Crystal Structure of 11,12,23,24-Tetradehydro-5,6,9,10,17,18,21,22-octahydro-7H,19H-dibenzo[*e,o*][1,11]dioxacycloeicosin-7,19-dione

Pablo WESSIG,[†] Charlotte PICK, and Burkhard ZIEMER

Institut für Chemie, Humboldt-Universität zu Berlin, Brook-Taylor-Str. 2, D-12489 Berlin

The title compound, bearing a twenty-membered ring, was synthesized by macrolactonization of a hydroxy carboxylic acid. The structure was investigated by X-ray crystallography. The compound crystallizes in the monoclinic system, space group $P2_1/c$. In the crystal, two remarkable kinds of interactions between two ester groups and between two arylacetylene moieties were detected.

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The preparation of macrocyclic compounds is still a challenge for synthetic organic chemistry. Because the formation of large rings consisting of 10 or more atoms is entropically very unfavorable, most of the successfully performed macrocyclizations rely either on large dilution (the Ruggli-Ziegler dilution principle) or on template effects. On the other hand, spontaneous ring closure to conformationally flexible macrocyclic compounds under thermodynamically controlled conditions has been rarely observed. The state of the art concerning macrolactonization in the synthesis of natural products has been collected very recently in an excellent review.¹

In connection with one of our current research projects, an investigation of the Photo-Dehydro-Diels-Alder (PDDA) reaction,^{2,3} we were interested in the preparation of ten-membered macrocyclic lactones **2** from hydroxycarboxylic acid **1**. Surprisingly, under acidic conditions (cat. TsOH·H₂O in toluene) not the desired lactone **2**, but the dilactone **3**, bearing a twenty-membered ring, was formed in moderate yield. We suppose that the two planar and rigid aryl acetylene moieties are responsible for the unexpected result. Obviously, the twenty-membered ring in **3** is more favorable than the ten-membered ring in **2** as well as polymerization products. Here, the crystal structure of **3** was analyzed. The formation of **2** could be forced

with a macrocyclization method previously described by Yamaguchi *et al.*⁴

The title compound **3** adopts an angle-like geometry in crystals, as can be seen in Fig. 2. The planar regions at both

Table 1 Crystal and experimental data of **3**

Empirical formula	C ₂₆ H ₂₄ O ₄
Formula weight	400.45
Temperature	180(2)K
Wavelength	0.71073 Å
Crystal system, space group	monoclinic, $P2_1/c$
Unit cell dimensions	$a = 9.9553(15)$ Å $b = 9.7622(9)$ Å $\beta = 98.256(18)^\circ$ $c = 23.145(3)$ Å
Volume	$2226.1(5)$ Å ³
Z, Calculated density	4, 1.195 Mg/m ³
Absorption coefficient	0.080 mm ⁻¹
$F(0\ 0\ 0)$	848
Crystal size	$0.48 \times 0.44 \times 0.28$ mm ³
Theta range for data collection	2.27 to 25.22°
Limiting indices	$-11 \leq h \leq 11, -11 \leq k \leq 11, -27 \leq l \leq 27$
Reflections collected/unique	14815/4032 [$R(\text{int}) = 0.1172$]
Completeness to theta = 25.22	99.6%
Max. and min. transmission	0.9780 and 0.9627
Absorption correction	none
Data/restraints/parameters	4032/0/345
Goodness-of-fit on F^2	1.068
Final R indices [$I > 2\sigma(I)$]	$R1 = 0.0856, wR2 = 0.2359$
R indices (all data)	$R1 = 0.1100, wR2 = 0.2538$
Extinction coefficient	0.011(3)
Largest difmap peak and hole	0.596 and -0.337 e.Å ⁻³
Measurement	Stoe IPDS
Program system	Stoe X-Area
Structure solution	direct methods, SHELXS-97
Refinement method	full-matrix on F^2 , SHELXL-97

Standard deviations are given as the last significant figures in parentheses throughout the paper. All hydrogen atoms could be located in difmaps and refined by the least-squares method. The rather high values of $R(\text{int})$ and $R1$ are caused by crystal twinning. The complete data for this X-ray analysis have been deposited at Cambridge Crystallographic Data Centre under CCDC 620203.

Fig. 1 Formation of lactone **2** and dilactone **3** from hydroxy carboxylic acid **1**.

[†] To whom correspondence should be addressed.
Email: pablo.wessig@chemie.hu-berlin.de

Fig. 2 Molecular structure of compound **3**. The probability level of thermal ellipsoids is 50%. Hydrogen atoms are omitted for clarity.

