

The Crystal Structure and the Absolute Configuration of Dilactophorbic Acid Chloride

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The crystal structure of dilactophorbic acid chloride ($C_8H_7O_5Cl$) has been determined from three-dimensional photographic data by means of the heavy atom method. The space group is $P2_1$, and the unit cell dimensions $a = 11.834 \text{ \AA}$, $b = 6.235 \text{ \AA}$, $c = 6.298 \text{ \AA}$, $\beta = 103.29^\circ$. The structure was refined by full matrix least squares methods. The final R value is 6.4 % for the 697 observed reflections. The absolute configuration of the molecule was determined from the anomalous scattering of $CuK\alpha$ radiation from the chlorine atom. The compound consists of two five-membered lactone rings, forming a spiro compound. Both lactone groups are planar, and the rings have an envelope conformation. Angles and distances are in general agreement with the values observed in similar compounds. The correct name of dilactophorbic acid should be (5*R*:8*R*)8-carboxy-2,6-dioxo-1,7-dioxo[4,4]-spirononane, and for the unlactonized molecule: (1*R*:3*R*)-1,3-dihydroxy-1,3,5-pentane tricarboxylic acid.

Phorbic acid (1,3-dihydroxy-1,3,5-pentane tricarboxylic acid) was first isolated by Nordal and Bærheim Svendsen¹ from the crude drug *Euphorbium*, which is the dried latex from *Euphorbium resinifera* Berg. The chemical structure of the compound was studied by Bernatek *et al.*²

Evaporation of an aqueous solution of the acid gives dilactophorbic acid (Fig. 1), which is the stable form of the dry compound. From the IR and NMR spectra of the dilactonic acid and its ethyl ester, a spiro γ -lactone was assumed to be the most probable structure. Phorbic acid contains two asymmetric centra. Correspondingly, there should be four isomeric forms of the acid, but all samples isolated so far from natural sources have shown the same optical activity. The structure determination was carried out in order to study the dilactone in detail, and to determine the absolute configuration.

The distribution of phorbic acid in plants has been studied by Nordal *et al.*,³ and an investigation on the biosynthesis and physiological aspects of the acid was carried out by Nordal and Benson.⁴ A theory for the possible role of lactic acids in the pH and water regulation in succulent metabolism has been put forward by Nordal.⁵

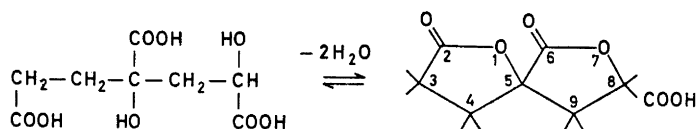


Fig. 1. Phorbic acid and its corresponding dilactone.

EXPERIMENTAL

a. *The lactonic acid.* Phorbic acid was isolated from powdered *Euphorbium* via the monoethyl ester, as described by Bernatek *et al.*⁸ The ester was characterized by its melting point (91°C) and by its optical rotation, $[\alpha]_D^{25} = +26.5^\circ$ ($c = 1.0$ in ethanol). (Nordal *et al.*: m.p. = 90°C; $[\alpha]_D^{18} = +33^\circ$.) After hydrolysis with 0.5 N HCl and drying, the dilactone was isolated. According to the crystallization procedure used, different types of crystals were formed. One type of crystals was obtained by crystallization from anhydrous ethanol. These crystals were orthorhombic plates, with space group $P2_12_12_1$ and cell dimensions $a = 18.9$ Å, $b = 9.6$ Å, $c = 6.6$ Å. The density was measured by flotation, and found to be 1.38 g/cm³. The crystals proved to contain one molecule of ethanol per molecule of dilactophorbic acid.

A second type of crystals was obtained by crystallization from a mixture of benzene and ethyl acetate. These crystals were monoclinic, space group $P2_1$, with cell dimensions $a = 9.69$ Å, $b = 6.15$ Å, $c = 7.17$ Å, $\beta = 100^\circ$. The observed crystal density was 1.55 g/cm³, which corresponds to two molecules of dilactophorbic acid in the cell. After drying, the following data were observed for both crystals. M.p. 153–155°C. Found: C 48.49; H 3.98. Calc. for C₈H₈O₆: C 48.01; H 4.01. $[\alpha]_D^{20} = +31.6^\circ$ ($c = 1.0$ in ethyl acetate).

b. *The acid chloride.* The present structure determination was carried out on the acid chloride of the dilactophorbic acid. This derivative was chosen because the chlorine atom would act as a heavy atom and also gives the possibility for determination of the absolute configuration. The compound was prepared in crystalline form by dissolving dry dilactophorbic acid in thionyl chloride and gradual concentration of the solution. M.p. 101°C. The crystals showed a marked tendency to cleave along the needle axis (b). From the acid chloride, dilactophorbic acid could be recovered by hydrolysis in water. M.p. and $[\alpha]_D$ of the recovered compound corresponded with those of dilactophorbic acid, from which it was concluded that no changes in the asymmetric centra had taken place during preparation of the acid chloride. When sealed in a glass capillary, the crystals were stable at room temperature for a long time. The cell dimensions were determined from Weissenberg photographs, calibrated against BaF₂.

The X-ray intensities for the layers $k = 0$ through 5, were recorded on integrated equi-inclination Weissenberg photographs, using Ni filtered CuK α radiation ($\lambda = 1.5418$ Å), and on precession photographs using Zr filtered MoK α radiation ($\lambda = 0.7107$ Å) for the $hk0$ layer. All diagrams were recorded at room temperature using a crystal of dimensions 0.84 × 0.42 × 0.24 mm³ sealed in a glass capillary. The intensities were measured photometrically, except for the very weak ones and for those from the $hk0$ layer, which were estimated visually, using a calibrated scale for comparison. The data were corrected for absorption. The structure determination was based on 831 reflections of which 697 were actually observed above the background level. The non-observed reflections were included in the refinement and given the value $1/2 I_{\min}$, where I_{\min} is the lowest observable intensity.

