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Crystal structure of the 1 : 1 complex of heptakis(2,3,6-tri-*O*-methyl)cyclomaltoheptaose (permethylated β-cyclodextrin) with ethyl laurate

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ABSTRACT

The crystal of the 1 : 1 complex of ethyl laurate with heptakis(2,3,6-tri-*O*-methyl)cyclomaltoheptaose (TM-βCD, permethylated β-cyclodextrin) is orthorombic, $P2_12_12_1$, with $a = 14.796(2)$, $b = 22.444(6)$, $c = 27.720(8)$ Å; $V = 9205(4)$ Å^3; and $Z = 4$. The macrocycles have a distorted conformation due to the absence of intramolecular hydrogen bonds and are stacked in a head-to-tail mode to form channels parallel to the *b* axis of the crystal. In the interior of the channel, the guest molecules are accommodated in extended conformation. Two water molecules have been located near the secondary rim of each TM-βCD molecule, forming hydrogen bonds with the oxygen atoms of the guest.

INTRODUCTION

In the continuing effort to modify the properties of compounds, their inclusion within cyclodextrin cavities has been tested. We are presently studying complexes of cyclodextrins and their methylated derivatives with linear molecules. For some of them, the complexation process can be followed by NMR techniques. However, in some cases, NMR does not indicate the formation of an inclusion complex because it does not detect interaction between host and guest. This is the case in the complex of ethyl laurate (one of the components of *Dacus oleae* pheromone) with both β-cyclodextrin(βCD) and permethylated βCD[1]. The present structure of ethyl laurate and heptakis(2,3,6-tri-*O*-methyl)βCD (permethylated βCD, TM-βCD) is the first in a series of linear molecules included in the CD cavity in order to study the various modes of interaction of long linear molecules with CDs.

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TABLE I

Positional and isotropic thermal parameters ($\times 10^4$) of the non-hydrogen atoms with esd's in parentheses and occupation factors (K) for the disordered atoms and the water molecules in the TM-βCD–ethyl laurate complex

Atom	x	y	z	U	K
C-11	8930 (20)	4670 (10)	4870 (10)	444	
C-21	8280 (20)	4280 (10)	5110 (10)	325	
C-31	7510 (20)	4070 (20)	4720 (10)	583	
C-41	7190 (20)	4570 (20)	4440 (10)	568	
C-51	7930 (20)	4970 (20)	4230 (10)	469	
C-61	7640 (20)	5510 (20)	3970 (10)	688	
C-71	8830 (30)	3790 (20)	5790 (10)	1048	
C-81	6800 (30)	3150 (20)	4800 (10)	1023	
C-91	6610 (30)	6330 (20)	3970 (20)	1218	
O-21	8590 (20)	3760 (10)	5326 (8)	600	
O-31	6850 (20)	3740 (10)	4967 (8)	708	
O-41	6690 (20)	4310 (10)	4046 (8)	578	
O-51	8490 (10)	5145 (9)	4623 (7)	405	
O-61	6930 (20)	5810 (10)	4222 (9)	819	
C-12	12030 (20)	4150 (20)	4050 (10)	559	
C-22	11780 (30)	3640 (20)	4430 (10)	701	
C-32	10710 (20)	3710 (20)	4480 (10)	592	
C-42	10480 (20)	4330 (20)	4580 (10)	556	
C-52	10790 (20)	4790 (10)	4210 (10)	472	
C-62	10680 (20)	5440 (10)	4300 (10)	481	
C-72	12940 (20)	2930 (20)	4370 (10)	740	
C-82	9920 (30)	2880 (20)	4760 (10)	904	
C-92	10720 (30)	6210 (20)	4860 (20)	1296	
O-22	11950 (20)	3070 (10)	4304 (8)	669	
O-32	10470 (20)	3330 (10)	4891 (8)	656	
O-42	9490 (10)	4320 (9)	4539 (7)	442	
O-52	11810 (10)	4704 (9)	4186 (7)	382	
O-62	10900 (20)	5590 (10)	4760 (9)	817	
C-13	12820 (20)	3910 (10)	2230 (10)	458	
C-23	12790 (20)	3350 (10)	2480 (10)	229	
C-33	12140 (20)	3380 (20)	2900 (10)	583	
C-43	12390 (20)	3930 (10)	3170 (10)	273	
C-53	12430 (20)	4510 (10)	2900 (10)	400	
C-63	12560 (30)	5050 (20)	3140 (10)	683	
C-73	12950 (30)	2370 (20)	2190 (20)	1270	
C-83	11360 (30)	2610 (20)	3260 (10)	985	
C-93	13690 (30)	5550 (20)	3590 (20)	1159	
O-23	12560 (20)	2890 (10)	2167 (9)	803	
O-33	12200 (20)	2860 (10)	3161 (9)	739	
O-43	11730 (10)	3960 (10)	3576 (8)	547	
O-53	13040 (10)	4392 (9)	2517 (7)	394	
O-63	13410 (20)	5000 (10)	3355 (8)	603	
C-14	10960 (20)	4490 (10)	670 (10)	448	
C-24	11730 (20)	4120 (20)	600 (10)	619	
C-34	12000 (20)	3810 (20)	1090 (10)	642	
C-44	12050 (20)	4340 (20)	1490 (10)	582	
C-54	11310 (20)	4770 (20)	1490 (10)	605	
C-64	11520 (30)	5340 (20)	1770 (10)	909	
C-74	11610 (30)	3820 (20)	−220 (10)	824	

