

CRYSTAL STRUCTURE OF 7-BROMO-5,8-DIHYDROXY-4,4-DIMETHYL-4*H*-NAPHTHALEN-1-ONE

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ABSTRACT

An X-ray diffraction study of the 7-bromo-5,8-dihydroxy-4,4-dimethyl-4*H*-naphthalen-1-one (**1**), obtained by bromination of 5,8-dihydroxy-4,4-dimethyl-4*H*-naphthalen-1-one with molecular bromine, gave unambiguous proof of its regiochemistry. Crystal is monoclinic, space group $P2_1/c$, and the unit cell parameters are $a = 8.300(1)$, $b = 14.101(1)$, $c = 19.239(2)$ Å, $\beta = 93.91(1)^\circ$, $Z = 8$. The final R factor at room temperature was 0.036 for 1717 observed reflections. The molecular structure is essentially planar, with the exception of the geminal methyl groups, and no unusual bond lengths or angles were found.

Key Words: X-ray crystallography, structure assignment, regioisomers, dienophiles, hydroquinone bromination.

RESUMEN

Un estudio de difracción de rayos X del 7-bromo-5,8-dihidroxi-4,4-dimetil-4*H*-naftalen-1-ona (**1**), obtenido por bromación de 5,8-dihidroxi-4,4-dimetil-4*H*-naftalen-1-ona con bromo molecular, demostró inequívocamente su regioquímica. El cristal es monoclinico, grupo espacial $P2_1/c$, y los parámetros de la celda unitaria son $a = 8.300(1)$, $b = 14.101(1)$, $c = 19.239(2)$ Å, $\beta = 93.91(1)^\circ$, $Z = 8$. El factor R final a temperatura ambiente fue de 0.036 para 1717 reflexiones observadas. La estructura molecular es esencialmente plana, con la excepción de los grupos metilo geminales, y no se encontraron longitudes ni ángulos de enlace fuera de lo común.

Palabras Claves: Cristalografía de rayos X, asignación estructural, regioisómeros, dienófilos, bromación de hidroquinona.

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INTRODUCTION

The 6- and 7-bromoderivatives of 4,4-dimethyl-4*H*-naphthalen-1,5,8-trione were envisioned as highly reactive dienophiles in hetero-Diels-Alder reactions expected to give aza-anthrahydroquinones of interest for their possible antiparasitic activity. When 5,8-dihydroxy-4,4-dimethyl-4*H*-naphthalen-1-one, a reasonable precursor of these compounds, was brominated with molecular bromine in acetic acid, it afforded a major monobromination product (**1**) whose structure could not be determined unambiguously, although it was clearly different from the regioisomer (**2**) obtained when the same precursor was brominated with *N*-bromosuccinimide (followed in this case by reduction of the intermediate quinone product). It was only clear at that time that one of them must bear a bromine atom at C-6 and the other at C-7¹⁾.

EXPERIMENTAL

An orange-colored plate of **1**, obtained as stated above by bromination of 5,8-dihydroxy-4,4-dimethyl-4*H*-naphthalen-1-one with molecular bromine in acetic acid, was crystallized from chloroform and subjected to X-ray diffraction analysis to solve its structure. Diffraction intensities were collected at 298 K on a Siemens *R3mV* four-circle diffractometer using graphite-monochromated Mo $K\alpha$ radiation²⁾. Cell parameters were obtained from 30 strong reflections in the range $15^\circ \leq 2\theta \leq 30^\circ$. Intensity data for 4673 total reflections ($0 < h < 10$, $0 < k < 17$, $-23 < l < 23$, $2\theta_{\max} = 52^\circ$) were collected in the $\theta/2\theta$ scan mode, of which 1717 were observed taking $F > 4.0 \sigma(F)$. Two standard reflections which were monitored every 98 reflections showed no decay during the exposure. Intensity data were corrected for Lorentz and polarization effects. Semi-empirical corrections for absorption were applied. The structure was solved by direct-phase determination using the SHELXTL/PC program package³⁾. The positional and anisotropic thermal parameters for all non-H atoms were refined by full matrix least squares cycles⁴⁾. The H-atom positions were calculated geometrically and refined using a riding model with isotropic temperature factors. A weighing scheme $\omega^1 = \sigma^2|F| + 0.0003 F^2$ to minimize $\sum \omega(|F_o| - |F_c|)^2$ was used in the refinement which converged to a final $R = 0.0360$ and $\omega R = 0.0336$. Atomic scattering factors were taken from the *International Tables for X-Ray Crystallography*, Vol. C (1991).

