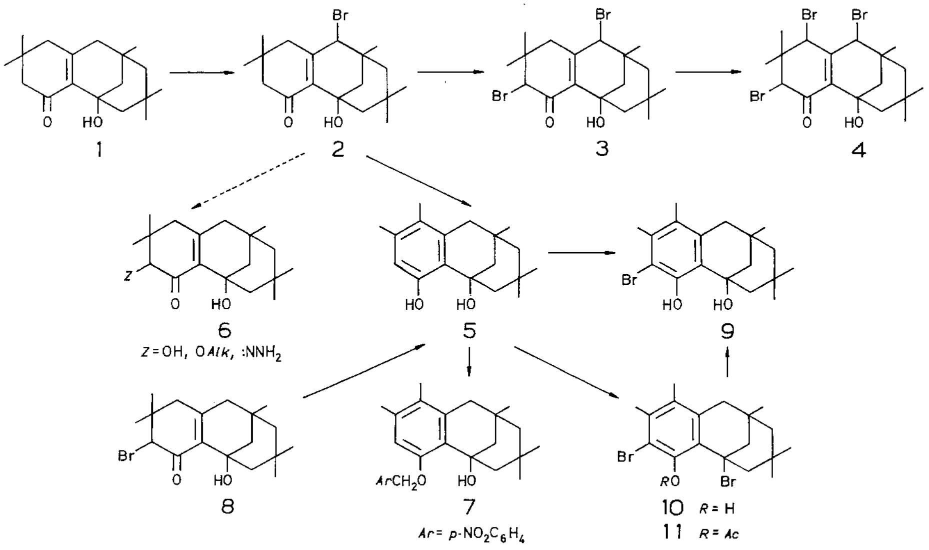


Bromination

Monobromination in glacial acetic acid converted **5** into a derivative formulated as **9**, the halogen entering the aromatic ring A rather than the usual[2,3] C-8 position. This formulation, which is in accord with the superior reactivity of phenolic moieties towards electrophiles[14], was supported by the observed resistance of the product towards alkaline hydrolysis and confirmed by the absence of doublets in its ^{13}C-NMR spectrum (see Table 1).

Dibromination in carbon tetrachloride converted **5** into the dibromohydroxy-compound **10**; it had spectral properties in accord with its proposed structure, and gave a monoacetyl-derivative (**11**). It thus arose by bromination of the phenolic moiety of **5**, and simultaneous replacement of the bridgehead 1-hydroxy-group. The latter exchange is likely to occur under the prolonged influence of the nascent hydrogen bromide: thus, concentrated hydrochloric acid is known to convert the parent ketol (**1**) remarkably easily into its 1-chloro-analogue[2], and hydrobromic acid acts analogously, though less readily[15]. The alkaline hydrolysis of the dibromo- (**10**) to the monobromo-compound (**9**), affecting only the bridgehead halogen, confirmed the relationship between the two compounds. Unequivocal proof of the structure of the aromatised diisophorones (**5**, **9**, **10**) in general, and of the location of their

Scheme 3



5- and 6-methyl groups in particular, was obtained by an X-ray analysis of **10**; this is the first determination by this technique of the structure of a diisophorone derivative and is recorded in full in the latter part of this paper.

^{13}C-*NMR Spectra*

A comparison of the ^{13}C-NMR spectra of **5**, **9**, and **10** with the fully assigned spectrum[1] of the parent ketol (**1**) and its derivatives confirmed the formulation of the compounds concerned and indicated the occurrence of aromatisation. Apart from the emergence of the characteristic signals in the aromatic range, the spectra resembled closely that of the parent diisophor-2(7)-en-1-ol-3-one (**1**) and were interpreted as far as possible on this basis (see Table 1).

Of the five *quartets* appearing in each of the spectra (of **5**, **9**, and **10**), three are assigned to C-16, C-17 and C-18, their chemical shifts being almost identical with those of the corresponding carbon atoms in diisophorone (**1**). The remaining two quartets (at ca. 15 and 20 ppm) are therefore allotted to the aromatic methyl-carbons C-14 and C-15; their appearance at appreciably higher field than those of the 5-*gem*-dimethyl carbons in **1** reflects their altered character, but a distinction between themselves is as yet not possible.

Similarly, the close correspondence in frequency of the three *triplets* of the aromatised diisophorones (**5**, **9**) and those of the parent ketol (**1**) identifies the signals due to C-10, C-12 and C-13. The remaining triplet, associated with C-8, shows an upfield displacement with respect to that of **1**, presumably due to the influence of the adjacent aromatic ring A.