TABLE I (continued)

Atom	*x*	*y*	*z*	*U*	*K*
C-84	12920 (30)	2950 (20)	940 (10)	1757	
C-94A	12470 (50)	6090 (40)	1970 (30)	2034	0.65
C-94B	13260 (50)	5830 (40)	1870 (30)	735	0.35
O-24	11650 (20)	3600 (10)	272 (8)	650	
O-34	12900 (20)	3560 (10)	1058 (8)	625	
O-44	12010 (10)	4030 (10)	1945 (8)	539	
O-54	11170 (10)	4990 (10)	990 (8)	581	
O-64	12300 (30)	5560 (20)	1570 (10)	1448	
C-15	7450 (20)	4050 (10)	700 (10)	299	
C-25	7940 (20)	3660 (20)	360 (10)	621	
C-35	8960 (20)	3670 (20)	470 (10)	480	
C-45	9310 (20)	4240 (10)	600 (10)	304	
C-55	8730 (20)	4570 (20)	960 (10)	560	
C-65	9060 (30)	5290 (20)	910 (20)	1271	
C-75	6820 (30)	3030 (20)	0 (10)	1067	
C-85	9630 (30)	2840 (20)	110 (10)	943	
C-95	8810 (50)	6130 (30)	1230 (30)	3105	
C-75	6820 (30)	3030 (20)	0 (10)	1067	
O-25	7630 (20)	3100 (10)	287 (9)	768	
O-35	9470 (20)	3420 (10)	71 (8)	639	
O-45	10200 (10)	4148 (9)	806 (7)	380	
O-55	7760 (20)	4600 (10)	783 (8)	565	
O-65	8530 (30)	5440 (20)	1310 (20)	1776	
C-16	5410 (20)	3560 (10)	2230 (10)	279	
C-26	5750 (20)	3050 (10)	2020 (10)	265	
C-36	6590 (20)	3060 (20)	1700 (10)	506	
C-46	6490 (20)	3620 (20)	1390 (10)	534	
C-56	6130 (20)	4170 (10)	1635 (9)	171	
C-66	5930 (20)	4720 (10)	1340 (10)	439	
C-76	5770 (30)	2020 (20)	2280 (20)	1366	
C-86	7660 (30)	2370 (20)	1420 (20)	1140	
C-96	4510 (20)	4740 (20)	1010 (10)	741	
O-26	5900 (20)	2590 (10)	2390 (10)	1022	
O-36	6740 (20)	2560 (10)	1434 (9)	797	
O-46	7350 (10)	3710 (10)	1139 (7)	486	
O-56	5300 (10)	4014 (9)	1888 (7)	431	
O-66	5430 (20)	4580 (10)	918 (9)	677	
C-17	5800 (20)	4590 (20)	3910 (10)	596	
C-27	5090 (20)	4130 (20)	3870 (10)	633	
C-37	5390 (20)	3710 (10)	3430 (10)	496	
C-47	5570 (20)	4160 (10)	3988 (9)	242	
C-57	6130 (20)	4630 (10)	3100 (10)	455	
C-67	5990 (20)	5100 (20)	2660 (10)	674	
C-77	4600 (20)	4000 (20)	4680 (10)	723	
C-87	4810 (20)	2730 (20)	3470 (10)	585	
C-97	6860 (40)	5890 (30)	2380 (20)	2787	
O-27	5010 (20)	3710 (10)	4263 (8)	644	
O-37	4640 (10)	3319 (9)	3306 (7)	408	
O-47	5950 (10)	3747 (9)	2622 (7)	437	
O-57	5810 (20)	4950 (10)	3522 (8)	613	
O-67	6670 (20)	5450 (10)	2726 (8)	941	
C-18A	9800 (70)	8070 (40)	3220 (50)	2465	0.39
C-18B	10040 (60)	7650 (40)	2860 (30)	2575	0.61

TABLE I (continued)

