from the C(1), C(2), P(2) plane, and the mean angle at N(7) is only 117·4°. The corresponding values in the *trans* isomer are −0·261 (5) Å and 117·1° at N(7), and 0·236 (5) Å and 117·6° at N(8).

Residual electron densities

Two composite drawings of the residual electron distributions in the final difference maps of the two isomers are shown in Fig. 3(*a*),(*b*), where only the significant peaks and troughs are drawn. They occur in the ranges −0·28 to 0·54 and −0·44 to 0·56 e $Å^{-3}$ for the *cis* and *trans* isomers respectively, and are considered significant beyond ±0·3 e $Å^{-3}$. While most of the peaks are typical of bonding electrons, there is some residual density in the PCl_2 plane on the Cl(3)···Cl(4) vector, especially in the *trans* isomer.

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Structure and Synthesis of 14α-Ethyl-5α-cholest-7-ene-3β,15α-diol Di-*p*-bromobenzoate

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Abstract

14α-Ethyl-5α-cholest-7-ene-3β,15α-diol has been shown to be a very potent inhibitor of sterol biosynthesis in cultured animal cells. The chemical synthesis and crystal structure of 14α-ethyl-5α-cholest-7-ene-3β,15α-diol di-*p*-bromobenzoate are described. The compound crystallized in the space group $P2_1$, two molecules per unit cell, with cell dimensions: a = 10·948 (9), b = 6·332 (2), c = 28·983 (8) Å, β = 97·33 (5)°. The structure was solved by the heavy-atom method and refined by block-matrix anisotropic least squares to R = 7·9%. Both the 14-ethyl group and the O substituent at C(15) are on the α side of the steroid nucleus. Ring *B* has a half-chair conformation and the *C–D* ring juncture is *trans*.

Introduction

A number of 15-oxygenated sterols have been found to be potent inhibitors of sterol biosynthesis in animal cells in culture (Schroepfer, Parish, Chen & Kandutsch, 1976, 1977; Schroepfer, Parish & Kandutsch, 1977, 1979; Schroepfer, Raulston & Kandutsch, 1977; Schroepfer, Pascal & Kandutsch, 1980; Schroepfer, Parish, Tsuda, Raulston & Kandutsch, 1979). Moreover, several of these 15-oxygenated sterols have been shown to have significant hypocholesterolemic activity in animals (Raulston, Mishaw, Parish & Schroepfer, 1976; Kisic, Monger, Parish, Satterfield, Raulston & Schroepfer, 1977; Schroepfer, Monger, Taylor, Chamberlain, Parish, Kisic & Kandutsch, 1977; Kisic, Taylor, Chamberlain, Parish & Schroepfer, 1978). The most potent of these inhibitors of sterol biosynthesis described to date are 14α-ethyl-5α-cholest-7-ene-3β,15α-diol (Schroepfer, Parish & Kandutsch, 1977; Schroepfer, Parish, Tsuda, Raulston & Kandutsch, 1979) and its corresponding 3-keto derivative, 14α-ethyl-15α-hydroxy-5α-cholest-7-en-3-one (Schroepfer, Raulston & Kandutsch, 1977; Schroepfer, Parish, Tsuda, Raulston & Kandutsch, 1979). These compounds caused a 50% inhibition of sterol synthesis in *L* cells at 5 × 10^{-8} *M* and 6 × 10^{-9} *M*, respectively. In

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view of the extraordinarily high biological potency of these compounds we have pursued the unequivocal determination of the structure of 14α-ethyl-5α-cholest-7-ene-3β,15α-diol by X-ray crystallographic analysis.

The purpose of this communication is to report the chemical synthesis of 14α-ethyl-5α-cholest-7-ene-3β,15α-diol di-*p*-bromobenzoate and the results of X-ray crystallographic studies of this compound.

Experimental

Synthesis

The recording of melting points, infrared spectra, optical rotations (chloroform solvent), nuclear magnetic resonance spectra, and low-resolution mass spectra were made as described previously (Pascal, Shaw & Schroepfer, 1979). 14α-Ethyl-5α-cholest-7-ene-3β,15α-diol was prepared as described previously (Schroepfer, Parish & Kandutsch, 1977; Parish, Tsuda & Schroepfer, 1979).

To 14α-ethyl-5α-cholest-7-ene-3β,15α-diol (0·50 g; 1·20 mmol) in pyridine (150 ml) was added *p*-bromobenzoyl chloride (2·0 g). The mixture was warmed on a steam bath until complete solution occurred. After standing at room temperature (298 K) for 36 h, the mixture was poured into a solution of NH_4Cl (1%) and the resulting white precipitate was collected, washed with water, dried, and subjected to chromatography on a silica-gel (55 g; 60–200 mesh) column (600 × 20 mm). With benzene as the eluting solvent, fractions 20 ml in volume were collected (flow rate, 5 ml min^{-1}). The contents of fractions 19 through 23, containing the major product, were pooled. Evaporation of the solvent under reduced pressure gave 14α-ethyl-5α-cholest-7-ene-3β,15α-diol di-*p*-bromobenzoate as a white crystalline solid (0·85 g; 89% yield) which melted at 524·5–525·5 K (spectral data are presented in Table 1). The compound showed a single component upon thin-layer chromatographic analyses on silica-gel *G* plates (solvent systems: benzene, R_f 0·81; 25% hexane in benzene, R_f 0·74). Crystals of the di-*p*-bromobenzoate suitable for X-ray crystal analysis were obtained by slow crystallization from a mixture of acetone and methylene chloride. Crystal density was determined by flotation in a solution of sodium bromide.