The two high-field *singlets* (at ca. 32 and 34 ppm) are assigned to C-11 and C-9 by the relevant comparisons (with **1**), as is that near 75 ppm to the C-1 bridgehead carbon. The signal at ca. 115 ppm is clearly due to the aromatic C-4, being the only *doublet* in the spectrum of **5**; the singlets of this resonance are therefore assigned to C-4 in **9** and **10** also. The remaining task is the differentiation of the *singlets* of five aromatic carbon atoms. An attempt to predict their chemical shifts by empirical additivity rules, employing available parameters[16–18] for substituted benzenes, gave only partially useful results: the uncertainties surrounding the application of this approach to multiply-substituted compounds are well recognised[17]. Thus, the use of this method, in conjunction with certain assumptions (see Table 2, notes) provides "calculated" chemical shifts that agree well with the observed values of the signals of C-3 and C-4 (the latter being independently confirmed as above). However, the remaining observed singlets, forming two pairs of very closely spaced lines (near 136 and 125 ppm, respectively, the first

Table 1. ^{13}C-*NMR chemical shifts and first order multiplicities in diisophorone* (**1**)[1] *and in its partly aromatised analogues* (**5**, **9**, **10**) *and their proposed assignments*

Compound[a]	**1**	**5**	**9**	**10**
C-1	71.4 s	75.6 s	74.6 s	70.5 s
C-2	135.4 s	+ 136.4 s	+ 135.3 s	+ 136.9 s
C-3	200.7 s	152.8 s	150.1 s	148.9 s
C-4	51.8 t	115.9 d	111.5 s	113.6 s
C-5	32.2 s	+ 124.3 s	+ 125.1 s	+ 125.5 s
C-6	45.7 t	+ 124.5 s	+ 126.1 s	+ 126.7 s
C-7	157.5 s	+ 136.4 s	+ 135.3 s	+ 135.4 s
C-8	44.6 t	41.5 t	41.6 t	42.1 t
C-9	32.4 s	33.5 s	32.9 s	34.2 s
C-10	52.1 t	52.8 t	52.8 t	53.7 t
C-11	31.4 s	31.7 s	31.4 s	33.1 s
C-12	50.3 t	49.4 t	49.3 t	53.2 t
C-13	46.6 t	47.9 t	47.2 t	51.1 t
C-14	26.8 q	* 14.3 q	* 15.7 q	* 15.9 q
C-15	29.7 q	* 20.4 q	* 20.2 q	* 20.6 q
C-16	28.2 q	27.3 q	27.4 q	27.5 q
C-17	32.7 q	33.2 q	33.5 q	33.5 q
C-18	37.1 q	37.1 q	37.1 q	36.8 q

[a] For numbering, see structure **B**. In compounds **5**, **9** and **10**, carbon atoms C-14 and C-15 are attached to C-5 and C-6, respectively.

* + Signals may be (vertically) interchanged.

Table 2. "*Estimated*" *resonances of aromatic carbons in compounds* **5**, **9**, *and* **10** *(in ppm)*

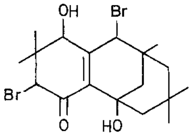
		C-2	C-3	C-4	C-5	C-6	C-7
Compound **5**	(a)	123.0	153.3	113.7 d	137.1	132.1	140.8
	(b)	132.7	150.0	114.1 d	137.6	131.0	143.8
Compounds	(a)	124.7	156.7	108.2	140.5	133.8	144.2
9 or **10**	(b)	134.4	153.4	108.6	141.0	132.7	147.2

(a) Substituents at C-2 and C-7 regarded as *Me*; (b) substituents at C-2 and C-7 regarded as $\mathrm{CH}\mathit{Me}_2$ and $\mathrm{CH}_2\mathit{Me}$, respectively.

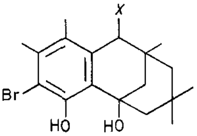
coinciding in **5** and **9**) cannot be reasonably matched with the predictions. One of the 136 ppm—singlets is therefore provisionally assigned to C-2, being coincident with the corresponding signal in the parent ketol (**1**), and the other to the adjacent C-7 carbon (i.e. the positions flanking the fixed double bond in the non-aromatic structures). The remaining two signals near 125 ppm are consequently allotted to the identically substituted C-5 and C-6 positions; however, these suggested assignments are as yet unconfirmed.