RESULTS AND DISCUSSION

The atomic coordinates and equivalent isotropic displacement coefficients are collected in Table I, and the bond lengths and angles are listed in Tables II and III respectively. Table IV shows the anisotropic displacement coefficients, and Table V lists the H-atom coordinates and isotropic displacement coefficients. The crystal structure of **1** consists of discrete molecules arranged in approximately perpendicular planes with in-plane hydrogen bonds between the carbonyl oxygen and the C(9) hydroxyl group (2.752 Å between oxygens, 1.913 Å O...H distance), and out-plane interactions between the C(2) hydroxyl oxygen and the hydrogen atom at C(6) (2.519 Å O...H distance). Figure 1 shows the atomic arrangement in the molecules together with the crystallographic atom-labelling scheme. Figure 2 shows the arrangement of four of the molecules in the unit cell. The structure of **1** was shown unambiguously to be 7-bromo-5,8-dihydroxy-4,4-dimethyl-4*H*-naphthalen-1-one.

TABLE I. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement coefficients ($\text{\AA}^2 \times 10^3$).

	x	y	z	U(eq)
Br(1)	2664 (1)	8976 (1)	3242 (1)	57 (1)
O (1A)	-1999 (6)	10950 (3)	4455 (2)	41 (2)
O (2A)	-337 (6)	9825 (3)	3767 (2)	47 (2)
O(3A)	5133 (5)	11648 (3)	4866 (3)	53 (2)
C (1A)	2497 (9)	9997 (4)	3866 (3)	35 (3)
C (2A)	964 (9)	10293 (4)	4043 (3)	28 (2)
C(3A)	861 (7)	11055 (5)	4503 (3)	26 (2)
C(4A)	-757 (9)	11364 (5)	4692 (3)	34 (3)
C(5A)	-854(9)	12154 (5)	5159 (4)	46 (3)
C(6A)	443 (9)	12612 (5)	5423 (3)	50 (3)
C(7A)	2143 (8)	12363 (5)	5290 (3)	35 (3)
C(8A)	2254 (8)	11536 (4)	4798 (3)	28 (2)
C(9A)	3753 (8)	11202 (5)	4596 (3)	37 (3)
C(10A)	3862 (9)	10453 (5)	4140 (3)	39 (3)
C(11A)	2912 (9)	13274 (4)	5006 (4)	58 (3)
C(12A)	3009 (9)	12119 (5)	6015 (3)	55 (3)
Br(2)	2904 (1)	9089 (1)	917 (1)	61 (1)
O(1B)	-1745 (5)	7116 (3)	2133 (2)	46 (2)
O(2B)	-90 (5)	8228 (3)	1441 (2)	47 (2)
O(3B)	5372 (5)	6361 (3)	2496 (2)	51 (2)
C(1B)	2734 (9)	8035 (4)	1518 (3)	37 (3)
C(2B)	1214 (9)	7752 (5)	1709 (3)	31 (3)
C(3B)	1110 (8)	6980 (4)	2169 (3)	27 (2)
C(4B)	-499 (8)	6692 (4)	2377 (3)	32 (3)
C(5B)	-599 (8)	5925 (5)	2858 (4)	41 (3)
C(6B)	704 (9)	5490 (5)	3127 (4)	42 (3)
C(7B)	2412 (9)	5707 (4)	2973 (4)	36 (3)
C(8B)	2512(8)	6506 (4)	2449 (3)	30 (2)
C(9B)	4019 (8)	6813 (5)	2238 (4)	34 (3)
C(10B)	4095 (9)	7562 (5)	1771 (3)	38 (3)
C(11B)	3122 (8)	4770 (4)	2705 (4)	52 (3)
C(12B)	3328 (9)	5976 (5)	3682 (3)	51 (3)

*Equivalent isotropic U defined as one third of the trace of the orthogonalized U_i tensor.