CRYSTAL DATA

The crystal data of dilactophorbic acid chloride (C₈H₇O₆Cl; $M = 219$) are as follows: $a = 11.833$ (0.006) Å; $b = 6.235$ (0.007) Å; $c = 6.298$ (0.003) Å; $\beta = 103.29$ (0.05)°. Reflections for $0k0$ are absent for k odd. As the compound is optically active the space group is $P2_1$. $D_m = 1.58$ g/cm³, measured by the flotation method in a mixture of bromobenzene/xylene at 20°C. $D_x = 1.607$ g/cm³ for $Z = 2$.

Linear absorption coefficient $\mu_{CuK\alpha} = 37.5$ cm⁻¹.

STRUCTURE DETERMINATION AND REFINEMENT

The structure was solved by the heavy atom method. From a sharpened three-dimensional Patterson map, the x - and z -coordinates of the chlorine atom were determined, and the y -coordinate was set to 0.75. It was also possible to locate one of the lighter atoms (C(1)). The enantiomorph used in the refinement was arbitrarily chosen.

A three-dimensional Fourier synthesis based on the phases of these two atoms, suggested a total structure, which corresponded to an R -value of 0.22 (assuming $B = 3.5 \text{ \AA}^2$). The three-dimensional refinement was performed by using a full matrix least squares program.^{6*}

The following weighting scheme was used in the least squares calculations:

$$F_{\text{obs}} \leq \text{FB}, w = A_1(F_{\text{obs}})^{B_1}$$

$$F_{\text{obs}} > \text{FB}, w = A_2(F_{\text{obs}})^{B_2}$$

Satisfactory values were obtained with

$$A_1 = 10.0, B_1 = 0, A_2 = 40.0, B_2 = -0.67, \text{FB} = 8.0$$

The unobserved reflections were given the weight of $A_1/3$. The atomic form factors used were those of Hanson *et al.*⁷ After three cycles of refinement with anisotropic thermal parameters for chlorine, and isotropic for the others, the R -index was reduced to 0.10. The hydrogen positions were calculated, assum-

Table 1. Fractional atomic coordinates x , y , z , and their estimated standard deviations. (For atomic numbering, see Fig. 2.)

Atom	x	y	z
Cl	0.1999(3)	0.7500(—)	0.6573(4)
O(1)	0.1167(6)	0.3701(14)	0.6822(10)
O(2)	0.0652(5)	0.2766(12)	0.2484(10)
O(3)	0.1254(6)	—0.0250(12)	0.1241(11)
O(4)	0.3216(4)	0.2174(11)	0.4475(8)
O(5)	0.4782(6)	0.0384(15)	0.6164(12)
C(1)	0.1370(7)	0.5013(15)	0.5606(13)
C(2)	0.1146(7)	0.4877(15)	0.3135(12)
C(3)	0.2225(7)	0.5025(15)	0.2242(12)
C(4)	0.1471(7)	0.1536(16)	0.1894(12)
C(5)	0.2612(6)	0.2758(15)	0.2253(11)
C(6)	0.3413(8)	0.2084(18)	0.0766(14)
C(7)	0.4309(8)	0.0597(22)	0.2225(17)
C(8)	0.4184(8)	0.1021(17)	0.4480(16)
H(1)	0.062	0.629	0.213
H(2)	0.185	0.619	0.067
H(3)	0.292	0.626	0.329
H(4)	0.384	0.339	0.058
H(5)	0.292	0.128	—0.046
H(6)	0.503	0.111	0.202
H(7)	0.404	—0.100	0.185

* All programs used are included in this reference.

ing sp^3 hybridized C-atoms and C-H distances 1.00 Å. Now the interlayer scale factors were adjusted, whereafter a number of cycles, including all the reflections and all the non-hydrogen atoms with anisotropic thermal parameters, were calculated. In the final cycle, the hydrogen parameters were included in the refinement. The final R -value was then 6.4 % for the observed reflections, and 8.0 % for all reflections ($R_w = 8.5$ %). The corresponding parameters and their standard deviations are given in Tables 1 and 2, and the structure factors in Table 3.

Table 2. Thermal parameters for dilacto-phorbic acid chloride. All b_{ij} values are multiplied by 10^4 . Standard deviations are given in parentheses.

Atom	b_{11}	b_{22}	b_{33}	b_{12}	b_{13}	b_{23}
C1	140(3)	279(8)	274(6)	113(8)	135(6)	211(13)
O(1)	106(7)	285(23)	317(21)	14(22)	163(19)	-104(38)
O(2)	33(4)	188(21)	343(19)	8(15)	-10(14)	80(33)
O(3)	117(7)	106(21)	395(24)	84(18)	2(19)	128(35)
O(4)	63(5)	191(20)	199(13)	-32(15)	22(12)	-5(27)
O(5)	83(6)	414(30)	388(24)	-175(23)	-6(19)	-119(47)
C(1)	48(6)	187(29)	239(22)	5(21)	55(18)	51(42)
C(2)	55(6)	164(26)	172(19)	-24(20)	16(17)	-14(36)
C(3)	83(8)	131(27)	171(19)	20(22)	64(18)	-44(35)
C(4)	64(7)	197(32)	169(19)	-25(23)	50(19)	-21(35)
C(5)	50(6)	164(27)	178(18)	-27(18)	35(16)	4(37)
C(6)	100(9)	235(37)	249(24)	-27(28)	90(23)	115(47)
C(7)	78(9)	392(43)	399(34)	-90(32)	193(28)	83(63)
C(8)	56(7)	272(35)	322(29)	-68(24)	30(22)	14(49)
	$B(\text{Å}^2)$					
H(1)	2.35					
H(2)	1.38					
H(3)	4.48					
H(4)	2.04					
H(5)	1.09					
H(6)	1.51					
H(7)	7.79					

DETERMINATION OF THE ABSOLUTE CONFIGURATION

The absolute configuration of the compound was established by utilizing the anomalous scattering of $\text{CuK}\alpha$ radiation from the C1 atom.⁸ The $\Delta f'$ and $\Delta f''$ components used for C1 ($\Delta f' = 0.3$, and $\Delta f'' = 0.7$) were according to the *International Tables for X-Ray Crystallography*, Vol. III (1962). For this purpose, a small crystal was mounted on a manual four circles Picker diffractometer, with its crystallographic b -axis along the ϕ -axis of the instrument. The radiation used was Ni filtered $\text{CuK}\alpha$ radiation.

