Polymorphism of 4′-Dimethylamino-3-hydroxyflavone

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Structures of two polymorphic crystals **1a** and **1b** of 4′-dimethylamino-3-hydroxyflavone (**1**) have been determined. Each crystal has intermolecular hydrogen-bonded dimers with the adjacent molecule. The dimeric structure in crystal **1a** is nearly planar, whereas that in crystal **1b** is slightly bent with respect to the chromane moieties. In both crystals there is a stacking structure of the dimers linked by π–π interactions.

3-Hydroxyflavones are of great interest due to their dual fluorescent properties, which arise from excited-state intramolecular charge transfer (CT) and proton transfer (PT).[1,2] In 4′-dimethylamino-3-hydroxyflavone (=2-(4-dimethylaminophenyl)-3-hydroxy-4*H*-chromen-4-one) both CT and PT emissions are observed in polar solvents. The relative intensities of the CT and PT emissions strongly depend on the chemical and physical environment, such as the solvent polarity, electric potential, and aggregation. It has been reported that the introduction of an electron-donating substituent to the 4′-position of 3-hydroxyflavones increases the fluorescence intensity of the molecule.[3] Therefore, 4′-substituted 3-hydroxyflavones are promising candidates for fluorescent molecular probes or sensors.[4] Thus, **1** is a good model system for the investigation of the CT and PT reactions, and its photophysics has been widely studied in solution.[5] **1** is a flexible molecule, since the torsional motions of the dimethylamino group and the C–C single bond connecting the two aromatic rings are possible. The introduction of the dimethylamino group into the 4′-position of 3-hydroxyflavone should have a large influence on the crystal packing and the intermolecular interactions of 3-hydroxyflavones. The subtle difference in hydrogen bonding, dipole–dipole, and π–π dispersion interactions may bring about marked changes in the fluorescence behavior of flavones. Very recently, we have observed emission spectra of **1**. Its spectral pattern is very different from those observed in solution. Hence, the analysis of the crystal structure is crucial to investigate the photophysical properties of **1** and its analogs and also their application as solid-state fluorescence sensors. The crystal structure of 7-diethylamino-4′-dimethylamino-3-hydroxyflavone has been reported,[6] however only PT emission has been observed. In this paper, we report on the crystal structure of two polymorphic crystals **1a** and **1b**, and compare their structures with that of the parent molecule, 3-hydroxyflavone.

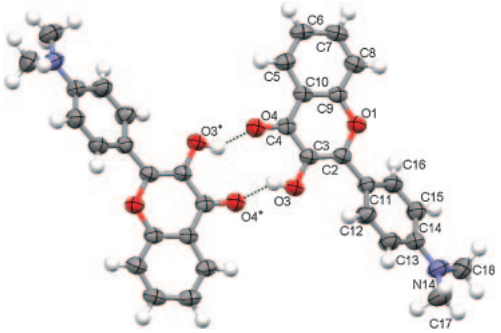

Figure 1. The hydrogen-bonded dimeric structure with atomic numbering in polymorphic crystal **1a**. The intermolecular hydrogen bonds are indicated by broken lines.

Table 1. Hydrogen-Bond Geometry (Å, °) for Polymorphic Crystal **1a**[a)]

D–H···A	D–H	H···A	D···A	D–H···A
O3–H3···O4^{i}	0.89(3)	2.04(3)	2.804(3)	143(3)

a) Symmetry code: (i) $-x+1, -y+1, -z+2$.

Table 2. Selected Torsion Angles (°) for Polymorphic Crystal **1a**[a)]

O3–H3–O4–H3^{i}	175(3)	C4–C3–O3–H3	8(2)

a) Symmetry code: (i) $-x+1, -y+1, -z+2$.

Crystals **1a** and **1b** were obtained concurrently from ethanol solution. Crystal **1a** has monoclinic symmetry with space group $P2_1/c$, and the molecules form a dimeric structure with two identical intermolecular O–H···O hydrogen bonds. Figure 1 shows the hydrogen-bonded dimeric structure and numbering of **1**, where atoms marked with an asterisk are related by an inversion center. The bond lengths and the bond angles associated with the hydrogen bonds are listed in Tables 1 and 2. The bond length O3–H3 (0.89(3) Å) is shorter than the corresponding bond length in 3-hydroxyflavone (0.96(3) Å).[7] The crystal structure of 3-hydroxyflavone has orthorhombic symmetry with space group $P2_12_12_1$, in which intermolecular hydrogen bonds link neighboring molecules to form dimers along a twofold screw axis. The intermolecular bond distances H3···O4^{i} (2.04(3) Å) and O3···O4^{i} (2.804(3) Å) are longer than those in the dimeric structure of 3-hydroxyflavone (1.88(4) and 2.734(3) Å, respectively). Only a single intermolecular hydrogen bond exists between the paired molecules. The crystal packing is shown in Figure 2. The thick broken lines show π–π dispersion interactions and thin broken lines show short contacts of atoms less than the sum of van der Waals radii. Each hydroxy group forms a hydrogen bond with the carbonyl

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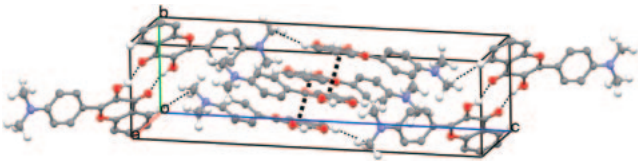

Figure 2. The crystal packing of polymorphic crystal **1a**. The thick broken lines show π–π dispersion interactions and thin broken lines show short contacts of atoms less than the sum of van der Waals radii.

