Crystal and Molecular Structure of the *p*-Bromobenzoate Chlorohydrin of Clerodendrin A [1]

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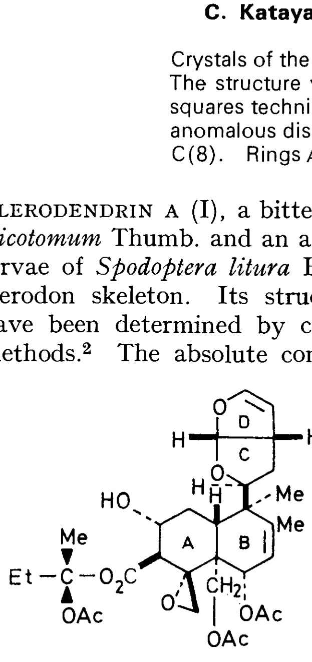
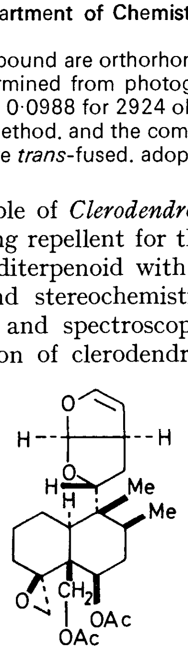
Crystals of the title compound are orthorhombic. a = 18·95, b = 22·74, c = 10·06 Å, Z = 4, space group $P2_12_12_1$. The structure was determined from photographic data by Patterson and Fourier methods, and refined by least-squares techniques to R 0·0988 for 2924 observed reflexions. The absolute configuration was determined by the anomalous dispersion method, and the compound shown to be an antipode of clerodin, except for C(2), C(3), and C(8). Rings A and B are *trans*-fused, adopting chair and sofa conformations, respectively.

CLERODENDRIN A (I), a bitter principle of *Clerodendron tricotomum* Thumb. and an antifeeding repellent for the larvae of *Spodoptera litura* F., is a diterpenoid with a clerodon skeleton. Its structure and stereochemistry have been determined by chemical and spectroscopic methods.[2] The absolute configuration of clerodendrin A appeared to be as shown (I) from comparison of the o.r.d. and c.d. curves of its derivative with those of cholestenone derivatives. Clerodendrin A is therefore an antipode of clerodin (II),[3] except for the configurations at C(2), C(3), and C(8).



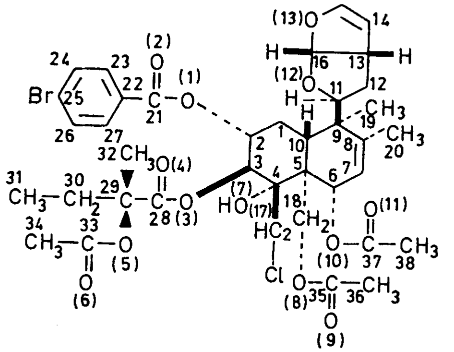
(I)



(II)

In recent studies, interesting knowledge has been obtained with regard to the constitution and absolute configurations of diterpenes with the clerodon skeleton. Columbin,[4] jateorin,[4] chasmanthin,[4] and isocolumbin [5] are antipodal to plathyterpol.[6] However, the diterpenes of the cascarillin group, possessing a *trans*-AB-ring junction, have virtually the same absolute configuration, *e.g.* cascarillin,[7] solidagonic acid,[8] kolavenic acid,[8] kolavelool,[9] and another.[10] The third is attributable to a group of clerodin which has the same configuration as cascarillin about the AB ring. Only two compounds, clerodin and clerodendrin A, have the antipodal structure.

In order to confirm the constitution and to determine unambiguously the absolute configuration of (I), a matter of vital importance in biosynthetic and mechanistic considerations, and also to study the molecular geometry of the two fused ring systems (*trans*-octalin and furo-furan rings), we have undertaken an X-ray study of clerodendrin *p*-bromobenzoate chlorohydrin (III).



(III)

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[9] R. Misra and S. Dev, *Tetrahedron Letters*, 1968, 2685.

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EXPERIMENTAL

Compound (III) was prepared by warming clerodendrin A (I) in *p*-bromobenzoyl chloride–pyridine at 70 °C for 11 h. At room temperature, *p*-bromobenzoylation of the C(2) hydroxy-group was not achieved; only the epoxide group was cleaved by the action of hydrochloric acid. This is because of steric interactions with the C(3) substituent. Crystals from ethanol were colourless prisms. The Laue symmetry and space group were determined from oscillation and Weissenberg photographs.