Table 1. *Spectroscopic data for* 14α-*ethyl*-5α-*cholest*-7-*ene*-3β,15α-*diol di-p-bromobenzoate*

Infrared (ν_{max}^{KBr}; cm^{-1}): 1720, 1595, 1280, 1120, 1107, 1017, 848, 761.

Nuclear magnetic resonance (δ; p.p.m.):
1·20 (*m*, methylene envelope),
5·09 [*m*, 1H, H–C(3)],
5·43 [*m*, 1H, H–C(7)],
5·56 [*m*, 1H, H–C(15)],
8·05 (*m*, 8H, aromatic).

Optical rotation ($[\alpha]_D$): +77·9° (*c*, 0·26 g dm^{-3}).

Mass (*m/e*, low resolution):
798, 796, and 794 (0·1, 0·1, and 0·1%; *M*),
769, 767, and 767 (1, 2, and 1%; $M - CH_2CH_3$),
596 and 594 (4 and 4%; *M* – bromobenzoic acid),
581 and 579 (1 and 1%; *M* – bromobenzoic acid – CH_3),
567 and 565 (49 and 49%; *M* – bromobenzoic acid – CH_2CH_3),
366 (100%; *M* – bromobenzoic acid – bromobenzoic acid – CH_2CH_3),
253 (8%; *M* – bromobenzoic acid – bromobenzoic acid – side chain – CH_2CH_3),
203 and 201 (10 and 10%; bromobenzoic acid),
186 and 184 (50 and 53%; bromobenzoic acid – OH).

Mass (*m/e*, high resolution):
794·2534 (*M*),
(calculated for $C_{43}H_{56}O_4^{79}Br_2$: 794·2545).

Structure analysis

Precession photographs using Ni-filtered Cu *Kα* radiation (λ = 1·5418 Å) showed space group $P2_1$ (systematic absence 0*k*0, for $k = 2n + 1$). Diffraction data were collected on a Syntex $P2_1$ diffractometer with Ni-filtered Cu *Kα* radiation using the variable $2\theta/\theta$ scan mode (range, 2 to 29·3° min^{-1}). Only one crystal was required for data collection. Crystal deterioration in the X-ray beam was minimized by sealing the crystal under vacuum in a 0·1 mm glass capillary. Three check reflections were monitored every 100 reflections. Less than 5% decay was observed in the intensities of the monitor reflections after 95 h of X-ray exposure. The data were corrected for background, Lorentz–polarization and absorption using a semi-empirical procedure (North, Phillips & Mathews, 1968). A total of 3170 reflections were measured (to a limit of $\sin\theta/\lambda$ = 0·42 $Å^{-1}$ or d_{min} = 1·2 Å) at two different power settings. Of these, 1144 reflections were replicate intensities measured for a given unique reflection within a given data set. Poor agreement between replicate intensities of identical reflections eliminated 29 reflections. An additional 206 reflections were rejected owing to either negative intensity (after background subtraction) or to uneven background (rejected if $0·5 > B_1/B_2 > 1·5$, where B_1 = left background count, B_2 = right background count). Each diffraction data set contained 483 identical reflections for correlation using a

Table 2. *Crystal data*

Molecular formula	$C_{43}H_{56}O_4Br_2$	*Z*	2
M_r	796·7	*V*	1992 (2) $Å^3$
Space group	$P2_1$	Radiation	Cu *Kα*
a	10·948 (9) Å	D_c	1·324 Mg m^{-3}
b	6·332 (2)	D_m	1·342 (8)
c	28·983 (8)	μ	3·167 mm^{-1}
β	97·33 (5)°		

linearized least-squares method (Rae, 1965). The final correlation R value ($R_{ij} = \sum_h |S_i I_{hi} - S_j I_{hj}| / \sum_h |S_i I_{hi} + S_j I_{hj}|$; where S = scale factor, I = intensity, i, j = correlated data sets, and $\mathbf{h}$ = reflection) was 0·022. An additional 48 reflections were deleted from the correlated data due to a relatively large average error ($\sigma_{F_o} \geq \frac{1}{5}F_o$) calculated for some structure factor amplitudes. A total of 1260 independent observable reflections were used in the refinement process. A list of the pertinent crystal data is presented in Table 2.

Table 3. *Fractional atomic coordinates* (×10⁴) *and equivalent isotropic thermal parameters for the non-hydrogen atoms with standard deviations in parentheses*