Eleven sets of reflections, where the differences in intensity were expected to be detectable, were measured by $\theta - 2\theta$ scan. The results which are given in Table 4 show that the orientation around the two asymmetric carbon atoms are R, R , using the nomenclature of Cahn *et al.*⁹ The correct atomic parameters, referring to a righthanded crystal system, are those given in Table 1.

Table 3. Observed and calculated structure factors. Columns are $h k l$, $10 F_{obs}$, $10|F_{calc}|$. * indicates unobserved reflections.

0 0 1	432	360	1 5 -5	31	28	3 1 1	137	143	4 3 3	3	44	89
0 0 2	384	348	1 5 -4	30	29	3 1 2	138	136	4 3 4	5	57	56
0 0 3	78	80	1 5 -3	19	64	3 1 3	143	191	4 3 5	21	19	19
0 0 4	33	33	1 5 -2	141	131	3 1 4	78	60	4 3 6	21	22	22
0 0 7	41	45	1 5 -1	51	53	3 1 5	92	74	4 4 -4	44	44	44
0 1 1	549	533	1 5 0	60	83	3 2 -7	23	43	4 4 -3	143	94	207
0 1 2	178	171	1 5 1	46	49	3 2 -6	64	57	4 4 -2	212	207	207
0 1 3	159	47	1 5 2	113	108	3 2 -5	53	41	4 4 -1	140	132	132
0 1 4	78	71	1 5 3	65	64	3 2 -4	90	83	4 4 0	194	95	95
0 1 6	61	57	1 5 4	128	127	3 2 -3	147	146	4 4 1	161	166	166
0 1 7	34	34	2 0 -7	32	18	3 2 -2	28	33	4 4 2	38	44	44
0 2 1	46	81	2 0 -6	231	233	3 2 -1	112	104	4 4 3	29	36	36
0 2 2	119	114	2 0 -5	419	397	3 2 0	271	264	4 4 4	46	51	51
0 2 3	134	143	2 0 0	242	235	3 2 1	136	141	4 4 5	46	17	17
0 2 6	29	30	2 0 1	1	41	3 2 2	223	219	4 5 -6	15	21	21
0 3 1	30	41	2 0 2	291	284	3 2 3	131	94	4 5 -5	41	45	45
0 3 2	334	349	2 0 3	123	133	3 2 4	51	37	4 5 -4	3	48	48
0 3 3	211	195	2 0 6	6	35	3 2 5	31	37	4 5 -3	55	128	128
0 3 4	45	42	2 0 7	50	53	3 2 6	81	82	4 5 -2	125	117	117
0 3 4	89	86	2 1 -7	44	44	3 2 7	24	24	4 5 -1	56	56	56
0 3 5	49	37	2 1 -6	44	44	3 3 -7	25	33	4 5 0	1	35	42
0 3 7	37	39	2 1 -5	44	42	3 3 -6	62	63	4 5 1	2	40	30
0 4 1	94	92	2 1 -4	111	110	3 3 -5	140	135	4 5 2	40	30	30
0 4 2	88	80	2 1 -3	64	56	3 3 -4	46	42	4 5 3	45	46	46
0 4 3	56	56	2 1 -2	452	406	3 3 -3	136	136	4 5 4	58	58	58
0 4 4	34	35	2 1 -1	412	414	3 3 -2	133	147	5 0 -6	7	52	76
0 4 5	44	49	2 1 0	406	409	3 3 -1	103	113	5 0 -5	46	46	46
0 4 6	15	21	2 1 1	320	337	3 3 0	88	84	5 0 -4	82	54	54
0 5 1	114	118	2 1 2	156	150	3 3 1	136	132	5 0 -3	82	95	95
0 5 2	125	120	2 1 3	187	197	3 3 2	100	99	5 0 -2	45	85	85
0 5 3	174	182	2 1 4	85	82	3 3 3	138	134	5 0 -1	152	104	104
0 5 4	66	66	2 1 5	85	73	3 3 4	111	99	5 0 0	118	115	115
0 5 6	29	38	2 2 -6	41	40	3 3 5	68	62	5 0 1	157	145	145
1 0 -6	34	49	2 2 -5	71	76	3 4 -6	41	51	5 0 2	1	63	66
1 0 -5	97	104	2 2 -4	27	31	3 4 -5	69	64	5 0 3	162	167	167
1 0 -4	197	189	2 2 -3	257	255	3 4 -4	197	183	5 0 4	3	37	37
1 0 -3	27	19	2 2 -2	52	49	3 4 -3	68	63	5 0 5	7	35	36
1 0 -2	149	146	2 2 -1	14	8	3 4 -2	160	83	5 0 6	43	43	43
1 0 -1	386	352	2 2 0	287	32*	3 4 -1	131	132	5 1 -5	155	147	147
1 0 0	184	188	2 2 1	335	345	3 4 0	79	85	5 1 -4	76	68	68
1 0 2	714	680	2 2 2	17	77	3 4 1	77	83	5 1 -3	76	87	87
1 0 3	132	133	2 2 3	44	39	3 4 2	48	44	5 1 -2	165	165	165
1 0 4	166	169	2 2 4	173	179	3 4 3	66	66	5 1 -1	200	214	214
1 0 5	182	193	2 2 5	85	87	3 4 4	64	64	5 1 0	1	165	173