Crystal Data.—$C_{38}H_{46}O_{13}BrCl,C_2H_5OH$, *M* 872·2. Orthorhombic, $a = 18{\cdot}95$, $b = 22{\cdot}74$, $c = 10{\cdot}06$ Å, $U = 4766{\cdot}01$ Å^3, D_c 1·337, $Z = 4$, D_o 1·343 (by flotation). Cu-K_α radiation, $\lambda = 1{\cdot}5418$ Å; μ(Cu-K_α) = 24·9 cm^{-1}. Space group $P2_12_12_1$ from absent spectra: $h00$ for h odd, $0k0$ for k odd, $00l$ for l odd.

Cell dimensions were obtained by a least-squares method from $0kl$ and $h0l$ Weissenberg photographs. Integrated equi-inclination Weissenberg data of the layers of $hk0$—6 and $h0$—$12l$ were collected with Ni-filtered Cu-K_α radiation by the multiple-film technique. Intensities were estimated visually by comparison with a calibrated strip. Lorentz and polarization corrections were applied and a total of 2924 independent reflexions derived.

Structure Analysis.—The position of the bromine atom was deduced from three Harker sections of the three-dimensional Patterson synthesis as $x = 0{\cdot}217$, $y = 0{\cdot}075$, and $z = 0{\cdot}377$. The three-dimensional minimum function method was used to obtain the positions of 26 carbon atoms; *R* was then 0·58. The correctness of these positions was ascertained by means of the least-squares method, with the co-ordinates fixed and with the atomic scattering factor of carbon assigned to all. After three cycles it was found that one of the carbon atoms was in fact a chlorine atom. After five further cycles of least squares with the atomic scattering factors of bromine, chlorine, and carbon, *R* was 0·385. The remaining sites were located by five more rounds of calculations. During these, those atoms for which the temperature factors converged into values which were smaller than those of the others, were identified as oxygen; *R* was then 0·188. Four cycles of refinement were carried out with anisotropic temperature factors for bromine and chlorine atoms and isotropic for light atoms, resulting in *R* 0·101. A weighting scheme of the Hughes [11] type was now introduced with $w = 1$ for $|F_o| \leq F_{\text{min.}}$; $w = (|F_o|/F_{\text{min.}})^2$ for $|F_o| > F_{\text{min.}}$; $F_{\text{min.}}$ was set at 45 on an absolute scale. A damping factor (*g*) of 0·8 was applied to all shifts and *R* fell to 0·0988 in three cycles for the 2924 observed reflexions; as the parameter shifts were very small the refinement was terminated.

The final atomic co-ordinates, with estimated standard deviations and temperature factors, are listed in Table 1, bond lengths in Table 2, and valency angles in Table 3. The final structure amplitudes for 2924 planes are listed in Supplementary Publication No. SUP 20550 (5 pp., 1 microfiche).*

TABLE 1

Final positional parameters as fractions of the unit cell edges with estimated standard deviations in parentheses. Atoms are numbered as in structure (III)