Revision of Previous Structural Assignment

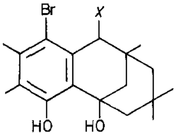
An aromatisation of ring A of diisophorone occurring under alkaline conditions has been observed by *Furth* et al.[3]. Solvolysis of 4,6,8-tribromodiisophor-2(7)-en-1-ol-3-one (**4**) by aqueous—ethanolic potassium carbonate gave a mixture of three compounds, one of which was a direct hydrolysis product (formulated as **L**, 12%). The other two, arising with simultaneous aromatisation, were represented as **M** (16%) and **N** (20%), respectively, and were each separately convertible into the bromophenol (**O**) on catalytic hydrogenation (**O**: m.p. 192–194°, ν_{max} 3 620, 3 450, 3 370, 1 603, 1 570 cm^{-1}, Ref.[3]).



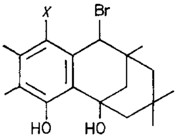
L



M: X = EtO
N: X = OH
O: X = H



P

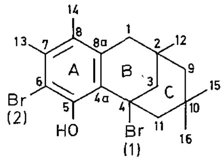


Q

However, since *Furth*'s bromophenol ("**O**") proves to be non-identical with the authentic 4-bromo-6-methyl-5-nordiisophora-2(7),3,5-triene-1,3-diol (**9**) now described, a reconsideration of its structure, and that of its precursors ("**M**", "**N**") is necessary. The sensitivity towards alkali of a 4-bromo-substituent in diisophorone (**1**) and its 1-carboxy-analogue has meanwhile been demonstrated[19], as has its rapid removal in the present aromatisation in acid medium (**8** → **5**, see above). It thus seems doubtful that aromatisation during alkaline solvolysis (of **4**) should proceeed with preservation of the 4-bromo-substituent. We are therefore inclined to formulate *Furth*'s compounds ("**M**", "**N**", "**O**") as the 4,5-dimethyl-6 (or 8)-bromo-isomers (**P** or **Q**; $X = EtO$, HO, H), and we shall comment on the divergent course of the aromatisations in a future discussion of further examples of these reactions.

Crystal Structure of **10**

The results of the X-ray analysis of **10** are embodied in Tables 3–6, which list respectively the final positional parameters, bond lengths, bond angles and selected torsion angles. The numbering of the diisophorone structure adopted in the crystallographic measurements is given in **R**; the usual[5] lettering of the rings is retained. A stereoview of the molecule is shown in Fig. 1. The crystal structure consists of individual molecules of **10** separated by normal *van der Waals* distances.



R

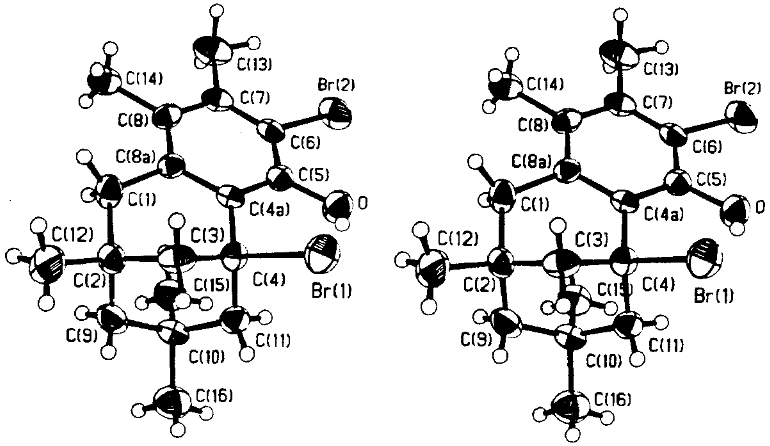


Fig. 1. Stereoscopic view of **10** showing the crystallographic numbering scheme and 50% probability thermal ellipsoids for the non-hydrogen atoms. Hydrogen atoms were assigned artificially small thermal parameters for the sake of clarity

The fully substituted aromatic ring A is significantly non-planar ($\chi^2 = 76.5$ for C_6), the mean and maximum deviations from the mean plane being 0.015 and 0.028 (5) Å, respectively. The distortion results in a boat-like conformation, in which C (6) and C (8 a) (in **R**) are displaced from the mean plane in a direction opposite to that of the remaining four atoms. All six substituent atoms are considerably displaced from the mean plane; C (1) by 0.226 (7) Å and the other five substituents by 0.048 (5)–0.081 (1) Å. The six-membered ring B has a distorted C (3)-sofa conformation. The fully saturated six-membered ring C has a distorted chair conformation flattened at one side as a result of steric interaction between C (15) and C (8 a) [H (15) ... C (8 a) = 2.59 (5) Å]. Bond distances and angles are generally as expected; the only significant exception is the increased bond length of C(8)–C(14) [1.563(9) Å, compared with the normal value of 1.511 Å for a C(sp^3)–C(sp^2) single bond].

