disorder was such that the molecular dimensions cannot be very reliable (Wood, Welberry & Rae, 1985).

The molecular packing is shown in Fig. 2. The shortest non-bonded contact between C atoms is C(4)···C(4) ($-x$, $1-y$, $1-z$) at 3.408 (6) Å.

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Structure of Racemic (±)-6,8-Dimethyl-6,12-methano-6H,12H,13H-[1]benzopyran[4,3-d][1,3]benzodioxocin-13-one

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**Abstract.** $C_{20}H_{16}O_4$, $M_r = 320.35$, monoclinic, $P2_1/n$, $a = 10.482$ (3), $b = 8.084$ (1), $c = 18.081$ (4) Å, $\beta = 92.59$ (2)°, $V = 1530.5$ (5) Å^3, $Z = 4$, $D_x = 1.390$ g cm^{-3}, $\lambda(\text{Mo } K\bar{\alpha}) = 0.70930$ Å, $\mu = 0.902$ cm^{-1}, $F(000) = 672$, $T = 225$ K, final $R = 0.051$ on 1776 observations. The title molecule, a derivative of warfarin formed by spontaneous dehydration of 2'-hydroxy-3'-methylwarfarin, is a cyclic ketal in which the side-chain phenyl is disposed pseudo-axially and is linked through a 2'-O atom to the ketal C atom in a fixed *cis* 1,3-diaxial configuration. Two dihydropyran rings are formed. One is fused with the benzopyran ring and adopts an *e,f*-diplanar shape; the other is a chroman and adopts a similar conformation.

Introduction. As part of a continuing study of the structures of dihydropyran derivatives containing various 2-oxygen substituents, the compound described here is one of a series of crystalline warfarin derivatives. Warfarins generally crystallize as hemiketals: 4-substituted 2-hydroxy-2-methyl-3,4-dihydro-2H,5H-pyrano[3,2-c][1]benzopyran-5-one; the parent in the series has a 4-phenyl substituent. A number of 2-hydroxy and 2-methoxy-4-aryl and 4-alkyl analogs have been made and studied crystallographically, revealing an operative anomeric effect in the uniform axial disposition of the 2-oxygen substituents, local influences on C—O bond lengths, and conformational preferences associated with the exoanomeric effect (Valente, Eggleston & Schomaker, 1986; Ruggiero, Thaggard, Valente & Eggleston, 1990). This contribution describes the structure of a 2-aryloxy warfarin ketal.

Experimental. Michael-type addition of 4-hydroxycoumarin to α,β-unsaturated ketones leads to 3-substituted 4-hydroxycoumarins of the warfarin group (Ikawa, Stahmann & Link, 1944). Synthesis of 2'-hydroxy-3'-methylwarfarin (I), through 4-(2'-hydroxy-3'-methylphenyl)but-3-en-2-one with 4-hydroxycoumarin, leads instead to a higher melting compound not soluble in dilute alkali. This substance is the racemic cyclic 2-aryloxy ketal (II) formed through spontaneous intramolecular dehydration (Porter & Trager, 1977). The homochiral dehydrated product is obtained by resolution (West, Preis, Schroeder & Link, 1961) of the addition product of 4-(2'-methoxy-3'-methylphenyl)-3-buten-2-one with 4-hydroxycoumarin followed by treat-

ment with LiI in refluxing actone; its structure has been reported (Ruggiero *et al.*, 1990).

(I)