Atom	*x*	*y*	*z*	B/Å^2
Br(1)	0·71703(019)	0·42452(016)	0·62252(022)	*
Cl(1)	0·45448(035)	0·84397(039)	0·98056(045)	*
O(1)	0·5980(08)	0·6904(08)	0·8126(09)	
O(2)	0·5072(10)	0·6700(10)	0·6788(11)	
O(3)	0·5773(08)	0·7327(08)	1·0765(08)	
O(4)	0·6766(09)	0·6780(09)	1·0905(09)	
O(5)	0·6361(10)	0·6546(10)	1·3527(11)	
O(6)	0·6637(11)	0·7506(11)	1·3321(11)	
O(7)	0·6528(08)	0·8397(08)	1·1146(10)	
O(8)	0·7355(09)	0·8182(09)	0·8513(09)	
O(9)	0·8431(14)	0·8532(13)	0·8825(16)	
O(10)	0·6422(08)	0·9616(08)	1·0225(09)	
O(11)	0·5476(14)	1·0055(14)	1·1077(16)	
O(12)	0·5046(10)	0·8422(10)	0·5196(10)	
O(13)	0·4235(15)	0·8496(15)	0·3475(17)	
O(14)	0·1673(37)	0·3442(34)	0·1574(39)	
C(1)	0·5986(13)	0·7887(13)	0·7271(14)	
C(2)	0·5705(12)	0·7508(12)	0·8362(13)	
C(3)	0·6087(11)	0·7665(11)	0·9665(13)	
C(4)	0·6043(12)	0·8322(11)	1·0083(13)	
C(5)	0·6263(11)	0·8742(11)	0·8916(13)	
C(6)	0·6028(12)	0·9374(11)	0·9173(13)	
C(7)	0·6156(15)	0·9791(14)	0·7977(16)	
C(8)	0·6163(14)	0·9592(13)	0·6750(14)	
C(9)	0·5992(13)	0·8960(12)	0·6307(15)	
C(10)	0·5871(11)	0·8546(11)	0·7616(13)	
C(11)	0·5318(13)	0·9003(13)	0·5523(14)	
C(12)	0·4669(14)	0·9297(15)	0·6223(16)	
C(13)	0·4015(16)	0·9024(15)	0·5503(17)	
C(14)	0·3777(20)	0·9360(20)	0·4219(21)	
C(15)	0·3920(20)	0·9033(19)	0·3158(20)	
C(16)	0·4331(15)	0·8442(15)	0·4885(17)	
C(17)	0·5338(12)	0·8483(12)	1·0820(14)	
C(18)	0·7071(12)	0·8774(12)	0·8761(14)	
C(19)	0·6589(15)	0·8698(15)	0·5385(17)	
C(20)	0·6369(18)	1·0038(17)	0·5656(19)	
C(21)	0·5599(13)	0·6552(13)	0·7344(14)	
C(22)	0·5976(12)	0·5972(12)	0·7097(13)	
C(23)	0·5719(13)	0·5623(13)	0·6114(16)	
C(24)	0·6072(14)	0·5077(14)	0·5868(15)	
C(25)	0·6654(13)	0·4949(13)	0·6595(14)	
C(26)	0·6923(14)	0·5301(14)	0·7638(15)	
C(27)	0·6577(14)	0·5826(15)	0·7868(15)	
C(28)	0·6190(12)	0·6914(12)	1·1311(14)	
C(29)	0·5813(14)	0·6626(14)	1·2478(15)	
C(30)	0·5685(16)	0·5956(16)	1·2086(17)	
C(31)	0·5188(20)	0·5894(20)	1·0955(22)	
C(32)	0·5179(17)	0·6939(16)	1·3062(18)	
C(33)	0·6722(17)	0·7050(17)	1·3887(20)	
C(34)	0·7270(25)	0·6897(24)	1·4970(26)	
C(25)	0·8040(16)	0·8114(16)	0·8563(18)	
C(36)	0·8258(21)	0·7494(21)	0·8399(23)	
C(37)	0·6112(15)	0·9969(15)	1·1112(18)	
C(38)	0·6622(21)	1·0236(21)	1·2064(21)	
C(39)	0·1430(61)	0·2695(57)	0·2057(61)	
C(40)	0·1673(46)	0·2980(43)	0·2833(47)	

* For these atoms an anisotropic temperature factor of the form: $T = \exp[-(\beta_{11}h^2 + \beta_{22}k^2 + \beta_{33}l^2 + \beta_{12}hk + \beta_{13}hl + \beta_{23}kl)]$ was employed with parameters:

	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
Br	0·00439	0·00173	0·02049	0·00124	0·00418	−0·00314
Cl	0·00217	0·00215	0·01386	0·00030	0·00203	0·00086

Absolute Configuration.—In the final stage of the analysis, the absolute configuration of the molecule was determined by Bijvoet's anomalous dispersion method [12] based on the bromine and chlorine atoms. The differences for thirty-one pairs of $I(hkl)$ and $I(\bar{h}\bar{k}\bar{l})$ were measured on a Hilger and Watts four-circle automatic diffractometer with Cu-K_α radiation.

Structure factors were calculated for all these reflexions with scattering factors for the bromine and chlorine atoms of f'' 1·5 and 0·7. These results are listed in Table 4. A comparison between the observed and calculated intensities

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* For details see Notice to Authors No. 7 in *J. Chem. Soc.* (*A*), 1970, Issue No. 20 (items less than 10 pp are sent as full size copies).

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[12] J. M. Bijvoet, A. F. Peerdeman, and A. J. Van Bommel, *Nature*, 1951, **168**, 271.

indicated that the assumed absolute configuration was in fact correct.