TABLE II. Bond lengths (Å)

Br(1)-C(1A)	1.885 (6)	O(1A)-C(4A)	1.244 (9)
O(2A)-C(2A)	1.343 (8)	O(3A)-C(9A)	1.377 (8)
C(1A)-C(2A)	1.403 (10)	C(1A)-C(10A)	1.377 (10)
C(2A)-C(3A)	1.398 (9)	C(3A)-C(4A)	1.481 (10)
C(3A)-C(8A)	1.425 (9)	C(4A)-C(5A)	1.437 (10)
C(5A)-C(6A)	1.327 (10)	C(6A)-C(7A)	1.493 (10)
C(7A)-C(8A)	1.509 (9)	C(7A)-C(11A)	1.551 (10)
C(7A)-C(12A)	1.563 (9)	C(8A)-C(9A)	1.409 (10)
C(9A)-C(10A)	1.380 (10)	Br(2)-C(1B)	1.894 (6)
O(1B)-C(4B)	1.258 (8)	O(2B)-C(2B)	1.346 (8)
O(3B)-C(9B)	1.355 (8)	C(1B)-C(2B)	1.397 (10)
C(1B)-C(10B)	1.373 (10)	C(2B)-C(3B)	1.408 (9)
C(3B)-C(4B)	1.477 (10)	C(3B)-C(8B)	1.416 (9)
C(4B)-C(5B)	1.429 (10)	C(5B)-C(6B)	1.318 (10)
C(6B)-C(7B)	1.500 (11)	C(7B)-C(8B)	1.518 (9)
C(7B)-C(11B)	1.549 (9)	C(7B)-C(12B)	1.562 (10)
C(8B)-C(9B)	1.409 (10)	C(9B)-C(10B)	1.391 (10)

TABLE III. Bond angles (°).

Br(1)-C(1A)-C(2A)	119.3 (5)	Br(1)-C(1A)-C(10A)	120.4 (5)
C(2A)-C(1A)-C(10A)	120.3 (6)	O(2A)-C(2A)-C(1A)	118.4 (6)
O(2A)-C(2A)-C(3A)	123.0 (6)	C(1A)-C(2A)-C(3A)	118.6 (6)
C(2A)-C(3A)-C(4A)	118.5 (6)	C(2A)-C(3A)-C(8A)	122.4 (6)
C(4A)-C(3A)-C(8A)	119.1 (6)	O(1A)-C(4A)-C(5A)	121.0 (6)
O(1A)-C(4A)-C(5A)	120.8 (7)	C(3A)-C(4A)-C(5A)	118.2 (6)
C(4A)-C(5A)-C(6A)	122.6 (7)	C(5A)-C(6A)-C(7A)	124.9 (7)
C(6A)-C(7A)-C(8A)	112.8 (6)	C(6A)-C(7A)-C(11A)	106.4 (6)
C(8A)-C(7A)-C(11A)	112.0 (6)	C(6A)-C(7A)-C(12A)	106.4 (6)
C(8A)-C(7A)-C(12A)	110.2 (5)	C(11A)-C(7A)-C(12A)	108.8 (5)
C(3A)-C(8A)-C(7A)	122.4 (6)	C(3A)-C(8A)-C(9A)	116.0 (6)
C(7A)-C(8A)-C(9A)	121.6 (6)	O(3A)-C(9A)-C(8A)	118.1 (6)
O(3A)-C(9A)-C(10A)	120.0 (6)	C(8A)-C(9A)-C(10A)	121.9 (6)
C(1A)-C(10A)-C(9A)	120.9 (7)	Br(2)-C(1B)-C(2B)	119.5 (5)
Br(2)-C(1B)-C(10B)	120.3 (5)	C(2B)-C(1B)-C(10B)	120.3 (6)
O(2B)-C(2B)-C(1B)	118.2 (6)	O(2B)-C(2B)-C(3B)	123.0 (6)
C(1B)-C(2B)-C(3B)	118.8 (6)	C(2B)-C(3B)-C(4B)	118.6 (6)
C(2B)-C(3B)-C(8B)	121.3 (6)	C(4B)-C(3B)-C(8B)	120.1 (6)
O(1B)-C(4B)-C(3B)	120.2 (6)	O(1B)-C(4B)-C(5B)	121.3 (6)
C(3B)-C(4B)-C(5B)	118.5 (6)	C(4B)-C(5B)-C(6B)	121.6 (7)
C(5B)-C(6B)-C(7B)	126.0 (6)	C(6B)-C(7B)-C(8B)	112.2 (6)
C(6B)-C(7B)-C(11B)	106.1 (5)	C(8B)-C(7B)-C(11B)	112.0 (6)
C(6B)-C(7B)-C(12B)	106.7 (6)	C(8B)-C(7B)-C(12B)	110.7 (5)
C(11B)-C(7B)-C(12B)	108.9 (5)	C(3B)-C(8B)-C(7B)	121.5 (6)
C(3B)-C(8B)-C(9B)	117.9 (6)	C(7B)-C(8B)-C(9B)	120.6 (6)
O(3B)-C(9B)-C(8B)	118.7 (6)	O(3B)-C(9B)-C(10B)	121.3 (6)
C(8B)-C(9B)-C(10B)	120.0 (6)	C(1B)-C(10B)-C(9B)	121.7 (7)