(II)
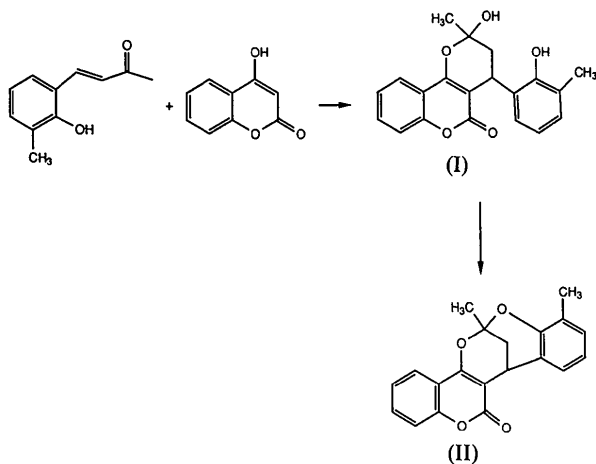
Crystals of (II) from acetone occur as colorless rhombs, m.p. 509.6–510.6 K. A specimen with dimensions of 0.60 × 0.40 × 0.35 mm was chosen for intensity data collection on a CAD-4 diffractometer and cell constants were determined from 25 intensities ($30 < 2\theta < 35°$). Intensities were measured with variable-speed θ–2θ scans to $2\theta = 55°$ (*h*: 0→12, *k*: 0→9, *l*: −21→21). The data (3870 collected, 3677 unique) were corrected for coincidence and polarization, and symmetry equivalents (193) were averaged (agreement 2.8% on intensity). Three intensities were periodically monitored over the 48 h data collection; average variation ±1.8%; no corrections for intensity variation or absorption were applied. Systematically absent reflections (0*k*0, $k = 2n + 1$; *h0l*, $h + k = 2n + 1$) established the space group. The structure was solved using *MULTAN*80 (Main, Fiske, Hull, Lessinger, Germain, Declercq & Woolfson, 1980). Non-H-atom positions were refined with U_{iso} values by full-matrix least squares on F minimizing $\sum w(|F_o| - |F_c|)^2$, then with U_{ij} values. Some H-atom positions were refined and others were placed at calculated positions; each were assigned B values fixed at approximately 1.3 times the value of B_{eq} for the attached C atom. Scattering factors were taken from *International Tables for X-ray Crystallography* (1974, Vol. IV) except for H (Stewart, Davidson & Simpson, 1965). In the final cycle, $(\Delta/\sigma)_{max} = 0.05$. A correction for secondary extinction (Zachariasen, 1963) refined to 8.28 (1) × 10^{-7}; the maximum extinction correction applied was −25% for [102]. Final agreement factors for (II): $R = 0.0513$, $wR = 0.0650$, GOF = 1.365 for the 1776 observations with $I \geq 3\sigma(I)$. Least-squares weights were taken as $4F_o/\sigma^2(I)$ where $\sigma^2(I) = \sigma(I_c) + 0.06(I_c)^2$ and the differences in structure factors were minimized for the 251 variables; scale factor =

1.985 (1); maximum final electron density excursions were less than ±0.32 e Å^{-3}. Other programs used were from the locally modified Enraf–Nonius (1987) *Structure Determination Package*. Final atom positions and equivalent isotropic vibrational amplitudes for non-H atoms are given in Table 1.* Bond distances and angles are given in Table 2. A refinement using all data (2941 observations) not flagged as weak in a prescan gave $R = 0.095$, $wR = 0.077$.

Discussion. A plot of the molecular structure of (II) is given in Fig. 1. A dihydropyran ring [composed of C(3), C(4), C(11), C(12) and O(3)] is fused with the coumarin benzopyranone. It bears substituents in the 2 and 4 positions [C(13) and C(11), respectively] which are constrained in a diaxial conformation. This dihydropyran ring has an e,f-diplanar conformation and ring displacement asymmetry parameter $\Delta C_2 = 0.090$ (1) (Nardelli, 1983). Displacements from idealized C_2 symmetry lie along a path of pseudo-rotation (Valente & Eggleston, 1991) for the heterocycle embedded in warfarin compounds. Warfarin derivatives lacking special constraining features show small displacements which essentially cluster about $\Delta C_2 = 0$. Other related and constrained diaxial 2-aryloxy warfarins show distorted dihydropyrans with $\Delta C_2 = 0.138$ (1) (Ruggiero, Valente & Eggleston, 1989) and 0.130 (1) (Ruggiero *et al.*, 1990). Such deviations from idealized C_2 symmetry suggests a diplanar rather than half-chair description for each dihydropyran conformation.

