

## Cholesteryl *p*-Toluenesulfonate

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**Abstract.**  $C_{27}H_{45}OSO_2C_6H_4CH_3$ ,  $M_r = 540.85$ , monoclinic, space group  $P2_1$ ,  $a = 13.069$  (6),  $b = 6.281$  (2),  $c = 19.01$  (1) Å,  $\beta = 94.34$  (4)°,  $Z = 2$ ,  $V = 1565.0$  (1) Å<sup>3</sup>,  $D_c = 1.154$ ,  $D_o = 1.143$  g cm<sup>-3</sup>. A three-dimensional data set was collected at room temperature with Cu  $K\alpha$  radiation ( $\lambda = 1.5418$  Å) on a Syntex  $P1$  diffractometer equipped with a graphite monochromator to a maximum  $2\theta$  value of 100°, by the  $\theta$ - $2\theta$  scan technique. The coordinates of the non-hydrogen atoms and their anisotropic temperature factors were refined by full-matrix least-squares methods to a final  $R$  of 0.092 based on  $F^2$ . Bond distances were normal except in the tail region, where high thermal vibration resulted in an apparent shortening of the C–C distances.

**Introduction.** Cholesterol is a completely ubiquitous compound in the plant and animal kingdoms. In addition to being a primary metabolic precursor for many of the steroid hormones, it, and some of its esters (*i.e.* cholesteryl sulfate; Bleau, Chapdelaine & Roberts, 1972), play an important role in the structural stabilization of membranes. The phase interactions of the cholesterol–phospholipid systems that comprise many membranes tend to be very complicated (Freeman & Finean, 1975), and thus an important first step towards deriving detailed structural membrane models is a study of the stereochemistry and packing of cholesterol and its derivatives. There are now five reported examples of cholesteric compounds in the literature. They are cholesteryl iodide (Carlisle & Crowfoot, 1945), 7-bromocholesteryl chloride (Burki & Nowacki, 1956), cholesteryl myristate (Craven & De Titta, 1976), cholesterol monohydrate (Craven, 1976), and the title compound of this communication (Chandross & Bordner, 1976).

The title compound ( $C_{27}H_{45}OSO_2C_6H_4CH_3$ , Eastman 10125) was recrystallized from acetone. Unit-cell dimensions were obtained by a least-squares fit of 15 reflections. Intensity data were taken to a resolution of 1 Å (maximum  $\sin \theta/\lambda = 0.5$ ) at a scan speed of 2° min<sup>-1</sup> in  $2\theta$  and scan width 1° below  $K\alpha_1$ , 1° above  $K\alpha_2$ . Systematic absences indicated the space group  $P2_1$ . We used our usual data collection and preliminary

processing procedures (Chandross & Bordner, 1974). 1789 reflections were collected of which 1560 were considered non-zero. All intensities with a value less than  $2\sigma$  were set equal to zero with zero weight. The density was measured by the flotation technique in KI–HgCl<sub>2</sub> solution.

The preliminary processing was routine and included the usual corrections. Standard deviations of the  $F^2$ 's were assigned on the basis of the following equation:  $\sigma^2(I) = S + \alpha^2(B_1 + B_2) + (dS)^2$ , where  $S$  is the number of counts collected during the scan,  $B_1$  and  $B_2$  are the background counts over half the scan time on each side of the peak,  $d$  is an empirical constant set at 0.02, and  $\alpha$  is the ratio scan time to total background time. Atomic scattering factors for C and O were taken from *International Tables for X-ray Crystallography* (1962). The scattering factor for S is that given by Cromer & Mann (1967). The scattering factor for H is that given by Stewart, Davidson & Simpson (1965). Both anomalous dispersion components were applied to S (*International Tables for X-ray Crystallography*, 1962). No corrections were made for absorption.

Normalized structure factors,  $|E|$ , (Karle & Karle, 1966) were calculated with an overall temperature factor of 3.27 Å<sup>2</sup>. All of the observable data were used, and the symmetry effects on the average distribution of the intensity data were corrected for by the method of Wilson (1950). The selection of the starting reflections and the phasing were done with the subprograms *MULTAN* (Germain, Main & Woolfson, 1971).