Experimental Part

General information is given in Part 1[5] concerning equipment, standard procedures, reagents, solvents and abbreviations. Light petroleum had b.p. 60–80°. The ^{1}H-NMR spectra were recorded in $CDCl_3$ at 60 MHz and are reported in ppm (δ) from *TMS* as the internal standard. ^{13}C-NMR spectra were obtained as specified in Part 10[1] of this series.

6-Methyl-5-nordiisophora-2(7),3,5-triene-1,3-diol (**5**)

A solution of 8-bromodiisophor-2(7)-en-1-ol-3-one[2,3] (1.78 g, 0.005 mol) in glacial acetic acid (25 ml) and concentrated hydrochloric acid (2 ml) was boiled under reflux for 2.5 h, and the dark liquid stirred into water. The brown precipitate gave pearly platelets (0.82–0.9 g, 60–66%) of **5**, m.p. 155–157° (from light petroleum) (Found: C 78.6; H 9.8. $C_{18}H_{26}O_2$ requires C 78.8; H 9.5%). ν_{max} 3 350 vs (OH), 3 080 mw, 1 620 ms, 1 585 s (*Ar*); 2 940–2 860 vs, 1 465 vs (CH_3, CH_2), 855 s (? pentasubst. *Ar*), 1 395 s, 1 305 s, 1 235 s, 1 200 m, 1 175 s, 1 070 s, 1 040 vs, 795 m cm^{-1}. λ_{max} 214, 287 nm (log ε 3.98, 3.31), λ_{sh} 223 (3.86). ^{1}H-NMR: 0.31 (s, 3 H, CH_3), 0.86 (s, 3 H, CH_3), 1.07 (s, 3 H, CH_3), 1.92 (s, 3 H, CH_3), 2.12 (s, 3 H, CH_3).

The compound was slightly soluble in 2-*N* sodium hydroxide, and was reprecipitated by acid. With aqueous ferric chloride, its ethanolic solution gave a deep greenish blue colour, slowly fading to olive-green.

The use of 4-bromodiisophor-2(7)-en-1-ol-3-one in the foregoing procedure gave the same product (identified by mixed m.p. and IR spectrum) in improved yield (up to 85%). This reactant is accessible by the action of hydrobromic acid on 2,7-epoxydiisophoran-1-ol-3-one[19].

p-Nitrobenzyl Ether (**7**)

A solution of the foregoing diol **5** (0.55 g, 0.002 mol) in ethanol (20 ml)—water (2 ml) containing sodium bicarbonate (0.42 g, 0.005 mol), treated with *p*-nitrobenzyl bromide (0.54 g, 0.0025 mol), was boiled under reflux for 1.5 h, then diluted with water. The product was isolated by ether extraction, and formed faintly yellow microprisms (0.52 g, 64%) of **7**, m.p. 162–163° (from ethanol) (Found: C 73.2, H 7.7, N 3.4. $C_{25}H_{30}NO_4$ requires C 73.5, H 7.35, N 3.4%). ν_{max} 3 580 s (OH), 2 960–2 870 vs br, 1 460 s (CH_3, CH_2), 1 605 s, 1 585 ms (*Ar*), 850 vs (? pentasubst. *Ar*), 825 s, 735 s (*p*-disubst. *Ar*) cm^{-1}.