TABLE IV. Anisotropic displacement coefficients ($\text{Å}^2 \times 10^3$)

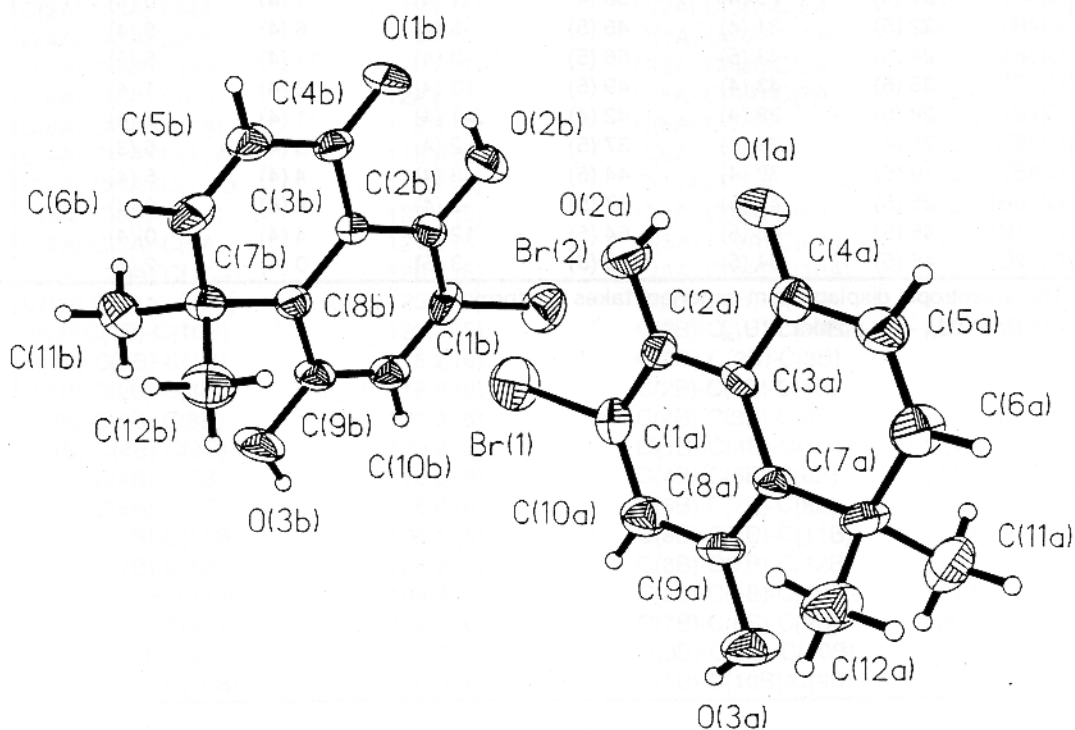
	U_{11}	U_{22}	U_{33}	U_{12}	U_{13}	U_{23}
Br(1)	61 (1)	52 (1)	58 (1)	9 (1)	5 (1)	-21 (1)
O (1A)	26 (3)	51 (3)	46 (3)	2 (3)	-1 (3)	1 (3)
O (2A)	34 (3)	46 (3)	59 (4)	-4 (3)	-2 (3)	-16 (3)
O(3A)	21 (3)	70 (4)	67 (4)	-2 (3)	1 (3)	-25 (3)
C(1A)	41 (5)	26 (4)	38 (5)	4 (4)	5 (4)	-2 (3)
C(2A)	32 (5)	23 (4)	28 (4)	-2 (4)	-2 (4)	1 (3)
C(3A)	20 (4)	28 (4)	30 (4)	-6 (4)	0 (3)	7 (4)
C(4A)	34 (5)	34 (4)	34 (4)	-1 (4)	3 (4)	6 (3)
C(5A)	31 (5)	49 (5)	58 (5)	3 (4)	5 (4)	-11 (4)
C(6A)	38 (5)	57 (5)	57 (5)	4 (4)	13 (4)	-32 (4)
C(7A)	23 (4)	43 (5)	40 (5)	-6 (4)	-1 (4)	-13 (4)
C (8A)	15 (4)	34 (4)	35 (4)	2 (3)	2 (4)	-5 (3)
C(9A)	22 (5)	45 (5)	42 (5)	-3 (4)	-7 (4)	-4 (4)
C(10A)	27 (5)	46 (5)	45 (5)	1 (4)	4 (4)	-2 (4)
C(11A)	61 (6)	41 (5)	71 (6)	-10 (4)	2 (5)	-13 (4)
C(12A)	48 (5)	67 (5)	50 (5)	-3 (5)	-2 (5)	-24 (5)
Br(2)	62 (1)	50 (1)	71 (1)	-9 (1)	13 (1)	14 (1)
O(1B)	17 (3)	53 (3)	67 (4)	4 (3)	2 (3)	-1 (3)
O(2B)	31 (3)	47 (3)	62 (4)	6 (3)	2 (3)	9 (3)
O(3B)	18 (3)	68 (4)	66 (3)	4 (3)	3 (3)	13 (3)
C(1B)	41 (5)	26 (4)	46 (5)	-6 (4)	15 (4)	-1 (4)
C(2B)	28 (5)	28 (4)	35 (4)	6 (4)	-4 (4)	-11 (3)
C(3B)	21 (4)	25 (4)	36 (4)	-1 (4)	1 (4)	0 (4)