1 0 6	36	42	2 2 6	58	51	3 4 5	66	62	5 1 1	2	202	225
1 1 -7	35	22	2 2 7	37	38	3 5 -5	45	50	5 1 2	60	58	58
1 1 -6	107	105	2 2 3	5	36	3 5 -4	58	58	5 1 3	80	119	109
1 1 -5	91	91	2 2 4	73	76	3 5 -3	43	41	5 1 4	5	70	69
1 1 -4	137	134	2 2 3	106	106	3 5 -2	103	94	5 1 5	7	31	30
1 1 -3	256	253	2 2 3	49	81	3 5 -1	50	43	5 2 -7	93	84	84
1 1 -2	195	187	2 2 3	190	213	3 5 0	33	34	5 2 -6	93	98	98
1 1 -1	108	102	2 2 3	88	92	3 5 1	74	75	5 2 -5	105	134	94
1 1 0	187	249	2 2 3	129	129	3 5 2	80	74	5 2 -4	134	94	94
1 1 1	226	227	2 2 3	97	103	3 5 3	68	63	5 2 -3	107	108	108
1 1 2	73	77	2 2 3	135	137	3 5 4	63	57	5 2 -2	65	60	60
1 1 3	285	290	2 2 3	46	46	3 5 5	17	22	5 2 -1	111	107	107
1 1 4	141	141	2 2 3	6	30	4 0 -6	48	48	5 2 0	1	123	124
1 1 6	43	34	2 2 4	4	36	4 0 -5	37	38	5 2 1	134	136	136
1 1 7	38	38	2 2 4	4	58	4 0 -4	124	124	5 2 2	62	62	62
1 2 -5	175	186	2 2 4	4	58	4 0 -3	157	155	5 2 3	179	174	174
1 2 -4	135	136	2 2 4	4	92	4 0 -2	348	351	5 2 4	133	137	137
1 2 -3	113	115	2 2 4	4	76	4 0 -1	207	196	5 2 5	6	42	42
1 2 -2	64	62	2 2 4	4	143	4 0 0	227	245	5 3 -7	14	21	21
1 2 -1	340	338	2 2 4	1	12	4 0 1	259	245	5 3 -6	28	22	22
1 2 0	250	294	2 2 4	4	35	4 0 2	139	147	5 3 -5	106	103	103
1 2 1	78	75	2 2 4	4	35	4 0 3	47	27	5 3 -4	55	52	52
1 2 2	227	234	2 2 4	4	13	4 0 4	38	36	5 3 -3	49	52	52
1 2 3	81	81	2 2 4	6	13	4 1 -7	36	36	5 3 -2	104	100	100
1 2 4	151	143	2 2 5	6	27	4 1 -6	116	119	5 3 -1	76	75	75
1 2 5	88	85	2 2 5	5	38	4 1 -5	244	240	5 3 0	0	130	134
1 2 6	28	27	2 2 5	4	59	4 1 -4	89	77	5 3 1	1	56	54
1 3 -7	28	36	2 2 5	3	47	4 1 -3	375	378	5 3 2	163	152	152
1 3 -6	71	73	2 2 5	2	62	4 1 -2	390	402	5 3 3	4	105	95
1 3 -5	76	77	2 2 5	1	82	4 1 -1	159	154	5 3 4	5	45	44
1 3 -4	77	74	2 2 5	0	117	4 1 0	101	109	5 4 -6	52	70	70
1 3 -3	109	108	2 2 5	1	38	4 1 1	3	89	5 4 -5	32	35	35
1 3 -2	102	103	2 2 5	2	98	4 1 2	43	84	5 4 -4	40	84	84
1 3 -1	84	86	2 2 5	3	53	4 1 3	56	53	5 4 -3	53	50	50
1 3 0	87	87	2 2 5	4	44	4 1 4	27	31	5 4 -2	110	87	87
1 3 1	259	259	3 0 -6	49	99	4 1 5	43	43	5 4 -1	27	26	26
1 3 2	66	69	3 0 -5	63	65	4 2 -3	16	15	5 4 0	1	111	114
1 3 3	268	265	3 0 -4	194	194	4 2 -2	153	153	5 4 1	2	90	83
1 3 4	107	108	3 0 -3	143	151	4 2 -1	268	277	5 4 2	3	127	126
1 3 6	67	67	3 0 -2	304	293	4 2 0	145	149	5 4 3	4	19	14
1 3 7	16	22	3 0 0	41	394	4 2 1	287	298	5 4 4	5	14	14
1 4 -6	27	18	3 0 1	501	475	4 2 2	34	34	5 5 -6	25	27	27
1 4 -5	60	56	3 0 1	46	44	4 2 3	56	54	5 5 -5	60	65	65
1 4 -4	44	42	3 0 2	189	170	4 2 4	77	68	5 5 -4	77	76	76
1 4 -3	113	94	3 0 3	118	121	4 2 5	56	56	5 5 -3	92	96	96
1 4 -2	47	85	3 0 4	52	53	4 2 6	56	56	5 5 -2	65	68	68
1 4 -1	33	29	3 0 6	34	39	4 2 7	57	47	5 5 -1	34	34	34
1 4 0	93	104	3 1 -7	36	100	4 3 -5	63	65	5 5 0	115	117	117
1 4 1	57	49	3 1 -6	10	100	4 3 -4	79	70	5 5 1	26	54	54
1 4 2	137	133	3 1 -5	157	156	4 3 -3	50	50	5 5 2	7	83	83
1 4 3	110	117	3 1 -3	164	167	4 3 -2	164	173	5 5 3	37	36	36
1 4 5	87	87	3 1 -2	206	212	4 3 0	242	311	5 5 4	4	34	30
1 4 6	14	24	3 1 -1	157	149	4 3 1	25	84	5 5 5	7	48	30
1 4 6	33	44	3 1 0	368	343	4 3 2	134	128	5 5 6	7	49	11

Table 3. Continued.