	x	y	z	$B_{eq.}$ or B (Å²)
C(1)	648 (24)	522 (48)	1314 (9)	5·0 (10)
C(2)	−491 (22)	1504 (47)	1014 (9)	4·5 (9)
C(3)	−1336 (20)	2378 (49)	1357 (8)	3·7 (7)
C(4)	−730 (22)	3883 (44)	1688 (8)	3·6 (8)
C(5)	468 (21)	3003 (43)	1956 (8)	3·6 (8)
C(6)	1099 (23)	4706 (47)	2270 (9)	4·3 (9)
C(7)	2351 (22)	3906 (44)	2518 (9)	4·0 (9)
C(8)	2910 (19)	2231 (42)	2370 (7)	3·0 (7)
C(9)	2394 (19)	940 (43)	1968 (8)	3·0 (7)
C(10)	1378 (20)	2121 (42)	1649 (8)	3·4 (8)
C(11)	3367 (22)	−82 (42)	1672 (9)	3·6 (8)
C(12)	4542 (22)	−859 (42)	1983 (9)	3·5 (8)
C(13)	5050 (20)	722 (42)	2337 (7)	3·0 (8)
C(14)	4075 (20)	1398 (45)	2660 (8)	3·1 (7)
C(15)	4790 (20)	2857 (42)	2998 (8)	3·0 (7)
C(16)	6111 (20)	1822 (46)	3081 (8)	4·1 (9)
C(17)	6129 (21)	157 (38)	2699 (8)	3·0 (7)
C(18)	5395 (20)	2787 (42)	2061 (8)	3·1 (7)
C(19)	1937 (24)	3795 (51)	1364 (10)	5·4 (10)
C(20)	7446 (21)	27 (44)	2543 (8)	3·6 (8)
C(21)	7551 (23)	−1733 (50)	2180 (10)	5·4 (10)
C(22)	8438 (22)	−258 (52)	2940 (9)	4·6 (9)
C(23)	8438 (22)	−2236 (58)	3228 (9)	5·6 (10)
C(24)	9299 (28)	−2188 (63)	3659 (12)	7·7 (13)
C(25)	9440 (30)	−3950 (103)	3960 (12)	11·4 (18)
C(26)	10271 (50)	−5718 (79)	3753 (17)	13·2 (18)
C(27)	9958 (37)	−3645 (100)	4432 (14)	12·2 (18)
C(28)	−3381 (23)	2284 (46)	914 (9)	4·3 (8)
C(29)	−4449 (20)	3511 (43)	731 (8)	3·5 (8)
C(30)	−4529 (21)	5632 (47)	877 (9)	4·7 (9)
C(31)	−5532 (19)	6804 (38)	728 (8)	3·3 (8)
C(32)	−6414 (22)	5930 (44)	451 (9)	4·2 (9)
C(33)	−6372 (22)	3824 (49)	281 (9)	4·3 (9)
C(34)	−5327 (20)	2639 (49)	430 (8)	3·8 (8)
C(35)	4791 (20)	4794 (49)	3682 (8)	3·9 (7)
C(36)	4254 (20)	5046 (46)	4112 (9)	3·8 (8)
C(37)	3569 (24)	3534 (51)	4309 (9)	4·9 (9)
C(38)	3127 (23)	3890 (63)	4728 (10)	6·1 (11)
C(39)	3266 (24)	5949 (56)	4992 (9)	5·4 (9)
C(40)	3970 (22)	7278 (53)	4784 (8)	4·7 (9)
C(41)	4442 (21)	7113 (48)	4366 (9)	4·6 (9)
C(42)	3669 (22)	−641 (44)	2930 (9)	4·0 (9)
C(43)	2486 (22)	−412 (45)	3166 (9)	4·1 (9)
O(3)	−2410 (15)	3464 (28)	1105 (6)	4·8 (6)
O(15)	4304 (13)	3159 (25)	3427 (5)	3·3 (5)
O(28)	−3375 (15)	381 (28)	908 (6)	5·0 (6)
O(35)	5576 (15)	5946 (29)	3574 (6)	4·5 (6)
Br(32)	−7926 (3)	7506 (8)	220 (1)	6·6 (1)
Br(39)	2720 (3)	6236 (9)	5528 (1)	8·4 (1)

Table 4. *Fractional atomic coordinates* (×10³) *for the hydrogen atoms*

Asterisks indicate hydrogen atoms located by the difference synthesis.

	x	y	z		x	y	z
H1(C1)	126	−10	109	H2(C21)*	852	−190	212
H2(C1)	34	−74	152	H3(C21)*	699	−131	185
H1(C2)	−97	32	80	H1(C22)	838	105	317
H2(C2)	−21	276	80	H2(C22)	930	−21	280
H1(C3)	−155	95	153	H1(C23)	868	−354	302
H1(C4)	−135	429	193	H2(C23)	753	−247	332
H2(C4)	−51	527	150	H1(C24)	902	−89	386
H1(C5)	19	170	215	H2(C24)	1019	−186	356
H1(C6)	52	513	253	H1(C25)	850	−439	397
H2(C6)	125	607	206	H1(C26)*	1047	−523	341
H1(C7)	278	473	282	H2(C26)*	977	−723	372
H1(C9)	199	−37	213	H3(C26)*	1114	−591	398
H1(C11)	363	108	143	H1(C27)*	1077	−261	444
H2(C11)	295	−140	148	H2(C27)*	1023	−518	459
H1(C12)	523	−121	176	H3(C27)*	927	−290	463
H2(C12)	432	−227	216	H1(C30)	−378	632	111
H1(C15)	477	442	286	H1(C31)	−560	843	84
H1(C16)	626	110	342	H1(C33)	−713	317	5
H2(C16)	681	299	305	H1(C34)	−523	104	30
H1(C17)	599	−144	280	H1(C37)	338	204	413
H1(C18)*	454	357	190	H1(C38)	265	261	488
H2(C18)*	595	233	178	H1(C40)	421	872	498
H3(C18)*	593	388	230	H1(C41)	492	841	423
H1(C19)*	121	450	111	H1(C42)	441	−104	319
H2(C19)*	264	307	117	H2(C42)	353	−191	268
H3(C19)*	237	503	160	H1(C43)*	264	77	345
H1(C20)	757	152	238	H2(C43)*	226	−194	331
H1(C21)*	722	−323	231	H3(C43)*	172	11	291

Patterson and Fourier methods were used to locate all non-hydrogen atoms. The non-hydrogen atomic coordinates (Table 3) were refined by both diagonal and block least-squares methods. The function minimized was $\sum w(k^2|F_o|^2 - |F_c|^2)^2$. Br and O atoms were given anisotropic temperature factors prior to calculation of the H positions. The C temperature factors were subsequently refined anisotropically after location of the methyl H atoms using difference Fourier analysis. H positions were not refined, but were recalculated after each three-cycle refinement of the non-hydrogen atomic coordinates and anisotropic temperature factors. Final H coordinates were calculated (Table 4) with no change in the structure factor obtained from the final non-hydrogen parameter refinements. A Hughes (1941) weighting scheme was employed in the refinements, where $w = 1/F_o$ for $F_o > 4(F_o)_{min}$ or $w = 1/[F_o(4F_o)_{min}]$ for $F_o < 4(F_o)_{min}$. The final unweighted R value was 0·079; R weighted was 0·031.* A check on the correctness of the structure was

* Lists of structure factors and anisotropic thermal parameters have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 35128 (21 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

made by calculating a final difference Fourier map. The largest electron density observed from this map which was not associated with a Br atom had a value of 0·3 e Å^{-3}.