C—O bond lengths in the ketal of (II) can be expected to show minor differences even though the enolate and phenolate groups attached have a relatively small difference in electron demand. Each may be imagined to compete in the ketal ground-state electronic structure. The dihydropyranyl endocyclic C(13)—O(3) bond length of 1.449 (4) Å is slightly longer than the exocyclic C(13)—O(4), 1.427 (4) Å, and conforms to the C—O bond length relationship found for dihydropyranyl ketals (Ruggiero *et al.*, 1990). That the ketal C—O lengths are sensitive to the groups attached may be seen by comparing (II) with the related warfarin hemiketals and methyl ketals (Valente *et al.*, 1986). In these, enolate competes somewhat more successfully with hydroxide or methoxide, and the dihydropyranyl endocyclic and exocyclic ketal C—O lengths are 1.47 and 1.40 Å, respectively.

The ring formed by dehydration of (I) [composed of C(15), C(14), O(4), C(13), C(12) and C(11)] is a

Table 1. *Fractional coordinates for the non-H atoms in* (II), *and their equivalent isotropic vibrational amplitudes* (Å²)

$$B_{eq} = (4/3)\Sigma_i\Sigma_j\beta_{ij}\mathbf{a}_i.\mathbf{a}_j.$$

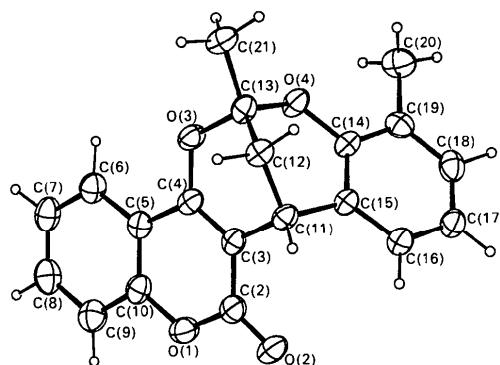|	x	y	z	B_{eq}
O(1)	6089 (2)	3962 (3)	1048 (1)	3.06 (5)
O(2)	5570 (2)	4666 (3)	2175 (1)	3.30 (5)
O(3)	2526 (2)	1969 (3)	0585 (1)	2.65 (4)
O(4)	985 (2)	3618 (3)	1091 (1)	2.66 (4)
C(2)	5228 (3)	3975 (4)	1608 (2)	2.54 (6)
C(3)	4011 (3)	3184 (4)	1465 (2)	2.14 (6)
C(4)	3694 (3)	2586 (4)	780 (2)	2.19 (6)
C(5)	4603 (3)	2534 (4)	207 (2)	2.35 (6)
C(6)	4369 (3)	1807 (4)	−489 (2)	2.91 (7)
C(7)	5311 (3)	1768 (4)	−993 (2)	3.25 (7)
C(8)	6491 (4)	2470 (5)	−816 (2)	3.41 (7)
C(9)	6756 (3)	3214 (4)	−134 (2)	3.37 (7)
C(10)	5795 (3)	3225 (4)	373 (2)	2.61 (6)
C(11)	3090 (3)	3062 (4)	2082 (2)	2.23 (6)
C(12)	2181 (3)	1644 (4)	1891 (2)	2.28 (6)
C(13)	1560 (3)	2019 (4)	1134 (2)	2.42 (6)
C(14)	1268 (3)	4796 (4)	1632 (2)	2.21 (6)
C(15)	2305 (3)	4631 (4)	2135 (2)	2.19 (6)
C(16)	2541 (3)	5871 (4)	2652 (2)	2.72 (6)
C(17)	1766 (3)	7255 (4)	2661 (2)	3.01 (7)
C(18)	739 (3)	7399 (4)	2154 (2)	2.91 (7)
C(19)	460 (3)	6159 (4)	1631 (2)	2.46 (6)
C(20)	−675 (3)	6305 (4)	1085 (2)	3.41 (7)
C(21)	545 (3)	825 (4)	862 (2)	3.07 (7)

Fig. 1. An ellipsoid plot (Johnson, 1976) of the structure of (II) showing 50% probability ellipsoids for the non-H atoms (arbitrary radii for H atoms).

smaller cell volume (1530 vs 1581 Å³), greater density (1.390 vs 1.345 g cm⁻³), and higher melting point (510 vs 477 K). About half the diminished volume and higher density of (II) compared to the homo-chiral structure can be ascribed to the fact that the present structure has been determined at 225 K while the homochiral phase was studied at 295 K. Other-wise, the physical differences are in accord with the usual bias (Brock, Schweizer & Dunitz, 1991) that affects Wallach's rule (Wallach, 1895).