6	0	-5	43	85	7	4	2	24	24	10	1	-3	66	63	4	1	-6	24	17	*		
6	0	-4	179	154	7	4	3	51	54	10	1	-2	116	114	4	1	-5	24	5	*		
6	0	-2	210	187	7	4	4	19	26	10	1	-1	63	62	4	1	-6	24	19	*		
6	0	-1	111	119	7	5	-5	31	33	10	1	1	64	62	4	2	-4	16	22	*		
6	0	0	2	143	147	7	5	-4	33	34	10	1	3	41	44	4	3	-4	11	*		
6	0	0	3	29	26	7	5	-2	25	23	10	2	-5	24	18	4	3	-4	12	*		
6	0	0	4	48	45	7	5	-1	63	63	10	2	-3	193	106	4	4	-5	10	*		
6	0	0	5	51	57	7	5	1	54	54	10	2	-1	125	131	4	4	-4	11	*		
6	0	0	6	81	81	7	5	1	34	34	10	2	1	69	64	4	4	-8	8	*		
6	0	0	7	64	64	7	5	2	35	31	10	2	2	60	47	4	4	-2	16	*		
6	0	0	8	44	44	7	5	0	32	39	10	2	3	27	24	4	4	-1	21	*		
6	0	0	9	238	234	7	5	0	5	75	10	3	-5	43	36	4	4	-1	16	*		
6	0	0	10	49	45	7	5	0	-3	24	10	3	-2	25	25	4	4	-1	13	*		
6	0	0	11	167	164	7	5	0	-2	42	10	3	-2	101	105	4	4	-2	10	*		
6	0	0	12	195	206	7	5	0	-1	125	127	10	3	-1	25	25	4	4	-3	7	*	
6	0	0	13	106	107	7	5	0	5	24	26	10	3	0	59	62	4	4	-8	7	*	
6	0	0	14	77	66	7	5	0	-7	29	16	10	4	-3	19	24	4	4	-3	17	*	
6	0	0	15	33	33	7	5	0	-6	40	31	10	4	-2	19	24	4	4	-3	14	*	
6	0	0	16	47	47	7	5	0	-4	47	44	10	4	1	18	21	4	4	-4	15	*	
6	0	0	17	43	45	7	5	0	-3	62	61	10	5	-3	14	16	4	4	-4	11	*	
6	0	0	18	66	67	7	5	0	-2	193	203	10	5	-2	34	31	4	4	-5	6	*	
6	0	0	19	215	218	7	5	0	-1	103	105	10	5	-1	33	28	4	4	-5	6	*	
6	0	0	20	98	104	7	5	0	1	0	55	10	5	0	23	24	4	4	-6	7	*	
6	0	0	21	40	42	7	5	0	1	106	110	10	5	1	33	32	4	4	-6	13	*	
6	0	0	22	96	96	7	5	0	2	45	45	11	0	-6	25	14	4	4	-5	18	*	
6	0	0	23	46	46	7	5	0	2	72	70	11	0	-5	26	18	4	4	-6	9	*	
6	0	0	24	64	64	7	5	0	2	110	106	11	0	-3	61	63	4	4	-5	12	*	
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6	0	0	26	13	13	7	5	0	2	-1	140	140	11	0	0	73	60	4	4	-6	10	*
6	0	0	27	43	37	7	5	0	2	1	174	143	11	0	1	108	116	4	4	-6	10	*
6	0	0	28	67	64	7	5	0	2	1	29	30	11	0	2	50	42	4	4	-4	17	*
6	0	0	29	140	140	7	5	0	2	5	33	34	11	1	-6	41	27	4	4	-2	15	*
6	0	0	30	81	85	7	5	0	2	-7	23	13	11	1	-4	78	67	4	4	-3	13	*
6	0	0	31	18	25	7	5	0	2	-6	34	25	11	1	-3	60	42	4	4	-3	10	*
6	0	0	32	25	31	7	5	0	2	-4	75	79	11	1	0	33	40	4	4	-3	11	*
6	0	0	33	41	42	7	5	0	2	-3	108	105	11	2	-4	42	30	4	4	-3	13	*
6	0	0	34	86	80	7	5	0	2	-2	134	105	11	2	-1	75	72	4	4	-3	18	*
6	0	0	35	66	71	7	5	0	2	-1	72	74	11	2	0	61	53	4	4	-3	19	*
6	0	0	36	56	53	7	5	0	2	0	21	24	11	2	1	77	74	4	4	-4	17	*
6	0	0	37	143	141	7	5	0	2	0	19	22	11	2	3	31	33	4	4	-4	17	*
6	0	0	38	63	64	7	5	0	2	0	48	56	11	3	-5	16	21	4	4	-4	16	*
6	0	0	39	154	153	7	5	0	2	-5	29	29	11	3	-1	22	26	4	4	-4	19	*
6	0	0	40	131	130	7	5	0	2	-4	55	47	11	3	0	62	60	4	4	-4	21	*
6	0	0	41	89	74	7	5	0	2	-3	70	63	11	4	-1	18	14	4	4	-4	25	*
6	0	0	42	39	41	7	5	0	2	-2	28	39	11	4	2	24	24	4	4	-4	25	*
6	0	0	43	51	51	7	5	0	2	-1	49	53	11	5	-2	29	25	4	4	-4	24	*
6	0	0	44	43	43	7	5	0	2	0	25	30	11	5	-1	22	18	4	4	-4	26	*
6	0	0	45	52	52	7	5	0	2	0	16	22	11	5	0	25	20	4	4	-4	24	*
6	0	0	46	34	34	7	5	0	2	0	35	35	11	5	0	26	24	4	4	-4	14	*
6	0	0	47	47	46	7	5	0	2	0	28	24	11	5	0	41	40	4	4	-4	17	*
6	0	0	48	94	94	7	5	0	2	0	44	50	11	5	0	41	41	4	4	-4	16	*
6	0	0	49	43	45	7	5	0	2	0	17	18	11	5	0	46	30	4	4	-4	13	*
6	0	0	50	117	113	7	5	0	2	0	54	40	11	5	0	45	43	4	4	-4	14	*
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6	0	0	54	31	34	7	5	0	2	0	56	56	11	5	0	11	10	4	4	-4	10	*
6	0	0	55	33	38	7	5	0	2	0	56	56	11	5	0	25	32	4	4	-4	25	*
6	0	0	56	86	86	7	5	0	2	0	93	70	11	5	0	23	23	4	4	-4	21	*
6	0	0	57	113	113	7	5	0	2	0	46	46	11	5	0	34	33	4	4	-4	16	*
6	0	0	58	83	83	7	5	0	2	0	35	35	11	5	0	34	34	4	4	-4	13	*
6	0	0	59	41	41	7	5	0	2	0	46	56	11	5	0	29	28	4	4	-4	18	*
6	0	0	60	29	24	7	5	0	2	0	3	3	14	2	-3	38	34	4	4	-4	15	*
6	0	0	61	83	83	7	5	0	2	0	46	56	11	5	0	31	31	4	4	-4	11	*
6	0	0	62	41	41	7	5	0	2	0	87	60	11	5	0	20	20	4	4	-4	13	*
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6	0	0	65	46	52	7	5	0	2	0	62	54	11	5	0	11	11	4	4	-4	11	*
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6	0	0	68	52	53	7	5	0	2	0	3	3	13	0	-7	16	21	*	*	*	*	
6	0	0	69	227	244	7	5	0	2	0	-6	48	45	1	0	-7	16	21	*	*	*	*
6	0	0	70	112	112	7	5	0	2	0	-5	42	34	1	0	-7	15	18	*	*	*	*
6	0	0	71	82	81	7	5	0	2	0	-4	65	61	1	0	-6	16	10	*	*	*	*
6	0	0	72	109	113	7	5	0	2	0	-3	73	68	1	0	-6	16	10	*	*	*	*
6	0	0	73	43	43	7	5	0	2	0	-2	43	48	1	0	-5	12	14	*	*	*	*
6	0	0	74	75	75	7	5	0	2	0	-1	29	36	1	0	-4	11	15	*	*	*	*
6	0	0	75	61	46	7	5	0	2	0	0	51	55	1	0	-3	11	15	*	*	*	*
6	0	0	76	15	15	7	5	0	2	0	1	81	85	1	0	-2	9	9	*	*	*	*
6	0	0	77	46	47	7	5	0	2	0	2	127	129	1	0	-1	6	6	*	*	*	*
6	0	0	78	46	47	7	5	0	2	0	3	37	33	1	0	0	4	4	*	*	*	*
6	0	0	79	92	85	7	5	0	2	0	3	47	34	1	0	0	4	4	*	*	*	*
6	0	0	80	30	30	7	5	0	2	0	3	24	25	1	0	0	4	4	*	*	*	*
6	0	0	81	30	30	7	5	0	2	0	3	57	57	1	0	0	4					