All crystallographic calculations were made with the *CRYM* system (an unpublished program system originated by D. J. DuChamp of the UpJohn Company and modified by R. E. Marsh at Caltech and by G. N. Reeke at Harvard Universities). Figs. 2–4 (see below) were drawn by the *ORTEP* program (Johnson, 1965).

Description of structure and discussion

Tables 5 and 6 list the bond lengths, bond angles and torsion angles for the steroid nucleus and for the extra-nuclear atoms, respectively. For ease of viewing, the non-hydrogen bond lengths are also included in the steroid numbering scheme shown in Fig. 1. The mirror plane $\{\Delta C_s = \sum_{l=1}^{m} [(\varphi_l + \varphi_{l'})^2/m]^{1/2}$, where φ_l and $\varphi_{l'}$ are symmetry-related torsion angles and m is the number of individual comparisons made$\}$ and twofold $\{\Delta C_2 = \sum_{l=1}^{m} [(\varphi_l - \varphi_{l'})^2/m]^{1/2}\}$ asymmetry parameters are presented in Table 7 (Duax & Norton, 1975). Ring *A* is in a chair conformation of high symmetry (Fig. 2). This is indicated by the low values for the asymmetry parameters, all of which fall below 6·0° (Table 7). The average of the dihedral angles in ring *A* is 55·3 (5)°. The presence of a double bond between C(7) and C(8) gives rise to a symmetrical 5α,10β-half-chair conformation in ring *B* with the only asymmetry param-

Table 5. *Intramolecular geometry: steroid nucleus with standard deviations in parentheses*

(*a*) Interatomic distances (Å)

Ring *A*		Ring *B*		Ring *C*		Ring *D*	
C(1)–C(2)	1·556 (4)	C(5)–C(6)	1·519 (5)	C(8)–C(9)	1·475 (4)	C(13)–C(14)	1·567 (3)
C(2)–C(3)	1·544 (3)	C(6)–C(7)	1·550 (3)	C(9)–C(11)	1·588 (3)	C(14)–C(15)	1·493 (4)
C(3)–C(4)	1·451 (4)	C(7)–C(8)	1·323 (5)	C(11)–C(12)	1·554 (3)	C(15)–C(16)	1·578 (4)
C(4)–C(5)	1·541 (3)	C(8)–C(9)	1·475 (4)	C(12)–C(13)	1·489 (4)	C(16)–C(17)	1·530 (4)
C(5)–C(10)	1·524 (3)	C(9)–C(10)	1·546 (3)	C(13)–C(14)	1·567 (3)	C(13)–C(17)	1·519 (2)
C(1)–C(10)	1·552 (4)	C(5)–C(10)	1·524 (3)	C(8)–C(14)	1·529 (3)		

(*b*) Valency angles (°)

Ring *A*		Ring *B*		Ring *C*		Ring *D*	
C(10)–C(1)–C(2)	113·6 (5)	C(8)–C(9)–C(10)	112·2 (5)	C(11)–C(12)–C(13)	113·3 (5)	C(16)–C(17)–C(13)	104·9 (5)
C(1)–C(2)–C(3)	106·7 (5)	C(9)–C(10)–C(5)	107·6 (5)	C(9)–C(11)–C(12)	112·2 (5)	C(14)–C(13)–C(17)	100·4 (5)
C(2)–C(3)–C(4)	113·6 (5)	C(10)–C(5)–C(6)	109·2 (4)	C(8)–C(9)–C(11)	115·9 (5)	C(15)–C(14)–C(13)	102·8 (5)
C(3)–C(4)–C(5)	112·6 (5)	C(5)–C(6)–C(7)	110·7 (5)	C(9)–C(8)–C(14)	116·8 (5)	C(14)–C(15)–C(16)	103·7 (5)
C(4)–C(5)–C(10)	114·6 (4)	C(6)–C(7)–C(8)	122·0 (4)	C(8)–C(14)–C(13)	110·5 (4)	C(15)–C(16)–C(17)	105·8 (5)
C(1)–C(10)–C(5)	106·3 (4)	C(7)–C(8)–C(9)	123·6 (5)	C(12)–C(13)–C(14)	111·8 (4)		
C(1)–C(10)–C(9)	109·4 (5)	C(10)–C(9)–C(11)	110·8 (4)	C(12)–C(13)–C(17)	120·4 (5)		
C(4)–C(5)–C(6)	109·8 (5)	C(7)–C(8)–C(14)	119·1 (6)	C(8)–C(14)–C(15)	118·6 (5)		