Initial phasing attempts generated ring fragments, but our efforts to develop additional interpretable peaks with tangent refinement procedures (Karle, 1968) failed. The structure was solved by noticing that the best phasing (defined by the higher values of the combined figure-of-merit computed by *MULTAN*) always occurred when the phase of one of the starting reflections (4,2,14) was started at the same value (*i.e.* 45° in this case). This was accepted as a known phase, and the next cycle produced a 31-atom fragment.

Least-squares refinement was started with full-matrix isotropic refinement, and concluded with all the non-hydrogen coordinates in one matrix and the scale factor, secondary extinction factor, and anisotropic

temperature factors in a second matrix. The methylene H atoms were introduced by calculation (with a C—H bond distance of 1.0 Å), and the methyl H atoms were found by a combination of difference Fourier maps and calculation.

The final *R* index,  $\Sigma |F_o| - |F_c| / \Sigma |F_o|$  was 9.2%, and the goodness of fit,  $[\Sigma w(F_o^2 - F_c^2)^2 / (m - s)]^{1/2}$  (where *m* is the number of observations and *s* is the number of parameters refined), was 1.64. Both data-fit criteria were based on non-zero reflections. The final positional coordinates for the non-hydrogen atoms with

their standard deviations (calculated from the least-squares residuals and the inverse matrix of the final least-squares cycle) are given in Table 1; the positional parameters of the H atoms with their appropriate isotropic temperature factors are given in Table 2.\*

\* Lists of structure factors, anisotropic thermal parameters and bond angles have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 32709 (13 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 13 White Friars, Chester CHI 1NZ, England.

Table 1. Heavy-atom positional parameters and their standard deviations ( $\times 10^4$ )

	<i>x</i>	<i>y</i>	<i>z</i>		<i>x</i>	<i>y</i>	<i>z</i>
S	2801 (3)	-2500	4829 (2)	C(16)	-1622 (8)	-1566 (25)	9844 (6)
O(1)	1774 (5)	-3331 (16)	5142 (4)	C(17)	-1985 (9)	519 (22)	9421 (6)
O(2)	2806 (7)	-230 (14)	4827 (5)	C(18)	-2670 (8)	-1549 (24)	8336 (5)
O(3)	2816 (6)	-3597 (18)	4174 (4)	C(19)	-1116 (8)	-2811 (24)	6437 (6)
C(1)	210 (8)	89 (23)	6309 (6)	C(20)	-3065 (8)	1256 (25)	9623 (6)
C(2)	669 (8)	-800 (20)	5615 (5)	C(21)	-3496 (9)	3116 (27)	9184 (6)
C(3)	1482 (8)	-2419 (25)	5809 (5)	C(22)	-3030 (9)	1798 (25)	10396 (7)
C(4)	1151 (8)	-4210 (25)	6243 (6)	C(23)	-4042 (9)	2343 (29)	10687 (7)
C(5)	672 (8)	-3363 (23)	6900 (6)	C(24)	-4020 (12)	2671 (35)	11484 (9)
C(6)	994 (7)	-4113 (24)	7538 (7)	C(25)	-3397 (10)	4289 (32)	11796 (8)
C(7)	533 (9)	-3559 (23)	8202 (6)	C(26)	-3564 (19)	6475 (41)	11521 (13)
C(8)	-485 (8)	-2346 (23)	8078 (6)	C(27)	-3462 (14)	4379 (46)	12564 (7)
C(9)	-379 (8)	-712 (21)	7506 (5)	C(28)	5307 (11)	-4885 (28)	6416 (8)
C(10)	-161 (8)	-1676 (22)	6796 (5)	C(29)	4496 (10)	-6189 (26)	6164 (6)
C(11)	-1303 (9)	852 (24)	7448 (6)	C(30)	3730 (10)	-5554 (24)	5677 (6)
C(12)	-1611 (9)	1723 (22)	8155 (6)	C(31)	3757 (9)	-3525 (25)	5432 (5)
C(13)	-1832 (9)	-106 (22)	8649 (6)	C(32)	4555 (10)	-2136 (22)	5655 (6)
C(14)	-819 (8)	-1372 (23)	8744 (6)	C(33)	5297 (10)	-2863 (30)	6151 (7)
C(15)	-957 (9)	-2869 (25)	9371 (6)	C(34)	6102 (9)	-5756 (30)	6991 (6)

Table 2. Hydrogen-atom parameters

The values for the coordinates have been multiplied by  $10^3$ .