4-Bromo-6-methyl-5-nordiisophora-2(7),3,5-triene-1,3-diol (**9**)

A stirred solution of **5** (1.85 g, 0.005 mol) in glacial acetic acid (50 ml) containing a few drops of 60% hydrobromic acid was treated dropwise during 15 min with *M* bromine (5 ml, 0.005 mol) in the same solvent. A white precipitate appeared; its separation was completed by the addition of water (100 ml) (crude: m.p. 205–207°, 1.50 g, 85%, nearly pure by IR). Crystallisation from ethanol (recovery > 80%) gave lustrous platelets of **9**, m.p. 212–213° (Found: C 61.1, H 7.2, Br 22.5. $C_{18}H_{25}BrO_2$ requires C 61.2, H 7.1, Br 22.6%). ν_{max} 3 380 vs (OH), 2 960–2 880 vs, 1 455 s, 1 425 vs (CH_3, CH_2), 1 595 m, 1 560 m, 845 ms (*Ar*), 1 310 s, 1 230 s, 1 170 ms, 1 150 ms, 1 070 ms, 1 040 s, 735 mw cm^{-1}. λ_{max} 213, 292 nm (log ε 4.39, 3.56). ^{1}H-NMR: 0.31, 0.86, 1.05, 2.01, 2.26 (all s, 3 H, CH_3).

1,4-Dibromo-6-methyl-5-nordiiosphora-2(7),3,5-trien-3-ol (**10**)

A stirred solution of **5** (2.75 g, 0.01 mol) in carbon tetrachloride (50 ml) was treated dropwise at room temperature with 0.5 *M* bromine (40 ml, 0.02 mol) in the same solvent. The resulting clear red liquid was stirred for 12 h, evaporated under reduced pressure, and the residual oil taken up in light petroleum. The product (m.p. 121–123°, 2.35 g, 56%) gave colourless microprisms of **10**, m.p. 124–125° (from light petroleum, recovery 80%). (Found: C 52.9, H 6.3, Br 37.6. $C_{18}H_{24}Br_2O$ requires C 51.95, H 5.8, Br 38.4%). ν_{max} 3 395 vs (OH), 2 940–2 850 vs, 1 440 vs (CH_3, CH_2), 1 575 w (*Ar*), 1 320 vs, 1 210 s, 1 165 s, 850 m, 790 ms, 695 s cm^{-1}. λ_{max} 213, 292 nm (log ε 4.52, 3.66). ^{1}H-NMR: 0.30, 0.96, 1.18, 2.11, 2.42 (all s, 3 H, CH_3), 6.59 (s, 1 H, OH).

Action of Alkali. The dibromophenol **10** (0.42 g, 0.001 mol) was dissolved in a solution of sodium hydroxide (0.40 g, 0.01 mol) in water (6 ml)—ethanol (24 ml), heated to boiling, and set aside at room temperature (1 h). The liquid was stirred into ice-water, and the product isolated by ether extraction. Trituration of the crude residual pale yellow oil with light petroleum produced a white solid (m.p. 200°, 0.28 g, 80%) which gave **9** (from ethanol—light petroleum, 1 : 3, recovery 80%), identified by mixed m.p. 208–210° and IR spectrum (see above) (Found: C 61.2, H 6.7%).

3-Acetoxy-1,4-dibromo-6-methyl-5-nordiisophora-2(7),3,5-triene (**11**)

A solution of the dibromphenol **10** (0.42 g, 0.001 mol) in glacial acetic acid (6 ml)—acetic anhydride (2 ml) was treated with 60% perchloric acid (4 drops, slight spontaneous warming), set aside at room temperature for 2 h, then stirred into ice-water. The precipitate (m.p. 192–194°, 0.36 g, 78%) gave microprisms of **11**, m.p. 200–201° (from light petroleum, recovery > 80%) (Found: C 52.9, H 5.7, Br 34.2. $C_{20}H_{26}Br_2O_2$ requires C 52.4, H 5.7, Br 34.9%). ν_{max} 2 940–2 850 m (CH_3, CH_2), 1 770 s br (CO of *Ac*), 1 355 w, 1 190 vs, 1 170 s, 875 m, 845 m, 710 m cm^{-1}.

X-Ray Crystallographic Analysis of **10**

A crystal bounded by the 7 faces (followed by their distances in mm from a common origin): $\pm$ (1 0 0) 0.075, $\pm$ (—1 0 1) 0.085, $\pm$ (0 1 1) 0.100, and (0 —1 1) 0.155, was mounted in a general orientation. Unit-cell parameters were refined by least-squares on $2 \sin \theta / \lambda$ values for 25 reflections ($2\theta = 28$—$45°$) measured on a diffractometer with Mo-Kα_1 radiation ($\lambda = 0.7093$ Å). Crystal data at 22° are:

$C_{18}H_{24}Br_2O$ f.w. = 416.2 Monoclinic, $a = 16.874\,(2)$, $b = 8.7342\,(11)$, $c = 11.7364\,(11)$ Å, $\beta = 96.418\,(4)°$, $V = 1\,718.9\,(3)$ Å^3, $Z = 4$, $\rho_c = = 1.608$ g cm^{-3}, $F(0\,0\,0) = 840$, μ (Mo-Kα) = 46.6 cm^{-1}. Absent reflections ($h\,0\,l$, $h + l$ odd and $0\,k\,0$, k odd) uniquely indicate the space group $P\,2_1/n$.