(*c*) Torsion angles (°) in the rings

Ring *A*		Ring *B*		Ring *C*	
C(10)–C(1)–C(2)–C(3)	−59·3 (5)	C(6)–C(7)–C(8)–C(9)	−1·6 (4)	C(12)–C(13)–C(14)–C(8)	−55·8 (4)
C(1)–C(2)–C(3)–C(4)	56·2 (5)	C(7)–C(8)–C(9)–C(10)	18·6 (5)	C(9)–C(8)–C(14)–C(13)	48·0 (4)
C(2)–C(3)–C(4)–C(5)	−53·8 (5)	C(8)–C(9)–C(10)–C(5)	−50·2 (5)		
C(3)–C(4)–C(5)–C(10)	52·7 (4)	C(6)–C(5)–C(10)–C(9)	67·0 (4)	Ring *D*	
C(4)–C(5)–C(10)–C(1)	−52·3 (4)			C(17)–C(13)–C(14)–C(15)	47·8 (5)
C(2)–C(1)–C(10)–C(5)	57·7 (4)	Ring *C*		C(13)–C(14)–C(15)–C(16)	−37·1 (5)
		C(14)–C(8)–C(9)–C(11)	−40·5 (5)	C(14)–C(15)–C(16)–C(17)	13·1 (5)
Ring *B*		C(8)–C(9)–C(11)–C(12)	38·3 (5)	C(15)–C(16)–C(17)–C(13)	17·0 (5)
C(10)–C(5)–C(6)–C(7)	−49·7 (4)	C(9)–C(11)–C(12)–C(13)	−47·1 (5)	C(14)–C(13)–C(17)–C(16)	−38·9 (5)
C(5)–C(6)–C(7)–C(8)	17·4 (4)	C(11)–C(12)–C(13)–C(14)	57·0 (4)		

(*d*) Torsion angles (°) at the ring junctions

C(2)–C(1)–C(10)–C(9)	173·6 (5)	C(7)–C(8)–C(14)–C(15)	−21·2 (6)	C(12)–C(11)–C(9)–C(10)	167·7 (4)
C(3)–C(4)–C(5)–C(6)	176·0 (5)	C(9)–C(8)–C(14)–C(15)	166·1 (5)	C(11)–C(12)–C(13)–C(17)	174·5 (5)
C(4)–C(5)–C(6)–C(7)	−176·1 (5)	C(7)–C(8)–C(9)–C(11)	147·2 (5)	C(12)–C(13)–C(14)–C(15)	176·8 (4)
C(4)–C(5)–C(10)–C(9)	−169·4 (4)	C(14)–C(8)–C(9)–C(10)	−169·1 (5)	C(17)–C(13)–C(14)–C(8)	175·3 (4)
C(6)–C(5)–C(10)–C(1)	−175·8 (4)	C(11)–C(9)–C(10)–C(1)	63·4 (4)	C(12)–C(13)–C(17)–C(16)	−162·1 (5)
C(6)–C(7)–C(8)–C(14)	−173·8 (5)	C(11)–C(9)–C(10)–C(5)	178·6 (4)	C(8)–C(14)–C(15)–C(16)	−159·2 (5)
C(7)–C(8)–C(14)–C(13)	−139·4 (5)	C(1)–C(10)–C(9)–C(8)	−165·3 (5)		

eter for the ring being less than 1° [$\Delta C_2^{5,10} = 0.9$ (4)°]. The average of the dihedral angles in ring *B* is 34·1 (4)°. The sp^2 hybridization of C(8) accounts for the quasi-*trans* *B*–*C* ring juncture. The other two ring junctures, *A*–*B* and *C*–*D*, are both *trans*. The slight distortion of the chair conformation of ring *C* can be seen in Fig. 2(*b*) on comparison with the symmetrical chair conformation of ring *A*. This is further substantiated by the larger asymmetry parameters for ring *C versus* those for ring *A* (Table 7). The average of the dihedral angles in ring *C* is 47·8 (5)°. Ring *D* has a conformation intermediate between a 13β,14α-half-chair and a 13β-envelope. Values for the maximal torsional parameter, φ_m, and phase angle of pseudorotation, Δ, fall in the range observed for most steroids (Duax & Norton, 1975). The Δ value of 4·5 (5)° (Table 7) indicates more of a half-chair conformation ($\Delta = 0°$, for the ideal 13β,14α-half-chair form) rather than an envelope conformation [$\Delta = -36$ or $+36°$, for the ideal C(14) or C(13) envelope form, respectively] (Altona, Geise & Romers, 1968). As a measure of ring-*D* puckering, the sum of the distances of atoms C(13) and C(14) to the plane through C(15)—C(16)—C(17) was found to be 0·75 Å, well within the range found for other steroids with *trans* *C*–*D* ring junctures, β substituents at C(13) and C(17), and saturated *C* rings (Altona, Geise & Romers, 1968). The average of the dihedral angles in ring *D* is 30·8 (5)°.

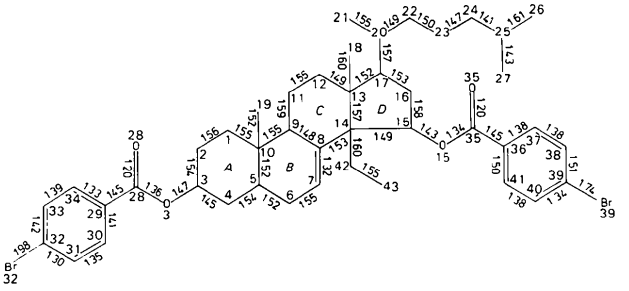

Fig. 1. Atomic numbering scheme for 14α-ethyl-5α-cholest-7-ene-3β,15α-diol di-*p*-bromobenzoate showing non-hydrogen interatomic distances (Å) [see Tables 5(*a*) and 6(*a*) for e.s.d.'s].