	<i>x</i>	<i>y</i>	<i>z</i>	<i>B</i>		<i>x</i>	<i>y</i>	<i>z</i>	<i>B</i>
H(1a)	-36	100	618	4.0	H(19b)	-160	-175	630	4.0
H(1b)	77	84	658	4.0	H(19c)	-90	-350	600	4.0
H(2a)	194	-214	553	4.0	H(20)	-355	2	950	4.0
H(2b)	384	274	528	4.0	H(21a)	-420	370	880	5.0
H(3)	205	-168	608	5.0	H(21b)	-340	200	870	5.0
H(4a)	154	-551	645	5.0	H(21c)	-320	350	930	5.0
H(4b)	52	-481	597	5.0	H(22a)	-255	292	1050	5.0
H(6)	142	-542	743	5.0	H(22b)	-277	44	1066	5.0
H(7a)	104	-277	850	5.0	H(23a)	-456	118	1055	6.0
H(7b)	41	-499	846	5.0	H(23b)	-429	368	1045	6.0
H(8)	-104	-341	793	4.0	H(24a)	-377	127	1170	9.0
H(9)	26	11	763	4.0	H(24b)	-473	289	1160	9.0
H(11a)	-189	9	720	5.0	H(25)	-271	386	1166	8.0
H(11b)	-110	207	716	5.0	H(26a)	-420	685	1160	12.0
H(12a)	-225	252	807	6.0	H(26b)	-320	700	1225	12.0
H(12b)	-107	258	838	6.0	H(26c)	-360	675	1090	12.0
H(14)	-20	-51	886	4.0	H(27a)	-300	375	1290	10.0
H(15a)	-27	-326	963	5.0	H(27b)	-370	480	1270	10.0
H(15b)	-129	-428	922	5.0	H(27c)	-400	350	1310	10.0
H(16a)	-122	-124	1029	5.0	H(29)	450	-774	635	5.0
H(16b)	-223	-250	996	5.0	H(30)	318	-661	552	5.0
H(17)	-161	180	954	5.0	H(32)	460	-71	546	5.0
H(18a)	-320	850	870	4.0	H(33)	587	-194	633	5.0
H(18b)	-320	750	810	4.0	H(34a)	-400	-750	720	9.0
H(18c)	-300	1000	810	4.0	H(34b)	400	-500	700	9.0
H(19a)	-170	-350	660	4.0	H(34c)	340	-500	660	9.0

**Discussion.** The thermal ellipsoids are shown in Fig. 1, and the bond distances are given in Table 3.\* The conformation of the steroid nucleus is normal, with no major deviations from the results of other workers. The appropriate ring torsion angles, along with the torsion angles within the tail are given in Table 4. Also given are the appropriate mirror plane and the twofold asymmetry parameters of the ring as defined by Duax

\* See deposition footnote on p. 2935.

Table 3. Bond distances (Å)