Intensities were measured with graphite-monochromated Mo-Kα radiation ($\lambda = 0.71073$ Å) on an Enraf-Nonius CAD4-F diffractometer. An ω-$2\,\theta$ scan at 1.26–10.06° min^{-1} over a range of $(0.65 + 0.35 \tan \theta)$ degrees in ω (extended by 25% on both sides for background measurement) was employed. Data were measured to $\theta = 55°$. The intensities of three check reflections, measured every

Table 3. *Final positional (fractional* $\cdot 10^4$*,* Br $\cdot 10^5$*,* H $\cdot 10^3$*) and isotropic thermal parameters (*$U \cdot 10^3$ Å^2*) with estimated standard deviations in parentheses*

Atom	x	y	z	U_{eq}/U_{iso}
Br (1)	36897 (4)	46468 (7)	30507 (5)	53
Br (2)	2830 (3)	50753 (7)	26527 (5)	56
O	1964 (3)	5769 (6)	2824 (4)	49
C (1)	2686 (4)	3074 (9)	—637 (6)	41
C (2)	3500 (3)	3867 (6)	—495 (5)	37
C (3)	3780 (4)	3867 (7)	771 (5)	40
C (4)	3233 (3)	4871 (5)	1382 (4)	30
C (4 a)	2376 (3)	4328 (5)	1215 (4)	29
C (5)	1808 (3)	4799 (6)	1906 (4)	33
C (6)	1017 (3)	4332 (6)	1670 (4)	33
C (7)	776 (3)	3375 (6)	773 (5)	35
C (8)	1333 (3)	2908 (6)	56 (4)	35
C (8 a)	2118 (3)	3416 (5)	251 (4)	31
C (9)	3502 (4)	5529 (8)	—935 (6)	47
C (10)	3133 (3)	6811 (6)	—253 (5)	38
C (11)	3323 (4)	6526 (7)	1042 (5)	38
C (12)	4063 (5)	2932 (10)	—1155 (9)	61
C (13)	—78 (5)	2820 (11)	576 (10)	58
C (14)	1083 (6)	1807 (11)	—970 (8)	45
C (15)	2250 (4)	6973 (10)	—611 (8)	51
C (16)	3531 (6)	8328 (9)	—531 (8)	60
H (O)	232 (3)	581 (7)	295 (5)	21 (19)
H (1 a)	273 (3)	197 (7)	—78 (5)	48 (17)
H (1 b)	242 (3)	336 (6)	—121 (5)	44 (20)
H (3 a)	378 (3)	289 (6)	100 (4)	26 (14)
H (3 b)	432 (3)	423 (5)	94 (4)	30 (13)
H (9 a)	395 (3)	579 (5)	—92 (4)	28 (15)
H (9 b)	321 (3)	560 (6)	—164 (5)	43 (16)
H (11 a)	379 (3)	685 (5)	130 (4)	20 (14)
H (11 b)	301 (3)	709 (5)	139 (4)	18 (13)
H (12 a)	452 (3)	330 (6)	—108 (4)	37 (18)
H (12 b)	409 (3)	187 (8)	—98 (5)	60 (21)
H (12 c)	381 (4)	284 (8)	—186 (7)	93 (30)
H (13 a)	—38 (5)	319 (9)	125 (7)	141 (32)
H (13 b)	—25 (6)	322 (13)	17 (9)	39 (53)
H (13 c)	—9 (5)	177 (10)	89 (7)	114 (31)
H (14 a)	134 (4)	124 (8)	—87 (6)	58 (34)
H (14 b)	76 (4)	130 (8)	—84 (6)	57 (27)
H (14 c)	109 (3)	222 (6)	—146 (4)	20 (20)
H (15 a)	214 (4)	720 (9)	—130 (8)	98 (31)
H (15 b)	212 (3)	765 (6)	—12 (5)	49 (22)
H (15 c)	189 (3)	612 (6)	—63 (4)	34 (15)
H (16 a)	404 (4)	835 (7)	—27 (6)	68 (24)
H (16 b)	343 (4)	858 (7)	—129 (6)	62 (22)
H (16 c)	333 (4)	921 (9)	—15 (5)	69 (22)

$U_{eq} = 1/3$ trace U_{diag}.