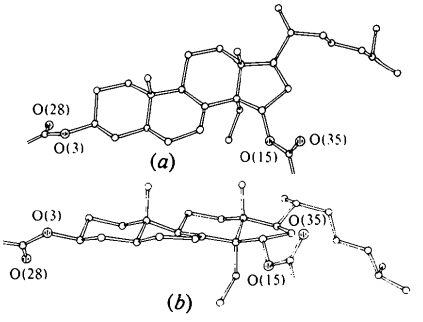

Fig. 2. (*a*) Top and (*b*) side views (*ORTEP*) of the steroid molecule without the *p*-bromophenyl substituents.

Fig. 3 is a projection of 14α-ethyl-5α-cholest-7-ene-3β,15α-diol di-*p*-bromobenzoate viewed with the

Table 6. *Intramolecular geometry: extra-nuclear with standard deviations in parentheses*

(*a*) Interatomic distances (Å)

Oxygen			
C(3)–O(3)	1·473 (3)	C(15)–O(15)	1·426 (1)
C(28)–O(3)	1·358 (4)	C(35)–O(15)	1·342 (4)
C(28)–O(28)	1·205 (5)	C(35)–O(35)	1·199 (4)
Bromine			
C(32)–Br(32)	1·975 (3)	C(39)–Br(39)	1·744 (1)
Methyl			
C(13)–C(18)	1·603 (5)	C(10)–C(19)	1·519 (5)
Ethyl			
C(14)–C(42)	1·601 (5)	C(42)–C(43)	1·547 (3)
Bromobenzoate			
C(28)–C(29)	1·447 (4)	C(35)–C(36)	1·453 (2)
C(29)–C(30)	1·414 (6)	C(36)–C(37)	1·383 (5)
C(29)–C(34)	1·333 (3)	C(36)–C(41)	1·502 (6)
C(30)–C(31)	1·350 (4)	C(37)–C(38)	1·382 (2)
C(31)–C(32)	1·298 (3)	C(38)–C(39)	1·509 (7)
C(32)–C(33)	1·424 (6)	C(39)–C(40)	1·336 (6)
C(33)–C(34)	1·390 (4)	C(40)–C(41)	1·380 (2)
17-Side chain			
C(17)–C(20)	1·568 (3)	C(23)–C(24)	1·466 (2)
C(20)–C(21)	1·547 (5)	C(24)–C(25)	1·412 (10)
C(20)–C(22)	1·489 (2)	C(25)–C(26)	1·606 (10)
C(22)–C(23)	1·505 (7)	C(25)–C(27)	1·426 (3)

(*b*) Valency angles (°)

Oxygen			
C(2)–C(3)–O(3)	110·7 (5)	C(14)–C(15)–O(15)	115·6 (5)
C(4)–C(3)–O(3)	106·9 (5)	C(16)–C(15)–O(15)	111·1 (6)
C(3)–O(3)–C(28)	118·6 (4)	C(15)–O(15)–C(35)	114·6 (4)
O(3)–C(28)–O(28)	123·4 (4)	O(15)–C(35)–O(35)	125·0 (4)
O(3)–C(28)–C(29)	114·1 (5)	O(15)–C(35)–C(36)	112·4 (5)
O(28)–C(28)–C(29)	122·5 (6)	O(35)–C(35)–C(36)	122·6 (5)
Bromine			
C(31)–C(32)–Br(32)	121·3 (3)	C(38)–C(39)–Br(39)	121·2 (6)
C(33)–C(32)–Br(32)	114·7 (4)	C(40)–C(39)–Br(39)	128·3 (4)
Methyl			
C(12)–C(13)–C(18)	107·2 (5)	C(1)–C(10)–C(19)	109·0 (5)
C(14)–C(13)–C(18)	107·3 (5)	C(5)–C(10)–C(19)	113·6 (5)
C(17)–C(13)–C(18)	108·9 (5)	C(9)–C(10)–C(19)	110·7 (5)
Ethyl			
C(8)–C(14)–C(42)	106·4 (5)	C(15)–C(14)–C(42)	109·4 (5)
C(13)–C(14)–C(42)	108·9 (6)	C(14)–C(42)–C(43)	116·2 (5)
Bromobenzoate			
C(28)–C(29)–C(30)	118·6 (5)	C(35)–C(36)–C(37)	125·3 (5)
C(28)–C(29)–C(34)	120·0 (5)	C(35)–C(36)–C(41)	118·1 (6)
C(30)–C(29)–C(34)	121·5 (5)	C(37)–C(36)–C(41)	116·6 (6)
C(29)–C(30)–C(31)	120·3 (5)	C(36)–C(37)–C(38)	121·3 (6)
C(30)–C(31)–C(32)	118·3 (4)	C(37)–C(38)–C(39)	124·2 (8)
C(31)–C(32)–C(33)	124·0 (5)	C(38)–C(39)–C(40)	110·0 (5)
C(32)–C(33)–C(34)	117·3 (5)	C(39)–C(40)–C(41)	130·6 (6)
C(29)–C(34)–C(33)	118·4 (5)	C(36)–C(41)–C(40)	116·9 (5)
17-Side chain			
C(13)–C(17)–C(20)	118·4 (4)	C(22)–C(23)–C(24)	114·2 (6)
C(16)–C(17)–C(20)	110·0 (4)	C(23)–C(24)–C(25)	121·2 (7)
C(17)–C(20)–C(21)	112·6 (5)	C(24)–C(25)–C(26)	110·0 (11)
C(17)–C(20)–C(22)	113·0 (5)	C(24)–C(25)–C(27)	119·0 (10)
C(21)–C(20)–C(22)	109·2 (5)	C(26)–C(25)–C(27)	106·1 (10)
C(20)–C(22)–C(23)	118·5 (6)		

Table 6 (*cont.*)

(*c*) Extra-nuclear torsion angles (°)