Table 2 Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($\text{\AA}^2 \times 10^3$). U_{eq} is defined as one third of the trace of the orthogonalized U_{ij} tensor

	x	y	z	U_{eq}
C1	3388(4)	2275(5)	2039(2)	33(1)
C2	1877(4)	2485(5)	1984(2)	35(1)
C3	1445(4)	3621(5)	2368(2)	34(1)
C4	-57(4)	3899(4)	2247(2)	30(1)
C5	-945(4)	3273(5)	2574(2)	35(1)
C6	-2324(4)	3483(5)	2454(2)	37(1)
C7	-2863(4)	4334(5)	2000(2)	40(1)
C8	-2010(4)	4961(5)	1664(2)	38(1)
C9	-599(4)	4748(4)	1781(2)	29(1)
C10	277(4)	5409(4)	1424(2)	36(1)
C11	1017(5)	5999(5)	1148(2)	42(1)
C12	1953(6)	6725(5)	823(3)	52(1)
C13	3287(5)	5977(5)	830(3)	48(1)
C14	3990(4)	3977(4)	399(2)	36(1)
C15	3578(4)	2807(4)	-4(2)	33(1)
C16	2227(4)	2106(4)	74(2)	34(1)
C17	1994(4)	867(4)	-308(2)	30(1)
C18	1113(4)	905(5)	-839(2)	40(1)
C19	917(5)	-216(5)	-1203(2)	42(1)
C20	1622(5)	-1423(5)	-1055(2)	39(1)
C21	2527(4)	-1486(4)	-534(2)	32(1)
C22	2709(4)	-366(4)	-167(2)	26(1)
C23	3627(4)	-433(4)	375(2)	25(1)
C24	4367(4)	-440(4)	833(2)	27(1)
C25	5208(4)	-416(5)	1408(2)	32(1)
C26	5118(4)	929(5)	1719(2)	37(1)
O1	3698(3)	1187(3)	1741(1)	36(1)
O2	4231(3)	3017(4)	2310(2)	60(1)
O3	2961(3)	4766(3)	478(2)	45(1)
O4	5151(3)	4209(4)	627(2)	53(1)

ends of the molecule contain C3 to C12 and C16 to C25, respectively. The angle between them is about $86.2(3)^\circ$, revealing a tilted and/or twisted conformation of the molecule (Fig. 2). All of the bond lengths and angles within the central 20-membered ring are listed in Table 3. In the crystal packing, the shortest contact is between O4 and C14' ($3.17 \text{ \AA}$), which may be caused by an electrostatic interaction between two ester groups (Fig. 3). Further short contacts are C23-C23' ($3.55 \text{ \AA}$) and C22-C24' ($3.57 \text{ \AA}$), which rest on π -electron interactions between the acetylene/phenyl subunits of neighbouring molecules. C14' and C23', C24' were generated by two different inversion centers, respectively. Together with their

Table 3 Bond lengths [$\text{\AA}$] and angles [$^\circ$] of the 20-membered ring

C1-O1	1.328(5)	C14-O3	1.316(5)
C1-C2	1.505(5)	C14-C15	1.494(6)
C2-C3	1.522(6)	C15-C16	1.543(6)
C3-C4	1.505(5)	C16-C17	1.497(6)
C4-C9	1.405(6)	C17-C22	1.412(5)
C9-C10	1.438(6)	C22-C23	1.444(5)
C10-C11	1.191(6)	C23-C24	1.199(5)
C11-C12	1.462(7)	C24-C25	1.469(5)
C12-C13	1.514(7)	C25-C26	1.505(6)
C13-O3	1.446(6)	C26-O1	1.444(5)
O1-C1-C2	111.6(3)	C14-C15-C16	115.6(4)
C1-C2-C3	114.3(3)	C17-C16-C15	110.6(3)
C4-C3-C2	112.3(3)	C22-C17-C16	121.4(3)
C9-C4-C3	120.7(4)	C17-C22-C23	118.4(3)
C4-C9-C10	120.5(4)	C24-C23-C22	177.3(4)
C11-C10-C9	177.1(5)	C23-C24-C25	176.7(4)
C10-C11-C12	178.4(6)	C24-C25-C26	112.4(4)
C11-C12-C13	112.6(4)	O1-C26-C25	107.2(3)
O3-C13-C12	105.3(4)	C1-O1-C26	117.4(3)
O3-C14-C15	112.7(4)	C14-O3-C13	116.2(4)