Table 2

Bond lengths (Å) with standard deviations in parentheses

Br(1)–C(25)	1·914(15)	C(5)–C(10)	1·569(19)
Cl(1)–C(17)	1·820(15)	C(5)–C(18)	1·541(20)
O(1)–C(2)	1·488(17)	C(6)–C(7)	1·551(21)
O(1)–C(21)	1·336(17)	C(7)–C(8)	1·315(22)
O(2)–C(21)	1·193(18)	C(8)–C(9)	1·539(21)
O(3)–C(3)	1·473(16)	C(8)–C(20)	1·547(24)
O(3)–C(28)	1·347(17)	C(9)–C(10)	1·633(20)
O(4)–C(28)	1·204(18)	C(9)–C(11)	1·506(21)
O(5)–C(29)	1·492(19)	C(9)–C(19)	1·579(23)
O(5)–C(33)	1·383(23)	C(11)–C(12)	1·567(22)
O(6)–C(33)	1·194(23)	C(12)–C(13)	1·563(24)
O(7)–C(4)	1·421(17)	C(13)–C(14)	1·566(27)
O(8)–C(18)	1·471(18)	C(13)–C(16)	1·580(25)
O(8)–C(35)	1·309(21)	C(14)–C(15)	1·328(30)
O(9)–C(35)	1·233(25)	C(21)–C(22)	1·520(20)
O(10)–C(6)	1·408(16)	C(22)–C(23)	1·357(21)
O(10)–C(37)	1·336(20)	C(22)–C(27)	1·417(21)
O(11)–C(37)	1·221(24)	C(23)–C(24)	1·433(22)
O(12)–C(11)	1·455(18)	C(24)–C(25)	1·353(22)
O(12)–C(16)	1·391(21)	C(25)–C(26)	1·415(22)
O(13)–C(15)	1·396(27)	C(26)–C(27)	1·382(22)
O(13)–C(16)	1·436(24)	C(28)–C(29)	1·522(21)
O(14)–C(40)	1·647(62)	C(29)–C(30)	1·592(24)
C(1)–C(2)	1·494(20)	C(29)–C(32)	1·516(24)
C(1)–C(10)	1·554(20)	C(30)–C(31)	1·484(28)
C(2)–C(3)	1·540(19)	C(33)–C(34)	1·545(34)
C(3)–C(4)	1·554(19)	C(35)–C(36)	1·480(30)
C(4)–C(5)	1·569(19)	C(37)–C(38)	1·489(28)
C(4)–C(17)	1·572(19)	C(39)–C(40)	1·114(78)
C(5)–C(6)	1·527(19)		

DISCUSSION

This analysis has shown the molecular structure of clerodendrin A *p*-bromobenzoate chlorohydrin to be (III), hence structure (I) is confirmed for clerodendrin A.

The results of the anomalous dispersion calculation confirmed the spectral evidence that the absolute configuration of (III) is as shown in Figure 1. The absolute configuration of the 2-acetoxy-2-methylbutyric acid obtained by alkaline hydrolysis of (I) was determined as *R*-(−) by comparison of $[\alpha]_D$ with the reported value for an authentic sample of known absolute stereochemistry.[13] This result agreed with that from this *X*-ray analysis.

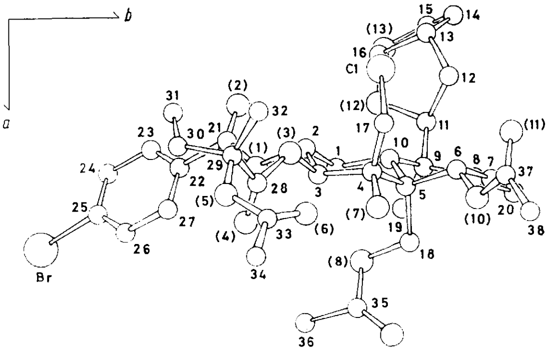

Figure 1 The molecule viewed along *c* axis showing the correct absolute configuration