Oxygen	
C(1)–C(2)–C(3)–O(3)	176·5 (5)
C(5)–C(4)–C(3)–O(3)	−176·2 (5)
C(2)–C(3)–O(3)–C(28)	81·1 (4)
C(4)–C(3)–O(3)–C(28)	−154·7 (4)
C(3)–O(3)–C(28)–O(28)	−6·0 (4)
C(3)–O(3)–C(28)–C(29)	172·0 (4)
O(3)–C(28)–C(29)–C(30)	−17·6 (5)
O(3)–C(28)–C(29)–C(34)	162·1 (5)
O(28)–C(28)–C(29)–C(30)	160·4 (6)
O(28)–C(28)–C(29)–C(34)	−20·0 (6)
C(17)–C(16)–C(15)–O(15)	137·8 (6)
C(13)–C(14)–C(15)–O(15)	−158·9 (5)
C(16)–C(15)–O(15)–C(35)	76·0 (5)
C(14)–C(15)–O(15)–C(35)	−166·3 (4)
C(8)–C(14)–C(15)–O(15)	79·0 (5)
C(42)–C(14)–C(15)–O(15)	−43·2 (5)
C(15)–O(15)–C(35)–O(35)	−0·3 (4)
C(15)–O(15)–C(35)–C(36)	179·3 (4)
O(15)–C(35)–C(36)–C(37)	16·1 (5)
O(15)–C(35)–C(36)–C(41)	−163·4 (6)
O(35)–C(35)–C(36)–C(37)	−164·2 (5)
O(35)–C(35)–C(36)–C(41)	16·2 (6)
Methyl	
C(11)–C(12)–C(13)–C(18)	−60·3 (5)
C(8)–C(14)–C(13)–C(18)	61·5 (4)
C(42)–C(14)–C(13)–C(18)	178·1 (6)
C(15)–C(14)–C(13)–C(18)	−65·9 (5)
C(16)–C(17)–C(13)–C(18)	73·6 (5)
C(20)–C(17)–C(13)–C(18)	−49·5 (4)
C(2)–C(1)–C(10)–C(19)	−65·2 (5)
C(4)–C(5)–C(10)–C(19)	67·7 (4)
C(6)–C(5)–C(10)–C(19)	−55·9 (4)
C(8)–C(9)–C(10)–C(19)	74·5 (5)
C(11)–C(9)–C(10)–C(19)	−56·8 (4)
C(19)–C(10)···C(13)–C(18)	8·6 (4)
Ethyl	
C(7)–C(8)–C(14)–C(42)	102·5 (6)
C(9)–C(8)–C(14)–C(42)	−70·2 (5)
C(8)–C(14)–C(42)–C(43)	−45·8 (5)
C(12)–C(13)–C(14)–C(42)	60·8 (5)
C(18)–C(13)–C(14)–C(42)	178·1 (6)
C(17)–C(13)–C(14)–C(42)	−68·2 (6)
C(13)–C(14)–C(42)–C(43)	−164·9 (6)
C(16)–C(15)–C(14)–C(42)	78·6 (5)
O(15)–C(15)–C(14)–C(42)	−43·2 (5)
C(15)–C(14)–C(42)–C(43)	83·5 (5)
Bromine	
C(30)–C(31)–C(32)–Br(32)	179·3 (4)
C(34)–C(33)–C(32)–Br(32)	−179·7 (4)
C(37)–C(38)–C(39)–Br(39)	−178·0 (7)
C(41)–C(40)–C(39)–Br(39)	178·8 (5)
Bromobenzoate	
C(28)–C(29)–C(30)–C(31)	−177·5 (5)
C(28)–C(29)–C(34)–C(33)	176·5 (5)
C(34)–C(29)–C(30)–C(31)	2·8 (5)
C(29)–C(30)–C(31)–C(32)	0·3 (4)
C(30)–C(31)–C(32)–C(33)	−2·2 (4)
C(31)–C(32)–C(33)–C(34)	1·2 (5)
C(32)–C(33)–C(34)–C(29)	1·9 (5)
C(33)–C(34)–C(29)–C(30)	−3·8 (5)
C(35)–C(36)–C(37)–C(38)	177·9 (6)
C(35)–C(36)–C(41)–C(40)	−177·2 (6)
C(41)–C(36)–C(37)–C(38)	−2·6 (6)
C(36)–C(37)–C(38)–C(39)	4·1 (7)
C(37)–C(38)–C(39)–C(40)	−5·8 (6)
C(38)–C(39)–C(40)–C(41)	7·2 (6)
C(39)–C(40)–C(41)–C(36)	−6·4 (6)
C(40)–C(41)–C(36)–C(37)	3·2 (6)
17-Side chain	
C(12)–C(13)–C(17)–C(20)	74·8 (4)
C(14)–C(13)–C(17)–C(20)	−162·0 (4)
C(18)–C(13)–C(17)–C(20)	−49·5 (4)
C(15)–C(16)–C(17)–C(20)	145·4 (4)
C(13)–C(17)–C(20)–C(21)	−63·3 (4)
C(16)–C(17)–C(20)–C(21)	176·2 (4)
C(13)–C(17)–C(20)–C(22)	172·4 (4)
C(16)–C(17)–C(20)–C(22)	51·9 (4)
C(17)–C(20)–C(22)–C(23)	62·9 (6)
C(21)–C(20)–C(22)–C(23)	−63·2 (6)
C(20)–C(22)–C(23)–C(24)	−168·9 (6)
C(22)–C(23)–C(24)–C(25)	−177·8 (6)
C(23)–C(24)–C(25)–C(26)	77·3 (9)
C(23)–C(24)–C(25)–C(27)	−160·0 (8)

Table 7. *Asymmetry and pseudorotation parameters* (°) *with standard deviations in parentheses*