Table 4. Comparison of the observed and calculated intensities used in the establishment of the absolute configuration.

h	k	l	$\frac{I_o(hkl)}{I_o(\bar{h}\bar{k}\bar{l})}$	$\frac{F_c^2(hkl)}{F_c^2(\bar{h}\bar{k}\bar{l})}$
1	1	$\bar{3}$	0.87	0.85
1	1	$\bar{2}$	0.86	0.85
1	3	0	1.39	1.48
2	2	$\bar{2}$	1.43	1.61
5	3	1	0.63	0.65
4	1	$\bar{3}$	1.33	1.34
4	2	$\bar{5}$	0.67	0.68
4	2	4	0.79	0.77
4	3	3	0.73	0.75
3	3	0	1.29	1.29
3	1	$\bar{3}$	1.17	1.18

Table 5. Distances (Å) and angles (°) with standard deviations. (For atomic numbering, see Fig. 2.)

Bond distances		Bond angles (°)	
C1 - C(1)	1.744(9)	C1 - C(1) - O(1)	121.0(7)
O(1) - C(1)	1.181(11)	C1 - C(1) - C(2)	111.3(6)
O(2) - C(2)	1.458(11)	O(1) - C(1) - C(2)	127.8(8)
O(2) - C(4)	1.359(10)	C(1) - C(2) - C(3)	114.6(6)
O(3) - C(4)	1.194(11)	C(1) - C(2) - O(2)	107.5(7)
O(4) - C(5)	1.459(8)	C(3) - C(2) - O(2)	105.5(6)
O(4) - C(8)	1.352(10)	C(6) - C(7) - C(8)	104.8(7)
O(5) - C(8)	1.195(11)	C(7) - C(8) - O(4)	111.5(8)
C(1) - C(2)	1.521(10)	C(8) - O(4) - C(5)	110.9(6)
C(2) - C(3)	1.516(11)	O(4) - C(8) - O(5)	120.2(8)
C(4) - C(5)	1.522(12)	C(7) - C(8) - O(5)	128.2(9)
C(3) - C(5)	1.483(13)	C(5) - C(6) - C(7)	103.7(7)
C(5) - C(6)	1.540(11)	C(6) - C(5) - O(4)	106.4(6)
C(6) - C(7)	1.537(15)	C(4) - C(5) - O(4)	103.5(6)
C(7) - C(8)	1.486(13)	C(3) - C(5) - C(6)	119.4(7)
		C(3) - C(5) - O(4)	108.8(6)
		C(4) - C(5) - C(6)	115.0(7)
		C(3) - C(5) - C(4)	102.6(6)
		O(3) - C(4) - C(5)	129.3(8)
		O(2) - C(4) - O(3)	120.9(8)
		O(2) - C(4) - C(5)	109.8(8)
		C(2) - O(2) - C(4)	108.9(7)
		C(2) - C(3) - C(5)	103.1(7)
Symmetry code:			
a	x	y	z
b	x	$y+1$	z
c	x	$y+1$	$z+1$
d	$-x$	$y+1/2$	$-z$
e	$1-x$	$y+1/2$	$1-z$