Atom	x	y	z	U	K
C-28	9750 (40)	7530 (30)	3400 (20)	1688	
C-38	9530 (50)	6920 (30)	3420 (30)	2436	
C-48	9880 (40)	6760 (30)	2940 (30)	2184	
C-58	9540 (40)	6200 (30)	3060 (20)	1854	
C-68	9640 (40)	5700 (30)	2760 (20)	1553	
C-78	9380 (40)	5120 (30)	2790 (20)	1948	
C-88	9330 (40)	4560 (30)	2540 (20)	1915	
C-98	8870 (40)	4040 (30)	2790 (30)	2310	
C-19	8690 (50)	3510 (30)	3010 (30)	2412	
C-29	8380 (40)	2980 (30)	3140 (20)	2211	
C-39	8010 (50)	2710 (40)	3530 (30)	3618	
O-49	8540 (30)	2250 (20)	3850 (20)	2565	
C-59	8730 (70)	1690 (40)	3660 (50)	5239	
O	7250 (20)	2410 (20)	3710 (10)	1721	
W-1	8090 (20)	1130 (20)	4370 (10)	1572	1.00
W-2	6340 (20)	1530 (10)	4240 (10)	1185	0.92

EXPERIMENTAL

Preparation of crystals and X-ray measurements.—The complex of TM-βCD with ethyl laurate was crystallized from an aqueous solution by slow evaporation of the solvent at room temperature.

One quadrant of data $2.5° < 2\theta < 40°$ was collected on a CAD4 automatic diffractometer with graphite-monochromated Cu$K\alpha$ radiation at 263 K, with a θ–2θ scan mode at a scan rate 2.7°/min and a scan width $1.20 + 0.15 \tan \theta$ in θ. The decay of the crystal was monitored by two standard reflections measured every 3600 s. No decay of the crystal was apparent. The intensities were corrected for Lorentz and polarization effects but no absorption ($\mu = 7.30$ cm^{-1}) correction has been applied. Of the 2767 unique reflections, 2167 with $F_o > 3.0\sigma(F_o)$ were used in the refinement of the structure.

Crystal data.—From the final results, the composition inferred was $C_{63}H_{112}O_{35} \cdot C_{14}H_{28}O_2 \cdot (H_2O)_{1.92}$. The final lattice parameters, as determined by the centering of 23 reflections with $28° < 2\theta < 30°$, were as follows: orthorombic, space group $P2_12_12_1$; $a = 14.796(2)$, $b = 22.444(6)$, $c = 27.720(8)$ Å; $V = 9205(4)$ Å^3; $Z = 4$; and $D_{calc} = 1.2$ g/cm^3.

Determination and refinement of the structure.—For the βCD skeleton itself, we used the coordinates of the corresponding atoms of the TM-βCD–p-iodophenol complex[2]. The coordinates of the atoms of the methoxyl groups of the host macrocycle, the guest, and the water molecules were located by subsequent difference electron-density maps. It was impossible to locate the methyl carbon atom of the ethyl moiety of the ester. The refinement was carried out by full-matrix least-squares techniques minimizing $\Sigma w(F_o - F_c)^2$ with unit weights for all reflections, as giving a satisfactory analysis of variance, using SHELX76[3]. At the

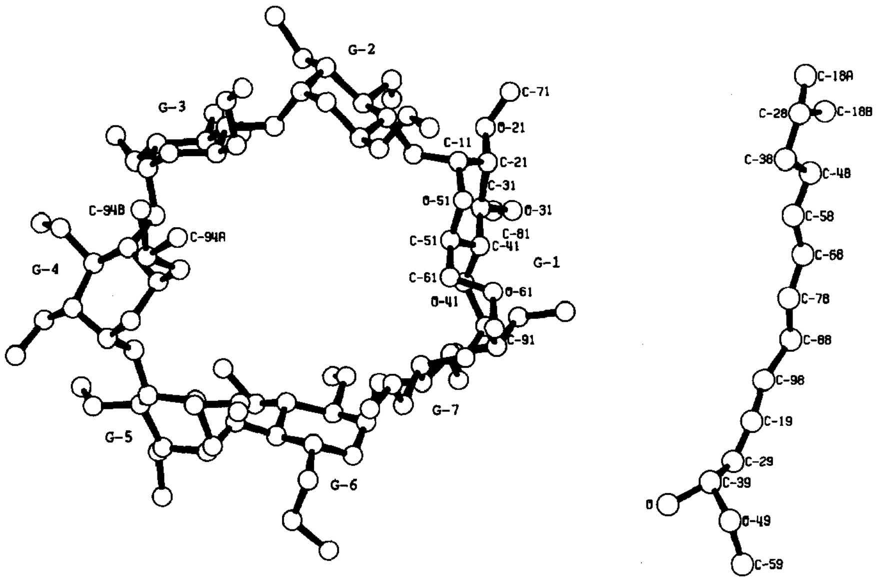

Fig. 1. The structure and numbering scheme of the TM-βCD and ethyl laurate molecules.