Table 3

Valency angles (deg.) with standard deviations in parentheses

C(2)–O(1)–C(21)	117·2(1·0)	C(11)–C(12)–C(13)	104·1(1·2)
C(3)–O(3)–C(28)	115·7(1·0)	C(12)–C(13)–C(14)	114·6(1·4)
C(29)–O(5)–C(33)	115·3(1·2)	C(12)–C(13)–C(16)	102·3(1·3)
C(18)–O(8)–C(35)	117·6(1·2)	C(14)–C(13)–C(16)	101·0(1·3)
C(6)–O(10)–C(37)	120·2(1·1)	C(13)–C(14)–C(15)	109·3(1·7)
C(11)–O(12)–C(16)	111·4(1·1)	O(13)–C(15)–C(14)	113·1(1·8)
C(15)–O(13)–C(16)	110·6(1·5)	O(12)–C(16)–O(13)	110·4(1·4)
C(2)–C(1)–C(10)	110·0(1·1)	O(12)–C(16)–C(13)	107·9(1·3)
O(1)–C(2)–C(1)	106·8(1·0)	O(13)–C(16)–C(13)	105·6(1·4)
O(1)–C(2)–C(3)	100·6(1·0)	Cl(1)–C(17)–C(4)	115·1(0·9)
C(1)–C(2)–C(3)	108·8(1·1)	O(8)–C(18)–C(5)	109·7(1·1)
O(3)–C(3)–C(2)	109·1(1·0)	O(1)–C(21)–O(2)	124·0(1·3)
O(3)–C(3)–C(4)	106·0(0·9)	O(1)–C(21)–C(22)	111·2(1·1)
C(2)–C(3)–C(4)	115·3(1·0)	O(2)–C(21)–C(22)	124·1(1·3)
O(7)–C(4)–C(3)	106·4(1·0)	C(21)–C(22)–C(23)	117·1(1·2)
O(7)–C(4)–C(5)	108·6(1·0)	C(21)–C(22)–C(27)	119·4(1·2)
O(7)–C(4)–C(17)	99·6(1·0)	C(23)–C(22)–C(27)	123·4(1·3)
C(3)–C(4)–C(5)	111·5(1·0)	C(22)–C(23)–C(24)	117·7(1·4)
C(3)–C(4)–C(17)	113·3(1·0)	C(23)–C(24)–C(25)	118·1(1·4)
C(5)–C(4)–C(17)	115·9(1·0)	Br(1)–C(25)–C(24)	119·3(1·1)
C(4)–C(5)–C(6)	111·6(1·0)	Br(1)–C(25)–C(26)	115·6(1·1)
C(4)–C(5)–C(10)	109·0(1·0)	C(24)–C(25)–C(26)	124·9(1·4)
C(4)–C(5)–C(18)	111·6(1·1)	C(25)–C(26)–C(27)	116·2(1·4)
C(6)–C(5)–C(10)	105·6(1·0)	C(22)–C(27)–C(26)	119·4(1·3)
C(6)–C(5)–C(18)	105·1(1·0)	O(3)–C(28)–O(4)	124·7(1·3)
C(10)–C(5)–C(18)	113·5(1·1)	O(3)–C(28)–C(29)	109·8(1·1)
O(10)–C(6)–C(5)	109·9(1·0)	O(4)–C(28)–C(29)	125·3(1·3)
O(10)–C(6)–C(7)	105·1(1·0)	O(5)–C(29)–C(28)	105·7(1·1)
C(5)–C(6)–C(7)	113·5(1·1)	O(5)–C(29)–C(30)	99·5(1·1)
C(6)–C(7)–C(8)	121·2(1·3)	O(5)–C(29)–C(32)	109·5(1·2)
C(7)–C(8)–C(9)	126·2(1·4)	C(28)–C(29)–C(30)	107·0(1·2)
C(7)–C(8)–C(20)	116·3(1·4)	C(28)–C(29)–C(32)	117·9(1·3)
C(9)–C(8)–C(20)	117·4(1·3)	C(30)–C(29)–C(32)	115·1(1·3)
C(8)–C(9)–C(10)	109·5(1·1)	C(29)–C(30)–C(31)	112·1(1·5)
C(8)–C(9)–C(11)	105·5(1·1)	O(5)–C(33)–O(6)	121·9(1·7)
C(8)–C(9)–C(19)	111·8(1·2)	O(5)–C(33)–C(34)	109·2(1·6)
C(10)–C(9)–C(11)	109·8(1·1)	O(6)–C(33)–C(34)	128·4(1·9)
C(10)–C(9)–C(19)	110·9(1·1)	O(8)–C(35)–O(9)	120·8(1·7)
C(11)–C(9)–C(19)	108·9(1·2)	O(8)–C(35)–C(36)	112·6(1·6)
C(1)–C(10)–C(5)	113·1(1·0)	O(9)–C(35)–C(36)	126·2(1·8)
C(1)–C(10)–C(9)	110·7(1·0)	O(10)–C(37)–O(11)	120·7(1·6)
C(5)–C(10)–C(9)	116·2(1·0)	O(10)–C(37)–C(38)	112·8(1·5)
O(12)–C(11)–C(9)	111·0(1·1)	O(11)–C(37)–C(38)	126·3(1·7)
O(12)–C(11)–C(12)	102·2(1·1)	O(14)–C(40)–C(39)	80·3(4·3)
C(9)–C(11)–C(12)	117·2(1·2)		

The C(arom.)–Br distance (1·917 Å) is not much longer than values obtained in recent studies, *e.g.* C(arom.)–Br 1·93 in the enmein derivative,[14] 1·91 in ε-caesalpin,[15] 1·90 in the bromoindole derivative of 3β-methoxy-21-oxo-Δ^{13}-serratene,[16] and 1·91 Å in the *O*-*p*-bromobenzoate of batrachotoxinin A.[17] The C(18)–Cl distance (1·826 Å) is longer than the reported mean of 1·767 Å,[18] but the C–Cl distances cover a wide range, *e.g.* 1·728—1·761 in *cis*-1,2-diacetonyl-1,2,3,3-tetrachlorocyclopropane,[19] 1·800—1·814 in a chlorine cage compound,[20] 1·779 in DL-*N*-chloroacetylalanine,[21]