C(4B)	22 (5)	31 (4)	45 (5)	-5 (4)	6 (4)	-8 (4)
C(5B)	24 (5)	43 (5)	56 (5)	-3 (4)	11 (4)	-5 (5)
C(6B)	35 (5)	43 (4)	49 (5)	-13 (4)	12 (4)	1 (4)
C(7B)	28 (5)	38 (4)	42 (4)	-1 (4)	-1 (4)	-2 (4)
C(8B)	25 (4)	29 (4)	37 (5)	2 (4)	3 (4)	-6 (3)
C(9B)	19 (5)	39 (4)	44 (5)	3 (4)	4 (4)	-5 (4)
C(10B)	25 (5)	41 (5)	47 (5)	-3 (4)	8 (4)	-8 (4)
C(11B)	45 (5)	46 (5)	64 (5)	12 (4)	4 (4)	0 (4)
C(12B)	46 (5)	64 (5)	43 (5)	-3 (5)	0 (4)	-2 (5)

The anisotropic displacement exponent takes the form:

$$-2\pi^2(h^2a^*{}^2U_{11} + \dots + 2hka^*b^*U_{12}).$$

TABLE V. H-Atom coordinates ($\times 10^4$) and isotropic displacement coefficients ($\text{\AA}^2 \times 10^3$).

	x	y	z	U
H(2A)	-1179	10071	3920	80
H(3A)	5951	11380	4708	80
H(5A)	-1912	12369	5257	80
H(6A)	266	13110	5750	80
H(10A)	4897	10251	4002	80
H(11A)	2367	13420	4563	80
H(11B)	2788	13793	5321	80
H(11C)	4039	13173	4948	80
H(12A)	2531	11554	6190	80
H(12B)	4136	12010	5964	80
H(12C)	2886	12630	6337	80
H(2B)	-933	7991	1599	80
H(3B)	6188	6650	2355	80
H(5B)	-1641	5729	2992	80
H(6B)	540	4987	3451	80
H(10B)	5128	7752	1622	80
H(11D)	2548	4601	2273	80
H(11E)	4242	4866	2630	80
H(11F)	3020	4269	3038	80
H(12D)	2873	6550	3851	80
H(12E)	3227	5479	4017	80
H(12F)	4449	6076	3610	80