early stages of the refinement, the occupancy factor of the guest molecule was allowed to vary but, since its value was very close to unity, it has been set at unity. The occupancy factors of the water molecules were refined; for the W-1, it converged to a value > 1 and thus was kept constant at unity. For the hydrogen atoms linked to carbon atoms of the TM-βCD macrocycle, calculated coordinates were used (C–H distance, 0.96 Å). Isotropic thermal parameters were used for all atoms throughout the refinement, the small number of observations not allowing the use of anisotropic refinement. The thermal parameters of the secondary and tertiary hydrogens were kept constant at 0.15 and 0.10, respectively. The refinement converged to $R = 0.1212$ and $R_w = 0.1231$ for the observed reflections, and $R = 0.1519$ and $R_w = 0.1458$ for all reflections. The refined parameters were 469. Maximum and minimum values in the final difference electron-density map were 0.437 and -0.427 eA^{-3}, respectively. The final atomic coordinates are listed in Table I *.

DISCUSSION

The numbering scheme for the TM-βCD and the guest molecules is given in Fig. 1. C-*mn* or O-*mn* denotes the *m*th atom within the *n*th glucosidic residue (G-*n*).

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* Atomic coordinates for this structure have been deposited with the Cambridge Crystallographic Data Centre. The coordinates may be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

TABLE II

Bond distance (Å) and angles (degrees) of the TM-βCD–ethyl laurate complex

TM-βCD Bond [a]	G-1	G-2	G-3	G-4	G-5	G-6	G-7	Mean Value
C-1–C-2	1.47 (4)	1.62 (4)	1.44 (4)	1.42 (4)	1.49 (4)	1.38 (3)	1.49 (4)	1.47 (8)
C-2–C-3	1.64 (4)	1.60 (4)	1.52 (4)	1.59 (4)	1.54 (4)	1.52 (4)	1.61 (4)	1.57 (5)
C-3–C-4	1.46 (4)	1.45 (4)	1.50 (4)	1.61 (4)	1.42 (4)	1.55 (4)	1.59 (4)	1.51 (7)
C-4–C-5	1.52 (4)	1.53 (4)	1.50 (4)	1.45 (4)	1.50 (4)	1.50 (4)	1.38 (3)	1.48 (5)
C-5–O-5	1.43 (3)	1.52 (3)	1.42 (3)	1.50 (3)	1.51 (3)	1.46 (3)	1.46 (3)	1.47 (4)
C-1–O-5	1.41 (3)	1.34 (3)	1.38 (3)	1.45 (3)	1.34 (3)	1.40 (3)	1.36 (3)	1.38 (4)
C-2–O-2	1.40 (3)	1.35 (4)	1.39 (3)	1.48 (3)	1.34 (3)	1.48 (3)	1.45 (4)	1.41 (6)
O-2–C-7	1.35 (4)	1.50 (4)	1.30 (4)	1.44 (3)	1.45 (4)	1.33 (4)	1.48 (4)	1.41 (8)
C-3–O-3	1.40 (3)	1.47 (3)	1.37 (3)	1.44 (4)	1.46 (3)	1.37 (3)	1.46 (3)	1.42 (4)
O-3–C-8	1.41 (4)	1.35 (4)	1.38 (4)	1.42 (3)	1.32 (3)	1.43 (4)	1.41 (3)	1.39 (4)
C-5–C-6	1.47 (4)	1.47 (4)	1.39 (4)	1.54 (4)	1.69 (5)	1.52 (4)	1.63 (4)	1.53 (10)
C-6–O-6	1.44 (4)	1.37 (3)	1.40 (4)	1.35 (4)	1.40 (5)	1.41 (3)	1.29 (3)	1.38 (5)
O-6–C-9	1.44 (4)	1.45 (4)	1.45 (4)	1.65 (8)A 1.76 (8)B	1.62 (7)	1.43 (4)	1.40 (6)	1.49 (10)
O-4–C-4	1.44 (3)	1.47 (4)	1.48 (3)	1.46 (3)	1.44 (3)	1.46 (3)	1.48 (3)	1.46 (2)
C-1–O-4′	1.45 (3)	1.46 (3)	1.45 (3)	1.42 (3)	1.45 (3)	1.42 (2)	1.51 (4)	1.45 (3)
Angle [a]	G-1	G-2	G-3	G-4	G-5	G-6	G-7	Mean value
C-1–C-2–C-3	109 (2)	102 (3)	111 (2)	109 (3)	110 (3)	122 (3)	105 (3)	110 (6)
C-2–C-3–C-4	110 (3)	111 (3)	105 (3)	106 (3)	115 (3)	105 (2)	106 (2)	108 (4)
C-3–C-4–C-5	115 (3)	117 (3)	118 (2)	118 (3)	114 (3)	116 (2)	114 (2)	116 (2)
C-4–C-5–O-5	107 (2)	104 (2)	104 (2)	108 (3)	111 (2)	109 (2)	112 (3)	108 (3)
C-5–O-5–C-1	115 (2)	112 (2)	116 (2)	110 (2)	110 (2)	114 (2)	110 (2)	112 (3)
O-5–C-1–C-2	111 (2)	115 (3)	114 (2)	112 (3)	120 (3)	111 (2)	111 (3)	113 (3)
C-1–C-2–O-2	119 (2)	118 (3)	111 (2)	120 (3)	118 (3)	110 (2)	117 (3)	116 (4)
C-3–C-2–O-2	105 (2)	108 (3)	110 (2)	102 (2)	113 (3)	107 (2)	103 (3)	107 (4)
C-2–O-2–C-7	117 (3)	109 (3)	122 (3)	108 (2)	118 (3)	119 (3)	109 (2)	115 (6)