Ring *A*		Ring *C*	
ΔC_s^1	2·5 (4)	ΔC_s^8	12·4 (4)
ΔC_s^2	2·9 (4)	ΔC_s^9	1·5 (4)
ΔC_s^3	5·1 (4)	ΔC_s^{11}	11·7 (4)
$\Delta C_2^{1,2}$	1·5 (4)	$\Delta C_2^{8,9}$	9·1 (4)
$\Delta C_2^{1,10}$	5·5 (4)	$\Delta C_2^{9,11}$	8·0 (4)
$\Delta C_2^{2,3}$	5·2 (4)	$\Delta C_2^{8,14}$	17·1 (4)
Ring *B*		Ring *D*	
$\Delta C_2^{5,10}$	0·9 (4)	Δ	4·5 (5)
		φ_m	47·9 (5)

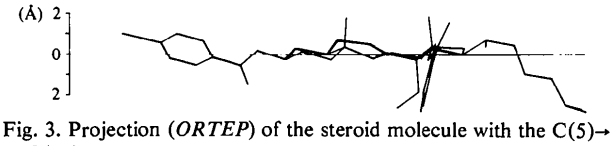

Fig. 3. Projection (*ORTEP*) of the steroid molecule with the C(5)→C(17) vector parallel to the horizontal line and the C(14)→C(12) vector parallel to the line of sight.

C(5)→C(17) nuclear vector parallel to the horizontal line passing through the figure. The C(14)→C(12) vector is normal to this horizontal line and parallels the viewer's line of sight. The 3β-*p*-bromobenzoate and 15α-*p*-bromobenzoate substituents are both almost perpendicular to the overall nuclear plane of the steroid.

The twist of the steroid nucleus about a line joining C(10) and C(13) is described by the C(19)–C(10)···C(13)–C(18) pseudotorsion angle of 8·6 (4)°. The bending of the C(18) and C(19) methyl groups towards each other along the horizontal line and the bowing of the *B* ring relative to the remainder of the steroid nucleus (*B*/*A*–*C*–*D*) are both functions of the flexibility of the trigonal C(8) atom involved in the *B*–*C* ring juncture.

A crystal-packing stereoview of the 14α-ethyl-5α-cholest-7-ene-3β,15α-diol di-*p*-bromobenzoate molecule is shown in Fig. 4. The unit cell is packed two-molecules thick, one wide, and one long. The steroid length is defined as the molecular dimension parallel to the C(10)→C(13) vector, the steroid width is parallel to the C(14)→C(12) vector, and the steroid thickness is orthogonal to the length and width. The box of enclosure for the packing diagram is 2*a* along *X*, 1*b* along *Y*, and 2*c* along *Z*. The length of the steroid is at 30° to the *a* axis, the width is at 40° to the *c* axis, and the thickness is at 37° to the *b* (screw) axis. The modified Hodgkin notation is $Mb_{37°}c_{40°}a_{30°}$ 211 (Duax & Norton, 1975).

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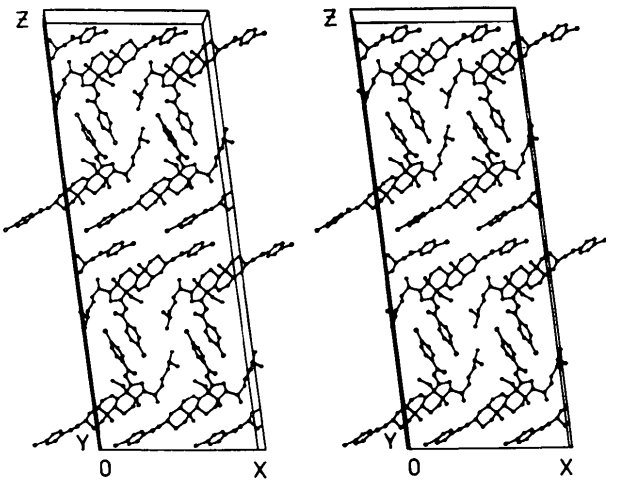

Fig. 4. Stereoview (*ORTEP*) of the crystal packing. The dimensions of the box of enclosure are: $X = 2a$, $Y = 1b$, and $Z = 2c$.

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The Structures of 2,4,6-Tri-*tert*-butyl-7,8,9-dithiazabicyclo[4.3.0]nona-1(9),2,4-triene and Its 7-Oxide

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Abstract

The crystal and molecular structures of 2,4,6-tri-*tert*-butyl-7,8,9-dithiazabicyclo[4.3.0]nona-1(9),2,4-triene (1) and its 7-oxide (2) have been determined by X-ray diffraction. Crystals of (1) are monoclinic, space group $P2_1/c$, with cell dimensions: $a = 15{\cdot}736$ (4), $b = 10{\cdot}083$ (1), $c = 13{\cdot}041$ (3) Å, $\beta = 115{\cdot}31$ (2)° and $Z = 4$. Crystals of (2) are triclinic, $P\bar{1}$, $a = 16{\cdot}724$ (4), $b = 7{\cdot}115$ (2), $c = 9{\cdot}910$ (2) Å, $\alpha = 106{\cdot}65$ (3), $\beta = 118{\cdot}45$ (2), $\gamma = 72{\cdot}53$ (2)° and $Z = 2$. The structures were solved by the heavy-atom method and refined by the block-diagonal least-squares method. The final R values were 0·045 for (1) and 0·039 for (2). The molecular moieties of the oxide and non-oxide are very similar. One of the *tert*-butyl groups is axial to the molecular plane in each molecule. In (2) the sulphinyl oxygen is *trans* to this *tert*-butyl group across the S—C

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