Table 4. *Bond lengths (Å) with estimated standard deviations in parentheses*

Bond	uncorr.	corr.	Bond	uncorr.	corr.
Br (1)—C (4)	2.033 (4)	2.037	C (4 a)—C (8 a)	1.412 (7)	1.415
Br (2)—C (6)	1.899 (5)	1.902	C (5)—C (6)	1.393 (6)	1.395
O—C (5)	1.373 (7)	1.375	C (6)—C (7)	1.369 (7)	1.373
C (1)—C (2)	1.531 (8)	1.533	C (7)—C (8)	1.391 (7)	1.394
C (1)—C (8 a)	1.524 (7)	1.527	C (7)—C (13)	1.514 (9)	1.514
C (2)—C (3)	1.508 (8)	1.512	C (8)—C (8 a)	1.391 (7)	1.393
C (2)—C (9)	1.541 (9)	1.544	C (8)—C (14)	1.562 (9)	1.563
C (2)—C (12)	1.527 (8)	1.527	C (9)—C (10)	1.548 (8)	1.551
C (3)—C (4)	1.512 (7)	1.516	C (10)—C (11)	1.539 (8)	1.543
C (4)—C (4 a)	1.513 (6)	1.516	C (10)—C (15)	1.508 (9)	1.510
C (4)—C (11)	1.512 (7)	1.515	C (10)—C (16)	1.537 (9)	1.537
C (4 a)—C (5)	1.386 (6)	1.389			

Table 5. *Bond angles (deg) with estimated standard deviations in parentheses*

Bonds	Angle (deg)	Bonds	Angle (deg)
C (2)—C (1)—C (8 a)	117.6 (5)	Br (2)—C (6)—C (5)	117.0 (4)
C (1)—C (2)—C (3)	106.6 (5)	Br (2)—C (6)—C (7)	121.2 (4)
C (1)—C (2)—C (9)	115.2 (6)	C (5)—C (6)—C (7)	121.8 (4)
C (1)—C (2)—C (12)	107.7 (5)	C (6)—C (7)—C (8)	118.8 (5)
C (3)—C (2)—C (9)	108.5 (5)	C (6)—C (7)—C (13)	120.6 (6)
C (3)—C (2)—C (12)	110.8 (6)	C (8)—C (7)—C (13)	120.6 (6)
C (9)—C (2)—C (12)	108.0 (5)	C (7)—C (8)—C (8 a)	120.1 (5)
C (2)—C (3)—C (4)	109.1 (5)	C (7)—C (8)—C (14)	120.3 (6)
Br (1)—C (4)—C (3)	102.4 (3)	C (8 a)—C (8)—C (14)	119.6 (6)
Br (1)—C (4)—C (4 a)	110.4 (3)	C (1)—C (8 a)—C (4 a)	119.8 (5)
Br (1)—C (4)—C (11)	107.9 (3)	C (1)—C (8 a)—C (8)	119.0 (5)
C (3)—C (4)—C (4 a)	112.5 (4)	C (4 a)—C (8 a)—C (8)	121.0 (5)
C (3)—C (4)—C (11)	110.1 (5)	C (2)—C (9)—C (10)	119.5 (5)
C (4 a)—C (4)—C (11)	112.9 (4)	C (9)—C (10)—C (11)	110.0 (5)
C (4)—C (4 a)—C (5)	123.0 (4)	C (9)—C (10)—C (15)	111.5 (6)
C (4)—C (4 a)—C (8 a)	119.0 (4)	C (9)—C (10)—C (16)	107.7 (5)
C (5)—C (4 a)—C (8 a)	117.7 (4)	C (11)—C (10)—C (15)	112.4 (6)
O—C (5)—C (4 a)	123.9 (5)	C (11)—C (10)—C (16)	107.5 (5)
O—C (5)—C (6)	115.6 (5)	C (15)—C (10)—C (16)	107.6 (6)
C (4 a)—C (5)—C (6)	120.4 (4)	C (4)—C (11)—C (10)	113.6 (5)