C-2–C-3–O-3	108 (2)	104 (3)	109 (3)	110 (3)	109 (3)	116 (3)	108 (2)	109 (4)
C-4–C-3–O-3	116 (3)	111 (3)	115 (3)	107 (3)	111 (3)	112 (3)	109 (2)	112 (3)
C-3–O-3–C-8	112 (3)	112 (3)	113 (3)	114 (3)	114 (3)	115 (3)	111 (2)	113 (1)
C-4–C-5–C-6	117 (3)	122 (3)	122 (3)	114 (3)	105 (3)	119 (2)	105 (3)	115 (7)
O-5–C-5–C-6	109 (3)	104 (2)	115 (3)	103 (3)	102 (3)	107 (2)	104 (2)	106 (5)
C-5–C-6–O-6	111 (3)	112 (3)	105 (3)	106 (3)	90 (3)	112 (2)	101 (3)	105 (8)
C-6–O-6–C-9(A)	113 (3)	113 (3)	112 (3)	97 (4)	89 (4)	108 (2)	118 (4)	107
C-6–O-6–C-9(B)				128 (4)				
C-3–C-4–O-4	104 (3)	102 (3)	104 (2)	104 (2)	108 (2)	107 (2)	102 (2)	104 (2)
C-5–C-4–O-4	109 (3)	105 (3)	111 (2)	106 (3)	110 (2)	115 (2)	114 (2)	110 (4)
C-2–C-1–O-4′	109 (2)	107 (3)	113 (2)	111 (3)	106 (2)	112 (2)	111 (3)	110 (3)
O-5–C-1–O-4′	112 (2)	117 (3)	111 (2)	116 (2)	112 (2)	111 (2)	116 (3)	114 (3)
C-4′–O-4′–C-1	121 (2)	119 (2)	122 (2)	123 (2)	124 (2)	120 (2)	117 (2)	121 (2)

Ethyl laurate

Bond		Angle	
C-18(A)–C-28	1.31 (7)	C-18(A)–C-28–C-38	158 (9)
C-18(b)–C-28	1.56 (7)	C-18(B)–C-28–C-38	105 (5)
C-28–C-38	1.40 (6)	C-28–C-38–C-48	97 (5)
C-38–C-48	1.47 (6)	C-38–C-48–C-58	84 (5)
C-48–C-58	1.39 (6)	C-48–C-58–C-68	123 (6)
C-58–C-68	1.38 (5)	C-58–C-68–C-78	135 (6)
C-68–C-78	1.38 (6)	C-68–C-78–C-88	146 (7)
C-78–C-88	1.42 (6)	C-78–C-88–C-98	118 (6)
C-88–C-98	1.52 (6)	C-88–C-98–C-19	164 (7)
C-98–C-19	1.37 (6)	C-98–C-19–C-29	168 (9)
C-19–C-29	1.32 (6)	C-19–C-29–C-39	141 (9)
C-29–C-39	1.34 (6)	C-29–C-39–O-49	123 (7)
C-39–O	1.41 (6)	C-39–O-49–C-59	120 (8)
C-39–O-49	1.56 (7)	O–C-39–C-29	146 (8)
O-49–C-59	1.39 (8)	O–C-39–O-49	83 (4)

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[a] Single primes denote the $n+1$ residues. If $n=7$, $n+1=1$.