Table 2. *Bond lengths* (Å) *and angles* (°) *between non-H atoms in* (II)

O(1)—C(2)	1.387 (4)	C(7)—C(8)	1.386 (5)
O(1)—C(10)	1.380 (4)	C(8)—C(9)	1.389 (5)
O(2)—C(2)	1.208 (4)	C(9)—C(10)	1.392 (5)
O(3)—C(4)	1.354 (4)	C(11)—C(12)	1.523 (4)
O(3)—C(13)	1.449 (4)	C(11)—C(15)	1.514 (4)
O(4)—C(13)	1.427 (4)	C(12)—C(13)	1.520 (4)
O(4)—C(14)	1.388 (3)	C(13)—C(21)	1.503 (5)
C(2)—C(3)	1.439 (4)	C(14)—C(15)	1.391 (4)
C(3)—C(4)	1.357 (3)	C(14)—C(19)	1.390 (4)
C(3)—C(11)	1.511 (4)	C(15)—C(16)	1.385 (4)
C(4)—C(5)	1.439 (4)	C(16)—C(17)	1.384 (5)
C(5)—C(6)	1.402 (4)	C(17)—C(18)	1.387 (5)
C(5)—C(10)	1.388 (4)	C(18)—C(19)	1.400 (4)
C(6)—C(7)	1.373 (5)	C(19)—C(20)	1.516 (4)

C(2)—O(1)—C(10)	121.5 (2)	C(3)—C(11)—C(15)	111.2 (2)
C(4)—O(3)—C(13)	117.6 (2)	C(12)—C(11)—C(15)	108.0 (2)
C(13)—O(4)—C(14)	120.5 (2)	C(11)—C(12)—C(13)	107.0 (2)
O(1)—C(2)—O(2)	116.5 (3)	O(3)—C(13)—O(4)	107.2 (2)
O(1)—C(2)—C(3)	117.8 (3)	O(3)—C(13)—C(12)	109.1 (2)
O(2)—C(2)—C(3)	125.8 (3)	O(3)—C(13)—C(21)	105.4 (2)
C(2)—C(3)—C(4)	120.0 (3)	O(4)—C(13)—C(12)	113.1 (2)
C(2)—C(3)—C(11)	119.1 (2)	O(4)—C(13)—C(21)	105.8 (2)
C(4)—C(3)—C(11)	120.9 (3)	C(12)—C(13)—C(21)	115.7 (3)
O(3)—C(4)—C(3)	123.4 (3)	O(4)—C(14)—C(15)	122.1 (3)
O(3)—C(4)—C(5)	115.0 (2)	O(4)—C(14)—C(19)	115.6 (3)
C(3)—C(4)—C(5)	121.6 (3)	C(15)—C(14)—C(19)	122.3 (3)
C(4)—C(5)—C(6)	124.3 (3)	C(11)—C(15)—C(14)	116.7 (3)
C(4)—C(5)—C(10)	116.9 (3)	C(11)—C(15)—C(16)	124.4 (2)
C(6)—C(5)—C(10)	118.8 (3)	C(14)—C(15)—C(16)	118.8 (3)
C(5)—C(6)—C(7)	120.3 (3)	C(15)—C(16)—C(17)	120.4 (3)
C(6)—C(7)—C(8)	119.9 (3)	C(16)—C(17)—C(18)	119.9 (3)
C(7)—C(8)—C(9)	121.5 (3)	C(17)—C(18)—C(19)	121.2 (3)
C(8)—C(9)—C(10)	117.8 (3)	C(14)—C(19)—C(18)	117.3 (3)
O(1)—C(10)—C(5)	121.8 (3)	C(14)—C(19)—C(20)	121.5 (3)
O(1)—C(10)—C(9)	116.4 (3)	C(18)—C(19)—C(20)	121.2 (3)
C(5)—C(10)—C(9)	121.8 (3)		
C(3)—C(11)—C(12)	107.1 (2)		

chroman dihydropyran, which also has a half-chair conformation strongly distorted toward the e,f-diplanar form. The displacement asymmetry parameter $\Delta C_2 = 0.205$ (1) (Nardelli, 1983).

Compared with the homochiral structure (Ruggiero *et al.*, 1990), this racemic structure has a

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