S—O(1)	1.596 (8)	C(13)—C(14)	1.544 (17)
S—O(2)	1.426 (9)	C(13)—C(17)	1.547 (16)
S—O(3)	1.425 (9)	C(13)—C(18)	1.508 (17)
S—C(31)	1.752 (12)	C(14)—C(15)	1.539 (18)
C(3)—O(1)	1.468 (12)	C(15)—C(16)	1.534 (18)
C(1)—C(2)	1.592 (15)	C(16)—C(17)	1.590 (19)
C(1)—C(10)	1.546 (17)	C(17)—C(20)	1.561 (16)
C(2)—C(3)	1.496 (18)	C(20)—C(21)	1.519 (21)
C(3)—C(4)	1.479 (19)	C(20)—C(22)	1.504 (18)
C(4)—C(5)	1.535 (16)	C(22)—C(23)	1.512 (17)
C(5)—C(6)	1.339 (17)	C(23)—C(24)	1.527 (21)
C(5)—C(10)	1.521 (17)	C(24)—C(25)	1.405 (26)
C(6)—C(7)	1.481 (17)	C(25)—C(26)	1.479 (32)
C(7)—C(8)	1.536 (17)	C(25)—C(27)	1.469 (20)
C(8)—C(9)	1.510 (17)	C(28)—C(29)	1.396 (21)
C(8)—C(14)	1.501 (16)	C(28)—C(33)	1.365 (25)
C(9)—C(10)	1.525 (15)	C(28)—C(34)	1.550 (20)
C(9)—C(11)	1.554 (17)	C(29)—C(30)	1.369 (18)
C(10)—C(19)	1.550 (16)	C(30)—C(31)	1.358 (21)
C(11)—C(12)	1.533 (17)	C(31)—C(32)	1.400 (19)
C(12)—C(13)	1.525 (18)	C(32)—C(33)	1.378 (18)

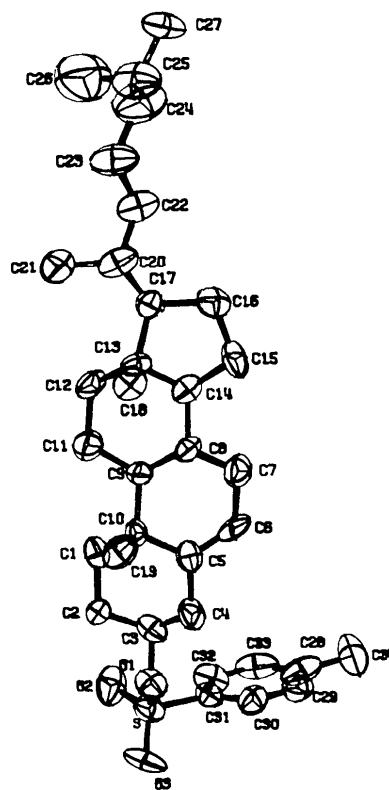


Fig. 1. ORTEP (Johnson, 1965) drawing presenting the thermal ellipsoids.

Table 4. Torsion angles (°) in the rings

$\phi$  is the torsion angle about the *A*—*B* bond in which the two atoms required to define the angle are those attached to either end of the bond and are in the same ring in question.  $\Delta C_i$  and  $\Delta C_j$  are defined in the text.

Ring A		Ring B		Ring C	
C(1)—C(2)	−52.7 (1.4)	C(5)—C(6)	5.5 (1.5)	C(8)—C(9)	−44.6 (1.4)
C(2)—C(3)	55.4 (1.4)	C(6)—C(7)	10.6 (1.4)	C(9)—C(11)	45.9 (1.3)
C(3)—C(4)	−53.5 (1.5)	C(7)—C(8)	−42.2 (1.3)	C(11)—C(12)	−55.6 (1.5)
C(4)—C(5)	50.6 (1.6)	C(8)—C(9)	61.9 (1.4)	C(12)—C(13)	60.1 (1.4)
C(5)—C(10)	−48.2 (1.3)	C(9)—C(10)	−45.8 (1.4)	C(13)—C(14)	−62.9 (1.3)
C(1)—C(10)	48.2 (1.3)	C(5)—C(10)	11.6 (1.3)	C(14)—C(8)	56.4 (1.4)
$\Delta C_i(1) = 5.16$	$\Delta C_2(1-2) = 6.30$	$\Delta C_i(5) = 25.1$	$\Delta C_2(5-6) = 2.62$	$\Delta C_i(8) = 12.2$	$\Delta C_2(8-9) = 9.1$
$\Delta C_i(2) = 3.66$	$\Delta C_2(2-3) = 1.79$	$\Delta C_i(6) = 22.0$	$\Delta C_2(6-7) = 49.0$	$\Delta C_i(9) = 1.83$	$\Delta C_2(9-11) = 8.2$
$\Delta C_i(3) = 1.70$	$\Delta C_2(3-4) = 4.64$	$\Delta C_i(7) = 42.2$	$\Delta C_2(7-8) = 46.0$	$\Delta C_i(11) = 11.2$	$\Delta C_2(11-12) = 16.4$
Ring D		Tail			
C(13)—C(14)	46.0 (1.3)	C(13)—C(17)—C(20)—C(22)	−179.5 (1.3)		
C(14)—C(15)	−33.4 (1.4)	C(13)—C(17)—C(20)—C(21)	−55.4 (1.4)		
C(15)—C(16)	8.2 (1.4)	C(21)—C(20)—C(22)—C(23)	59.6 (1.3)		
C(16)—C(17)	19.5 (1.3)	C(20)—C(22)—C(23)—C(24)	174.0 (1.5)		
C(13)—C(17)	−39.0 (1.3)	C(22)—C(23)—C(24)—C(25)	60.2 (1.9)		
		C(23)—C(24)—C(25)—C(26)	55.8 (2.2)		
$\Delta C_i(13) = 11.0$	$\Delta C_2(13-14) = 8.92$				
$\Delta C_i(14) = 23.5$	$\Delta C_2(14-15) = 30.0$				
$\Delta C_i(15) = 49.6$	$\Delta C_2(15-16) = 70.8$				
$\Delta C_i(16) = 54.7$	$\Delta C_2(16-17) = 65.2$				
$\Delta C_i(17) = 40.7$	$\Delta C_2(17-18) = 34.8$				