TABLE III

Selected torsion angles[a] (degrees) of the TM-βCD molecule

Angle	G-1	G-2	G-3	G-4	G-5	G-6	G-7
C-1–C-2–C-3–C-4	−47	−50	−50	−50	−39	−42	−53
C-2–C-3–C-4–C-5	48	58	54	46	45	41	50
C-3–C-4–C-5–O-5	−54	−57	−56	−50	−52	−51	−53
C-4–C-5–O-5–C-1	62	59	55	59	56	58	61
C-5–O-5–C-1–C-2	−65	−67	−61	−71	−56	−58	−70
O-5–C-1–C-2–C-3	53	59	56	66	47	51	67
C-3–C-4–O-4–C-1′	137	142	141	100	133	157	104
C-1–O-4′–C-4′–C-5′	−96	−90	−135	−102	−72	−133	−100
C-2–C-1–O-4′–C-4′	−124	−124	−145	−135	−128	−160	−105
C-1–C-2–O-2–C-7	90	79	139	73	74	146	74
C-3–C-2–O-2–C-7	−147	−166	−98	−167	−157	−80	−171
C-2–C-3–O-3–C-8	−119	−117	−132	−96	−93	−137	−105
C-4–C-3–O-3–C-8	117	124	111	150	139	101	140
C-4–C-5–C-6–O-6	44	43	61	54	−171	47	−164
O-5–C-5–C-6–O-6	−78	−74	−65	−62	74	−77	78
C-5–C-6–O-6–C-9	−179	−175	176	−172A −134B	−176	102	173
O-2–C-2–C-3–O-3	57	65	63	68	61	67	68
O-5–C-1–O-4′–C-4′	112	104	85	97	100	75	100

[a] Primed atoms as in Table II.

The host conformation.—The mean values of bond lengths and angles of the glucosidic residues of TM-βCD are the same as those of βCD[4] within two standard deviations, but the dispersion of the individual values is much greater (Table II).

All glucose residues have the $^4C_1$ chair conformation. Except for the C-94 atom, disordered over two positions A and B (occupancy factors 0.65 and 0.35), no other disordered atoms have been observed. Five primary methoxyl groups have the *gauche–gauche* orientation pointing outward from the βCD cavity. In the glucosidic residues G-5 and G-7, the C-6–O-6 bond has the *gauche–trans* orientation pointing inward, as shown by their torsion angles (Table III). Unlike βCD, the sevenfold symmetry of TM-βCD is not well maintained. This fact is reflected in the geometrical parameters of the glycosidic O-4 heptagonal ring. The O-4$n \cdots$ O-4($n + 1$) distances range between 4.13(3)–4.60(3) Å and the O-4($n - 1$)$\cdots$O-4n $\cdots$ O-4($n + 1$) angles vary from 116(6) to 136(6)° (Table IV). The deviations of the O-4 atoms from their optimum plane range between 0.029–0.542 Å while the corresponding deviations for the βCD dimeric structures are less than 0.02 Å[4]. This conformation is attributed to the absence of O-3$n \cdots$ O-2($n + 1$) hydrogen bonds that exist in the βCD dimeric complexes and lock the macrocycle in a round shape[5]. The O-3 $\cdots$ O-2($n + 1$) distances range between 3.19–3.54 Å, while the corresponding values for the βCD dimeric complexes are 2.74–2.82 Å[4]. The tilt-angles, defined as the dihedral angles between the O-4 mean plane and the planes through the atoms C-1, C-4, O-4, and O-4′ of each residue, are all positive

TABLE IV

Parameters describing the conformation of the TM-βCD molecule

Residue	d_1 [a]	d_2 [b]	θ_1 [c]	d_3 [d]	θ_2 [e]	d_4 [f]
G-1	0.405	4.36 (3)	122 (6)	5.22 (3)	33	3.35 (3)
G-2	0.293	4.33 (3)	122 (6)	5.27 (3)	14	3.19 (3)
G-3	−0.405	4.54 (3)	133 (6)	4.63 (3)	13	3.22 (3)
G-4	0.029	4.16 (3)	134 (6)	4.81 (3)	31	3.46 (3)
G-5	0.542	4.42 (3)	116 (6)	5.43 (3)	27	3.31 (3)
G-6	−0.429	4.60 (3)	127 (6)	4.99 (3)	17	3.65 (3)
G-7	−0.581	4.28 (3)	136 (6)	4.64 (3)	30	3.54 (3)
Mean value		4.4 (2)	127 (7)	5.0 (3)		3.4 (2)

[a] Deviations (Å) from the least-squares optimum plane of the seven O-4n atoms. [b] O-4n ··· O-4(n + 1) distances. [c] O-4(n − 1) ··· O-4n ··· O-4(n + 1) angles. [d] Distances (Å) of the O-4n atoms from the center K of the O-4n heptagon. [e] Tilt angles formed between the O-4n and the O-4n–C-1n–C-4n–O-4n' mean planes. [f] O-3n ··· O-2(n + 1) distances.

and vary from 13 to 33°. This feature is in contrast to other TM-βCD complexes[2,5] that have two of their residues inclined to the opposite side of the macrocyclic ring and show negative tilt-angles. As a consequence, all the residues incline with their O-6 toward the cavity of the macrocyclic ring. The linear shape of the guest in the present structure might play a role in this feature.