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TABLE 4

Forms used for the establishment of the absolute configuration

h	k	l	$F_c(hkl)$	$F_c(\bar{h}\bar{k}\bar{l})$	ΔF *	ΔI †
1	2	1	60·44	53·62	0·238	0·276
1	5	1	96·41	101·46	−0·102	−0·295
1	12	1	23·74	20·54	0·288	0·275
4	2	1	49·71	43·64	0·259	0·254
5	13	1	20·38	24·34	−0·355	−0·449
6	14	1	35·26	30·72	0·274	0·325
8	1	1	43·84	37·86	0·291	0·376
8	13	1	24·08	19·53	0·413	0·535
1	18	2	33·54	29·42	0·261	0·294
2	5	2	57·55	53·07	0·162	0·224
3	2	2	26·91	31·53	−0·314	−0·914
4	7	2	73·73	69·69	0·112	0·050
4	15	2	16·30	20·09	−0·412	−0·668
5	1	2	36·94	32·62	0·247	0·265
5	11	2	31·93	25·68	0·429	0·727
2	4	3	51·78	45·19	0·270	0·387
2	10	3	53·08	48·15	0·194	0·180
3	1	3	50·63	46·25	0·181	0·203
3	2	3	88·59	93·13	−0·100	−0·201
3	9	3	42·70	47·34	−0·206	−0·443
4	4	3	70·18	64·67	0·163	0·190
5	6	3	53·44	48·04	0·212	0·316
6	2	3	41·01	36·25	0·246	0·409
1	1	4	63·17	69·70	−0·196	−0·335
4	1	4	14·93	19·11	−0·484	−0·991
6	5	4	69·16	64·04	0·154	0·159
7	4	4	60·60	56·03	0·157	0·246
9	2	4	62·42	58·60	0·126	0·162
1	4	5	41·95	38·30	0·182	0·246
7	2	5	33·37	36·81	−0·196	−0·326
6	4	6	36·46	33·10	0·192	0·187

* $\Delta F = 2\{[F_c(hkl)]^2 - [F_c(\bar{h}\bar{k}\bar{l})]^2\}/\{[F_c(hkl)]^2 + [F_c(\bar{h}\bar{k}\bar{l})]^2\}$.

† $\Delta I = 2\{[I_o(hkl)]^2 - [I_o(\bar{h}\bar{k}\bar{l})]^2\}/\{[I_o(hkl)]^2 + [I_o(\bar{h}\bar{k}\bar{l})]^2\}$.

TABLE 5

(*a*) Mean planes in (III). Distances, d, in Å of atoms from the planes are given in square brackets, with, in parentheses d/σ

Plane (1): C(22), C(23), C(25)—(27)

[C(22) 0·001 (0·07), C(23) 0·004 (0·28), C(25) −0·013 (0·87), C(26) 0·016 (1·15), C(27) −0·011 (0·74), Br(1) 0·009 (4·73), C(21) 0·024 (1·84), O(2) −0·036 (3·39)]

Plane (2): C(2), C(3), C(5), C(10)

[C(2) −0·001 (0·07), C(3) 0·001 (0·08), C(5) −0·001 (0·08), C(10) 0·001 (0·08), C(1) 0·708(54·46), C(4) −0·616 (51·33)]

Plane (3): C(6)—(10)

[C(6) 0·000 (0·98), C(7) −0·015 (1·80), C(8) 0·026 (1·61), C(9) −0·021 (1·61), C(10) 0·010 (0·84), C(5) 0·713 (63·66)]

Plane (4): C(12), C(13), C(16), O(12)

[C(12) −0·006 (0·41), C(13) 0·009 (0·54), C(16) −0·010 (0·63), O(12) 0·007 (0·69), C(11) 0·516 (39·09)]

Plane (5): C(13)—(16), O(13)

[C(13) −0·006 (0·36), C(14) 0·003 (0·14), C(15) 0·002 (0·10), O(13) −0·007 (0·44), C(16) 0·008 (0·50)]

(*b*) Equations of planes, where X, Y, and Z are co-ordinates in Å

(1): $0{\cdot}5882X + 0{\cdot}4621Y - 0{\cdot}6636Z - 8{\cdot}1996 = 0$
(2): $0{\cdot}8756X - 0{\cdot}2475Y - 0{\cdot}4147Z - 1{\cdot}7509 = 0$
(3): $0{\cdot}9779X - 0{\cdot}2024Y + 0{\cdot}0506Z - 7{\cdot}3232 = 0$
(4): $0{\cdot}2221X + 0{\cdot}5062Y - 0{\cdot}8333Z - 7{\cdot}4563 = 0$
(5): $0{\cdot}9006X + 0{\cdot}4290Y - 0{\cdot}0685Z - 15{\cdot}2858 = 0$
(6) [a]: $0{\cdot}8910X + 0{\cdot}0254Y + 0{\cdot}4532Z - 13{\cdot}8799 = 0$
(7) [b]: $0{\cdot}9503X - 0{\cdot}0340Y + 0{\cdot}3094Z - 13{\cdot}3790 = 0$
(8) [c]: $0{\cdot}7658X + 0{\cdot}3353Y - 0{\cdot}5487Z - 10{\cdot}8329 = 0$