DESCRIPTION AND DISCUSSION OF THE STRUCTURE

The present study shows that the dilactone derived from the naturally occurring (+)-phorbic acid consists of two five-membered lactone rings, forming a spiro compound. Thus, as concluded from the determination of the absolute configuration, the correct configurational formula of the dilactophorbic acid chloride should be:

(5*R*:8*R*) 8-chloroformyl-2,6-dioxo-1,7-dioxo[4,4]spirononane (*cf.* Fig. 1).

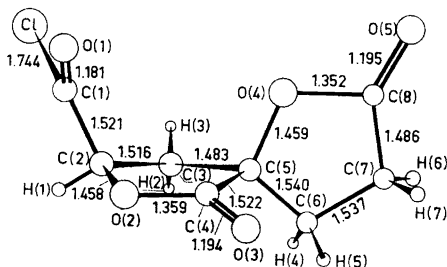


Fig. 2. The molecular structure of dilactophorbic acid chloride. Bond lengths in Å.

The molecular structure and the packing of the molecules in the unit cell are shown in Figs. 2 and 3, respectively. The interatomic distances and angles are given in Table 5. These values are calculated from the atomic parameters

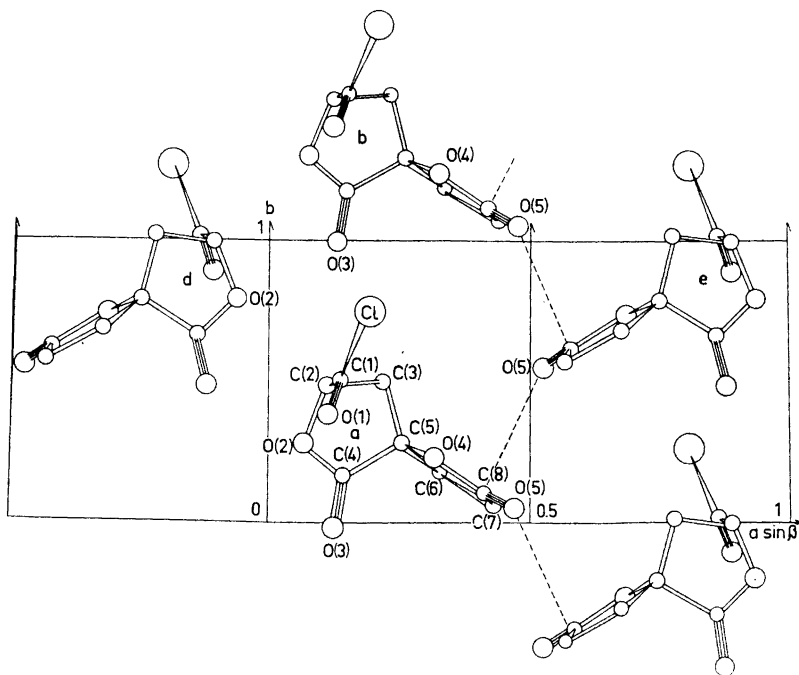


Fig. 3. The structure viewed along the *c* axis.

Table 6. The principal axes of the thermal vibration ellipsoids, given by the components of a unit vector in fractional coordinates e_x , e_y , e_z , and the corresponding r.m.s. amplitudes and B-values.

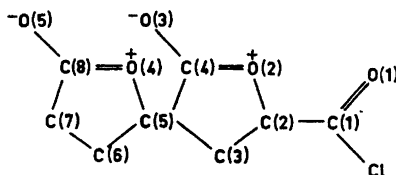
Atom	$(u^2)^{1/2}(\text{\AA})$	$B(\text{\AA}^2)$	e_x	e_y	e_z
Cl	0.323	8.26	0.078	0.068	0.059
	0.246	4.77	-0.035	0.093	0.097
	0.182	2.61	0.018	-0.112	0.117
O(1)	0.280	6.19	0.073	-0.025	0.113
	0.250	4.95	0.035	0.132	-0.050
	0.198	3.11	-0.031	0.088	0.106
O(2)	0.275	5.99	-0.021	0.028	0.143
	0.195	2.99	0.049	0.133	0.019
	0.175	2.41	0.069	-0.086	0.077
O(3)	0.316	7.86	0.058	0.007	-0.092
	0.263	5.44	0.060	0.054	0.128
	0.121	1.15	0.024	-0.151	0.042
O(4)	0.222	3.91	-0.065	0.065	0.056
	0.195	3.01	0.015	-0.104	0.124
	0.180	2.57	0.056	0.104	0.090
O(5)	0.322	8.21	-0.051	0.125	0.014
	0.291	6.69	0.008	0.054	-0.145
	0.174	2.38	0.070	0.084	0.073
C(1)	0.219	3.77	0.014	0.066	0.149
	0.186	2.73	0.004	-0.146	0.066
	0.178	2.50	0.086	-0.004	0.010
C(2)	0.222	3.90	-0.060	0.026	0.085
	0.183	2.64	0.016	-0.145	0.070
	0.156	1.92	0.060	0.065	0.121
C(3)	0.237	4.45	0.086	0.022	0.023
	0.186	2.72	0.012	-0.075	0.144
	0.150	1.78	-0.007	0.140	0.073
C(4)	0.214	3.63	0.074	-0.085	0.028
	0.190	2.86	0.044	0.130	-0.030
	0.178	2.50	0.016	0.040	0.158
C(5)	0.198	3.10	-0.059	0.094	0.044
	0.183	2.65	0.030	-0.043	0.156
	0.167	2.21	0.056	0.123	0.020
C(6)	0.262	5.43	0.083	-0.044	0.015
	0.240	4.56	0.025	0.104	0.123
	0.182	2.62	0.010	0.114	-0.106
C(7)	0.292	6.75	-0.030	0.148	0.013
	0.288	6.56	0.050	0.012	0.151
	0.164	2.13	0.064	0.060	-0.061
C(8)	0.261	5.36	-0.026	0.079	0.119
	0.238	4.46	0.033	-0.117	0.105
	0.176	2.45	0.076	0.076	0.038