As far as the orientation of the methoxyl groups is concerned, the O-6–C-9 bonds are *trans* to the corresponding C-5–C-6, the C-5–C-6–O-6–C-9 torsion angles being close to 180°, except for the one disordered methoxyl of G-4 (B position) and that of residue G-6 forming a dihedral angle of 134° and 102°, respectively. The O-2–C-7 bonds point outward from the cyclodextrin cavity while the O-3–C-8 bonds point slightly inside, five of them forming a small angle with the approximate sevenfold symmetry axis of the TM-βCD molecule. The orientation of the CH_3O-2 methoxyl groups is more uniform, as can be seen from the torsion angles C-7–O-2–C-2–C-1 and C-7–O-2–C-2–C-3 (Table III), than those of C-8–O-3 methoxyl groups (torsion angles C-8–O-3–C-3–C-2 and C-8–O-3–C-3–C-4). This is caused by the steric hindrance between the above methoxyl groups.

The guest molecule.—The ethyl laurate molecule has been found in the interior of the cavity along its axis (Fig. 2). The thermal parameters of its atoms have high values indicating thermal motion and/or disorder manifested clearly only for the extreme atom C-18 of the lauric acid moiety, disordered over two positions A and B (occupation factors 0.39 and 0.61), and our inability to locate the methyl group of the ethyl moiety.

The optimum line passing through the linear molecule forms an angle of 11° with the normal to the optimum plane of the O-4 atoms. Since the depth of the TM-βCD molecule is not enough to cover the whole length of the guest, its ends protrude from both sides of the macrocycle. The hydrophobic end of the lauric acid moiety protruding from the primary side protects itself by entering the