(*c*) Angles (deg.) between planes

(2)–(6)	125·9	(3)–(8)	130·8
(2)–(7)	122·8	(4)–(5)	118·1

[a] Plane (6): C(1), C(2), C(10). [b] Plane (7): C(3)—(5). [c] Plane (8): C(5), C(6), C(10).

and 1·82 and 1·85 Å in 3β-chloro-5-androstan-17β-ol.[22] The C(sp^3)–C(sp^3) distances are 1·486—1·626 Å and the C(sp^3)–C(sp^2) distances vary from 1·481 to 1·557 Å. The mean values (1·553 and 1·529 Å) do not differ significantly from the accepted means. The C(8)–C(20) distance (1·553 Å) however, is within the range for a C(sp^3)–C(sp^3) rather than a C(sp^2)–C(sp^3) bond.[23-25]

The aromatic ring [C(22)—(27)] is planar (Table 5) with a mean deviation of 0·008 Å [plane (1)]. When the substituent atoms Br, C(21), O(2) are included this value increases to 0·023 Å.

The cyclohexane and cyclohexene rings of the *trans*-octalin system are in chair and sofa conformations. In ring A, valence angles vary from 109·3 to 115·6°. The mean value (111·3°) is close to that of 111·6° for a chair form of cyclohexane calculated by Hendrickson from strain-energy minimization calculations.[26] Dihedral angles about the C(3)–C(4) and the C(4)–C(5) bonds (51·0 and 47·7°) show some deviation from the theoretical[26] value (54·4°). The values obtained for rings A and B are shown in Table 6 and 7. The C(2), C(3), C(5), and C(10) atoms [plane (2)] are coplanar and the deviations of the atoms C(1) and C(4) from the plane are 0·708 and 0·616 Å, respectively. The angle between plane (2) and that of the atoms C(1), C(2), and C(10) is 125·9°, whereas that between plane (2) and the plane of the atoms C(3)—(5) is expanded

TABLE 6

Dihedral angles (deg.) for rings A and B. The value quoted for each bond refers to the dihedral angle about that bond within the ring in question

Ring A			Ring B		
Bond	Found	Calc.*	Bond	Found	Calc.†
C(1)–C(2)	−58·9	−54·4	C(5)–C(6)	55·0	56
C(2)–C(3)	56·2	54·4	C(6)–C(7)	−27·9	−28
C(3)–C(4)	−51·0	−54·4	C(7)–C(8)	5·2	0
C(4)–C(5)	47·6	54·4	C(8)–C(9)	−5·3	0
C(5)–C(10)	−54·1	−54·4	C(9)–C(10)	27·1	29
C(1)–C(10)	61·3	54·4	C(5)–C(10)	−56·0	−58

* From ref. 26. † From ref. 28.

TABLE 7

Valence angles (deg.) for rings A and B. The value quoted for each atom refers to the valency angles about that atom within the ring in question

Ring A			Ring B		
Atom	Found	Calc.*	Atom	Found	Calc.†
C(1)	110·0	111·6	C(5)	105·6	110·5
C(2)	108·8	111·6	C(6)	113·5	108·5
C)3)	115·3	111·6	C(7)	121·2	123·0
C(4)	111·5	111·6	C(8)	126·2	124·0
C(5)	109·0	111·6	C(9)	109·5	113·5
C(10)	113·1	111·6	C(10)	116·2	112·5

* From ref. 26. † From ref. 28.