STRUCTURE 1

STRUCTURE DETERMINATION SUMMARY

Crystal Data

Empirical Formula	$C_{12}H_{11}BrO_3$
Color; Habit	pale orange plate
Crystal size (mm)	0.24 x 0.24 x 0.08
Crystal system	Monoclinic
Space group	$P2_1/c$
Unit cell dimensions	$a = 8.300(1) \text{ \AA}$
	$b = 14.107(1) \text{ \AA}$
	$c = 19.239(2) \text{ \AA}$
	$\beta = 93.91(1)^\circ$
Volume	$2246.4(5) \text{ \AA}^3$
Z	8
Formula weight	283.1
Density(calc.)	1.674 Mg/m^3
Absorption coefficient	3.648 mm^{-1}
F(000)	1136

Data Collection

Diffractometer used	Siemens R3mV
Radiation	$\text{MoK}\alpha$ ($\lambda = 0.71073 \text{ \AA}$)
Temperature (K)	298
Monochromator	Highly oriented graphite crystal
2θ Range	3.0 to 52.0°
Scan type	$\theta/2\theta$
Scan speed	Variable; 3.00 to $29.30^\circ/\text{min}$ in θ
Background measurement	Stationary crystal and stationary counter at beginning and end of scan, each for 1.0% of total scan time.
Standard reflections	2 measured every 98 reflections
Index ranges	0 h 10, 0 k 17, -23 l 23
Reflections collected	4673
Independent reflections	4360 ($R_{\text{int}} = 1.94\%$)
Observed reflections	1717 ($F > 4.0\sigma(F)$)
Absorption correction	Semi-empirical
Min/Max transmission	0.5719/1.0000

Solution and Refinement

System used	Siemens SHELXTL PLUS (PC version)
Solution	Direct methods
Refinement method	on F; Full-Matrix Least-Squares
Quantity minimized	$\sum w(F_o - F_c)^2$
Hydrogen atoms	Riding model, fixed isotropic U = 0.08
Weighing scheme	$w^{-1} = \sigma^2(F) + 0.0003F^2$
Number of parameters refined	289
Final R indices (obs. data)	$R = 3.60\%$, $wR = 3.36\%$
Goodness-of-Fit	0.96
Largest and mean Δ/σ	0.000, 0.000
Data-to-parameter ratio	5.9:1
Largest difference peak	$0.32 \text{ e}\text{\AA}^{-3}$
Largest difference hole	$-0.32 \text{ e}\text{\AA}^{-3}$

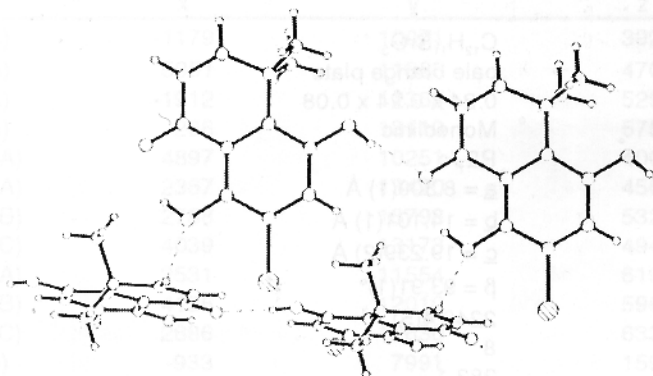


FIG. 2.

The molecule is essentially flat, with only a slight deviation (-0.0045 Å) of the bromine atom from the aromatic ring plane, aside from the expected out-of-plane positions of the methyl carbon atoms (-1.2525 and 1.2794 Å). Planarity of the non-aromatic ring is enforced by a hydrogen bond between the C-8 hydroxyl group and the C-1 carbonyl oxygen.

ACKNOWLEDGEMENTS

This work was supported by FONDECYT (Chile) Grant Nº 01950301 and by the (Chilean) Presidential Chair in Science 1996.

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