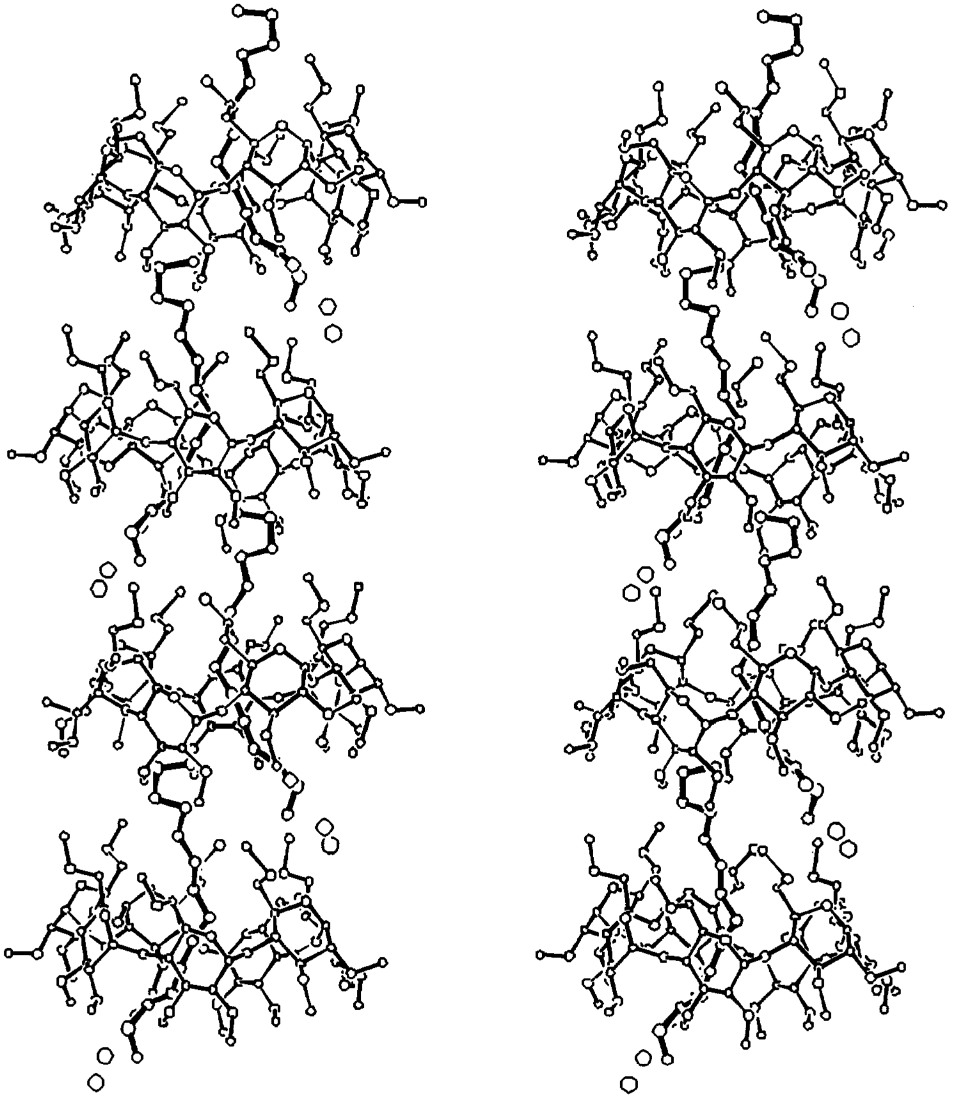

Fig. 2. Stereoscopic view of the TM-βCD channels with the guest molecules inside.

secondary side of the adjacent host molecule, forming a channel with the original and related to it by the twofold screw axis parallel to *b*. The ethyl moiety of the guest protrudes from the secondary side of the cavity towards the primary side of another adjacent host along the opposite direction of the channel. (Its missing CH_3 group would be just entering the edge of the cavity.)

Both water molecules of the structure are located near the oxygen atoms of the ester, which are exposed, forming hydrogen bonds with them [distances O-49 · · · W-1 and O · · · W-2, 2.98(7) and 2.82(7) Å, respectively] and between themselves [W-1 · · · W-2 distance 2.77(7) Å].

TABLE V

Intermolecular atomic distances up to 4.0 Å

Between the host and guest atoms of the same asymmetric unit			
O···C-81	3.52 (1)	O-49···C-82	3.54 (6)
O···C-87	3.74 (1)	C-68···C-64	4.00 (7)
Between the host and guest atoms of adjacent asymmetric units			
O···C-94A	3.53 (9)	C-39···C-94A	3.9 (1)
···C-94B	4.0 (1)	O-49···C-94A	3.8 (1)
C-18A···O-23	3.7 (1)	C-59···O-54	3.9 (1)
···C-34	3.7 (1)	···C-64	3.3 (1)
···O-44	3.5 (1)	···O-64	3.0 (1)
···O-45	3.6 (1)	···C-94A	2.8 (1)
C-18B···O-23	3.87 (9)	···C-94B	3.8 (1)
···C-83	3.7 (1)	···C-95	3.9 (1)
···C-86	4.0 (1)		
C-28···O-23	3.83 (6)		
···C-86	3.89 (7)		
Between the guest atoms of adjacent asymmetric units			
C-18B···C-98	4.0 (1)		
···C-19	3.6 (1)		
···C-29	3.7 (1)		

The host–guest and guest–guest atomic distances less than 4.0 Å are given in Table V. The majority of them are found between the extreme atoms of the guest and some atoms of the host of the adjacent asymmetric unit linked with it by the twofold screw axis parallel to *b*, in the cavities of which these extreme atoms penetrate. Exceptions are the interactions of the ester oxygens with some methoxyl groups linked to O-3 atoms, and the C-68 atom in the middle of the lauric group interacting with the C-64 atom at the primary edge. Interactions closer than 3.5 Å are only those of the CH_2 of the ethyl group and the primary methoxyl group of residue 4 (Table V).

Molecular packing.—The TM-βCD macrocycles linked by the twofold screw axis parallel to *b* are stacked to form a channel-type structure in a head-to-tail mode, in the interior of which the guest molecules are accommodated (Fig. 2). Each ethyl laurate molecule spans three hosts, remaining in the extended form. The closest intermolecular contacts between the guests are at the secondary side of TM-βCD (Table V) where two opposite ends of it are forced to coexist. The ethyl moiety of the guest has been located between the O-6 methyl groups of residues G-4 and G-5 of the adjacent macrocycle inside the channel; its missing methyl group must lie at the primary entrance of the latter. The water molecules were found outside the channel near its rim. The O-4 mean planes of two neighboring macrocycles in the channel form an angle of 10° between them, and of 5° with the (*a*,*c*) crystal plane. The structure has the characteristics of a Screw Channel (SC) packing mode observed in the dimeric βCD structures (space group $P2_1$)[4]. However, in the present case, the projections of the centers of the O-4 mean planes of two subsequent macrocycles on the (a,c) crystal plane have a distance of 6.39 Å, considerably greater than the mean value of 2.6 Å observed for the SC structures. The crystal is built by channels moving along the a and c twofold screw axis.

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