obtained when neglecting the anomalous scattering. Root mean squares amplitudes, and the corresponding B -values for the atomic anisotropic thermal vibration along the principal axes, together with the components of these axes along the crystal axes, are given in Table 6.

The two lactone groups are very similar and in good agreement with other lactone structure determinations,^{10,11} Both C—C—O—C groups are planar



within the standard deviations, and they also show the characteristic short and long C—O bonds. As pointed out by Mathieson¹² this indicates a significant contribution from the valence-bond resonance form shown below:



In both rings one of the carbon atoms is out of the plane, giving rise to the characteristic envelope configuration. The internal angles of the rings are similar to those found in furanose rings¹³ and in other five membered lactones. This determination gives a mean value of 104.3° for the sp^3 hybridized carbon atoms, 110.7° for the “ sp^2 hybridized”, and 109.9° for the ring oxygen atom. In both rings the characteristic large external angles around the carbonyl group were observed: 129.3° for the grouping C(5)—C(4)—O(3), and 128.2° for C(7)—C(8)—O(5). The C—C bond lengths range from 1.540 Å to 1.483 Å ($\sigma = 0.013$ Å). In each ring there is one short C—C bond, but the respective locations of these in the rings do not correspond.

The distances and angles in the acid chloride group agree with those of related compounds (acetyl chloride¹⁴ and cyclopropane carboxylic acid chloride¹⁵). The C=O bond (1.181 Å) is shorter than usual in carbonyl groups, which may be explained by the strong electronegativity of the chlorine atom. When a halogen atom is directly attached to the carbonyl group, the lone pair oxygen electrons are no longer localized on the oxygen atom, and the carbonyl bond has a partly triple bond character.^{14,16,17}

It should be noted that almost the only significant changes in bond angles and distances, which occurred when including the imaginary part of the atomic form factors for chlorine in the refinement, were found in the acid chloride group. By neglecting the imaginary part we got a C—Cl distance of 1.744 Å, while the structure which was confirmed to be the correct one was refined to give a C—Cl distance of 1.766 Å. The value 1.766 Å *versus* 1.744 Å is an example of the error which may arise when refining in an acentric space group neglecting the anomalous scattering.

The atom O(2) was found to lie in the plan of the chloroformyl group (*cf.* Table 7). This planarity implicates short non-bonded intramolecular distances O(1)⋯O(2) of 2.72 Å, and Cl⋯C(3) of 3.18 Å. It seems to be a general feature

Table 7. Deviation of atoms from the least square planes (Å).

Plane 1		Plane 2		Plane 3	
C(2)	-0.023	C(5)	0.008	C1	0.000
C(5)	0.012	C(7)	-0.009	O(1)	0.001
C(4)	-0.003	C(8)	0.019	C(1)	-0.003
O(2)	0.022	O(4)	-0.012	C(2)	0.001
O(3)	-0.011	O(5)	-0.001		
C(3) ^a	-0.495	C(6) ^a	0.254	O(2) ^a	-0.035

^a Atoms not included in the least square plane.

in carboxylic acids that the α -substituent is in an eclipsed position to the carbonyl group.^{19,20}

In crystals of certain carboxylic acid halides the formation of charge transfer bonds between halogen and oxygen appeared to be possible,²¹ but in this case no particular short Cl \cdots O contacts were observed, and the angles C-Cl \cdots O are far from 180°. Thus there is no indication of bonds connecting Cl and O.

The orientation of the carbonyl group C(8)=O(5) and the distance C(8) \cdots O(5') of 3.05 Å are particularly interesting because it corresponds to a dipolar alignment about the screw axis (Fig. 4). Similar oppositely oriented carbonyl groups have been observed, *e.g.* in D-galactono- γ -lactone,¹⁰ where the C \cdots O distances are 3.096 and 3.185 Å. (For a review of similar interactions, see Jeffrey *et al.*¹⁰) As pointed out by Bolton,²² interaction between C δ^+ =O δ^- dipoles seems to be a very important packing factor in crystals with carbonyl groups, where there is no possibility to form hydrogen bonds. In alloxan²³ it appears that interactions of a similar type are predominant, even over possible hydrogen bonds, in determining the structure.

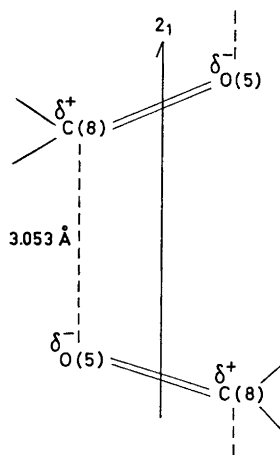


Fig. 4. The orientation of the carbonyl group along the screw axis.

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