& Norton (1975). In this formulation,  $\Delta C_s(n) = [(\sum_{i=1}^m (\theta_i + \theta'_i)^2/m)^{1/2}]$ , and  $\Delta C_2(n-o) = [(\sum_{i=1}^m (\theta_i - \theta'_i)^2/m)^{1/2}]$ ; where  $\Delta C_s(n)$  is a measure of the deviations from mirror symmetry about a plane passing through atom  $n$  and the diametrically opposed atom  $o$ , and  $\Delta C_2(n-o)$  is a measure of the deviations from twofold symmetry about an axis bisecting bond ( $n-o$ ). The symmetry-related torsion angles are  $\theta_i$  and  $\theta'_i$ , and  $m$  is the number of such pairs. Rings  $A$  and  $C$  assume chair conformations, with ring  $C$  somewhat distorted (for ring  $A$ ,  $\langle C_s \rangle = 3.5 \pm 1.2$  and  $\langle C_2 \rangle = 4.2 \pm 1.6$ ; while for ring  $C$ ,  $\langle C_s \rangle = 8.4 \pm 4.4$  and  $\langle C_2 \rangle = 11.2 \pm 3.4$ ). Ring  $B$  is a half chair, and ring  $D$  is the expected  $13\beta, 14\alpha$  half chair.

The tail of the molecule is approximately fully extended, with C(24)–C(25) synclinal with respect to C(22)–C(23), rather than in the antiperiplanar conformation that one generally expects for the alkane chain.

The bond distances are normal for this type of compound with the exception of those on the distal part of the tail. The refinement placed them in positions where they appear to be shortened. This is probably a result of the high thermal motion in this area, and in view of the fact that other workers (Craven, 1976; Craven & De Titta, 1976) had similar results in this region of the molecule it may be taken as an indication that in a membrane system, the tail may be considered to be in a liquid or semi-liquid state.

The packing in this compound is not remarkable. The molecules are aligned in the unit cell with their long axes approximately parallel to [101]. The most interesting feature is the close proximity of the tosylate group of one molecule to its screw-axis-related neighbor. Since the smallest C–C contact between these two molecules is 3.64 Å and the rings are inclined by 56° with respect to each other,  $\pi$ -bonding is unlikely; it may be the van der Waals contacts in this area which stabilize the crystal.

We can conclude, then, that cholesterol derivatives in general will show few deviations from the normal

nuclear configuration, but the tail configuration will be extremely variable. In this derivative, the presence of the non-biological sulfonate moiety probably precludes the possibility of obtaining much useful information about the role of cholesterol sulfate in membrane packing.

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