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to 135·4° compared with values of 122·8° obtained from the theoretical value for a chair-form of cyclohexane. This would appear to be a torsion caused by an axial chloromethyl group at C(4) and by the fusion of the distorted ring B.[27]

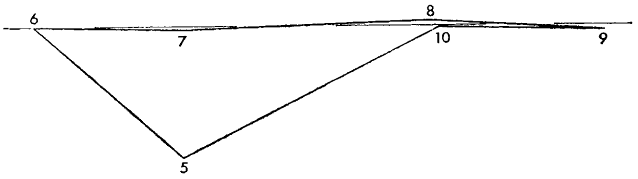

FIGURE 2 Conformation of ring B viewed through C(7)–C(8) along plane (3)

In cyclohexene ring B, the observed dihedral angles are in good agreement with the value calculated by Bucourt and Hainaut [28] for the ' sofa ' conformation, which is more energetic than the ' half-chair ' conformation. The dihedral angles (5·20 and 5·26°) at C(7)–C(8) and C(8)–C(9) deviate from the theoretical value (0° for both angles), while the values of the other angles are very close to those calculated. The deviations of the valence angles are within 5°, mean deviation 3·1°, compared with the theoretical values (Table 7). Atoms C(6)—(10) [plane (3); Table 5] are closely coplanar and the deviation of atom C(5) from the plane is 0·713 Å. The angle of 130·8° between plane (3) and that of the atoms C(5), C(6), and C(10) is close to the calculated value. Then, ring B is closer to the ideal sofa conformation than is ring E of 3β-methoxy-21-oxo-Δ^{13}-serratene [29] and ring C of ε-caesalpin (Figure 2).[15] Ring B exists in the sofa conformation even if it is not attached to small rings as in the serratene and ε-caesalpin derivatives.

It is shown both theoretically [28] and empirically [30] that Δ^2-octalin is more stable than Δ^1-octalin. Bucourt and Hainaut also made calculations concerning dihedral angles and concluded that the stable Δ^2-octalin possesses a monoplanar conformation, and a favourable conformation for the energetic Δ^1-octalin is an intermediate between mono- and 1,2-di-planar forms. We have applied these data to the problem of the conformation of the octalin system in clerodendrin A. This distortion of the normally stable octalin ring may be caused by the effect not only of the 1,3-diaxial interactions between the C(5)–CH_2·OAc and the C(9)–CH_3 [3·522 Å between the C(18) and C(19) distance] but also the distortion of the C(5) substituent from the steric-compression effect by groups at C(4) and C(6) (Figure 3). The sum of the dihedral angles of the plane C(1)–C(10)–C(5)–C(4) and C(6)–C(5)–C(10)–C(9) is 110·06° which is less than the calculated value (120°). This is attributed to bending of ring A by the C(4) substituent.

Rings C and D of the tetrahydrofurofuran ring exhibit the envelope and coplanar conformations. Bond lengths of ring C vary from 1·388 to 1·580 Å and their values are very close to those in ring C of clerodin bromolactone. Valence angles of ring C are also close to those of the clerodin derivative. The mean values of bond lengths and valence angles are close to those of the tetrahydrofuran ring.[31] However, in ring D, bond lengths and valence angles are very close to those of the outer dihydrofuran ring in aflatoxin B_1.[32] Ring C exists in the envelope form, where atoms C(12), C(13), C(16), and O(12) [plane (4)] are almost coplanar, with C(11) displaced by 0·516 Å and all atoms of ring D lying within 0·007 Å of the plane [plane (5)]. The angle between plane (4) and the plane of ring D is 118·1° which is close to the value (117·2°) for the similar ring system in aflatoxin B_2,[33] but greater than for clerodin (114·3°) and aflatoxin B_1 (113·3°).

The solvated ethanol molecule is associated with a high thermal vibration, as can be seen from the high σ values for the bond lengths and valence angles. The bond lengths of C(39)–C(40) and C(39)–O(14) are very different from those of the solvated ethanol of the serratene derivative (1·610 and 1·232 Å) and in ethanol itself (1·54 and 1·48 Å).[18] It seems reasonable to reverse the C–O and C–C bonds the ethanol molecule. However, if the atomic parameters of C(39) and O(14) are interchanged, the isotopic temperature factors of the atoms are very high, giving rise to large uncertainties in the atomic locations.

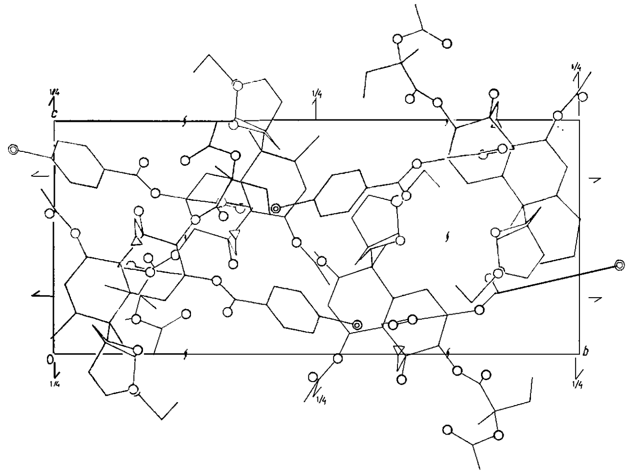

FIGURE 3 The unit cell contents viewed along *a*

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