3 600 s throughout the data collection, remained constant to within 2%. After data reduction (by suitable computer programs), an absorption correction was applied using the *Gaussian* integration method[20]. Transmission factors ranged from 0.336 to 0.586 for 212 integration points. Of the 3 919 independent reflections measured, 1 598 (40.8%) had intensities greater than 3 σ (*I*) above

Table 6. *Intra-annular torsion angles (deg). Standard deviations in parentheses*

Atoms	Value (deg)
C(8a)—C(1)—C(2)—C(9)	−80.9 (7)
C(1)—C(2)—C(9)—C(10)	72.7 (7)
C(2)—C(9)—C(10)—C(11)	38.0 (8)
C(9)—C(10)—C(11)—C(4)	−42.6 (7)
C(4a)—C(4)—C(11)—C(10)	−67.5 (6)
C(11)—C(4)—C(4a)—C(8a)	102.2 (5)
C(4)—C(4a)—C(8a)—C(1)	−3.6 (7)
C(2)—C(1)—C(8a)—C(4a)	−5.4 (9)
C(8a)—C(1)—C(2)—C(3)	39.6 (8)
C(1)—C(2)—C(3)—C(4)	−66.1 (6)
C(2)—C(3)—C(4)—C(4a)	59.6 (6)
C(3)—C(4)—C(4a)—C(8a)	−23.2 (6)
C(4)—C(4a)—C(8a)—C(1)	−3.6 (7)
C(2)—C(1)—C(8a)—C(4a)	−5.4 (9)
C(9)—C(2)—C(3)—C(4)	58.6 (6)
C(2)—C(3)—C(4)—C(11)	−67.3 (6)
C(3)—C(4)—C(11)—C(10)	59.2 (6)
C(9)—C(10)—C(11)—C(4)	−42.6 (7)
C(2)—C(9)—C(10)—C(11)	38.0 (8)
C(3)—C(2)—C(9)—C(10)	−46.7 (8)

background, where $\sigma^2(I) = S + 2B + [0.04(S-B)]^2$ with S = scan count and B = normalised background count.

The structure was solved by conventional heavy-atom methods, the Br positions being determined from the *Patterson* function and those of all other atoms (including hydrogen) from subsequent difference maps. The scattering factors for non-hydrogen atoms[21], for hydrogen atoms[22], and for bromine atoms[23], were taken from literature. The weighting scheme, $w = 1/\sigma^2(F)$ where $\sigma^2(F)$ is derived from the previously defined $\sigma^2(I)$ gave uniform average values of $w(|F_0| - |F_c|)^2$ over ranges of both $|F_0|$ and $\sin\theta/\lambda$, and was employed in the final stages of refinement. Convergence was reached at $R = 0.031$ and $R_w = 0.036$ for 1598 reflections with $I \geqslant 3\sigma(I)$. For all 3919 reflections $R = 0.147$.

On the final cycle of refinement, the mean and maximum parameter shifts corresponded to 0.03 and 0.32 σ respectively. The mean error in an observation of unit weight was 1.510. A final difference map showed maximum fluctuations of $\pm 0.40\,e\text{Å}^{-3}$ in the vicinity of Br atoms and was essentially featureless elsewhere. The final positional and thermal parameters appear in Tables 3 and 7*, respectively.

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* Tables 7–10 and other data mentioned in the text (including observed and calculated structure amplitudes) have been deposited with, and are obtainable on request from the authors.

The ellipsoids of thermal motion for the non-hydrogen atoms are shown in Fig. 1. The thermal motion has been analysed in terms of the rigid-body modes of translation, libration, and screw motion[24]. The rms standard error in the temperature factors σU_{ij} (derived from the least-squares analysis) is 0.0034 Å^2. Analysis of all 21 non-hydrogen atoms gave reasonable derived rigid-body parameters and rms $\Delta U_{ij} = 0.0048$ Å^2. The appropriate bond distances have been corrected for libration[24,25], using shape parameters q^2 of 0.08 for all atoms involved. Corrected bond lengths appear in Table 4, together with the uncorrected values. Corrected bond angles do not differ by more than 1 σ from the uncorrected values given in Table 5. Intra-annular torsion angles defining the conformations of bicyclo[3.3.1]nonane rings are listed in Table 6. Bond lengths and angles involving hydrogen and a complete listing of torsion angles (Tables 8–10) are available as unpublished supplementary material*. The numbering of the molecule in all the crystallographic Tables and Data is shown in structure **R**.

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