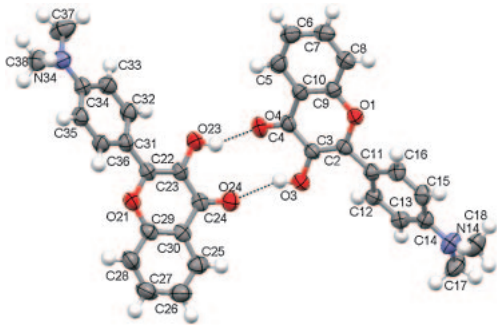

Figure 3. The hydrogen-bonded dimeric structure with atomic numbering in polymorphic crystal **1b**. The intermolecular hydrogen bonds are indicated by broken lines.

Table 3. Hydrogen-Bond Geometry (Å, °) for Polymorphic Crystal **1b**[a)]

D–H···A	D–H	H···A	D···A	D–H···A
O3–H3···O24^{i}	0.86(3)	2.11(3)	2.899(2)	154(2)
O23–H23···O4^{ii}	0.83(3)	1.87(3)	2.629(2)	151(3)

a) Symmetry code: (i) x, $y+1$, z; (ii) x, $y-1$, z.

Table 4. Selected Torsion Angles (°) for Polymorphic Crystal **1b**[a)]

O3–H3–O4–H23^{i}	−173(2)	C4–C3–O3–H3	−15(2)
O23^{i}–H23^{i}–O24^{i}–H3	−173(2)	C24^{i}–C23^{i}–O23^{i}–H23^{i}	−7(2)

a) Symmetry code: (i) x, $y+1$, z.

O atom, as shown in Figure 1. The two intermolecular hydrogen bonds form a centrosymmetric dimeric structure. The chromane moieties that consist of the O1 and C2–C10 and the O1^{i} and C2^{i}–C10^{i} atoms for the two molecules are nearly planar, since the torsion angle of O3–H3–O4–H3^{i} is close to 180°. In crystal **1a** there is a stacking structure of the dimers linked by π–π interactions (spacing 3.32 Å between the adjacent chromane moieties). The torsional motion of the dimethylamino group for the phenyl ring in crystal **1a** is hindered due to the van der Waals interaction between aromatic H5 and methyl C18 atoms.

On the other hand, crystal **1b** has triclinic symmetry with space group $P\bar{1}$. In this polymorphic crystal, the two crystallographically independent molecules form a dimeric structure with two intermolecular hydrogen bonds, as shown in Figure 3. Among the bond lengths and angles associated with the hydrogen bonds shown in Tables 3 and 4, the most prominent feature is that the two O–H bonds (0.86(3) and 0.83(3) Å) are

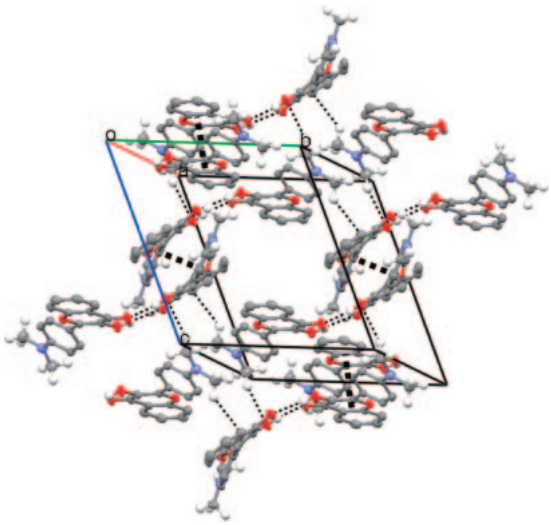

Figure 4. The crystal packing of polymorphic crystal **1b**. The thick broken lines show π–π dispersion interactions and thin broken lines show short contacts of atoms less than the sum of van der Waals radii.

nonequivalent. The intermolecular hydrogen-bond distance of O3–H3···O24^{i} (2.899(2) Å) is longer, and that of O23–H23···O4^{ii} (2.629(2) Å) is shorter than each corresponding distance (2.734(3) Å) in the dimeric structure of 3-hydroxyflavone. Nevertheless, the two intermolecular O–H···O bond angles (154(2) and 151(3)°) are almost the same. As shown in Figure 4, the chromane moieties that consist of the O1 and C2–C10, and the O21 and C22–C30 atoms for the two molecules are unsymmetrically bent, since the torsion angles of C4–C3–O3–H3 and C24^{i}–C23^{i}–O23^{i}–H23^{i} are in-phase and nonequivalent (Table 4). In crystal **1b** there is a similar stacking structure of the dimers to that in crystal **1a** linked by π–π interactions (two spacings 3.49 and 3.42 Å between the adjacent chromane moieties). The torsional motion of the dimethylamino group for the phenyl ring in crystal **1b** is blocked by the hydroxy O23···H17 and the aromatic C25···H18 interactions with both methyl C17 and C18 groups.

According to the previous study,[7] no intermolecular hydrogen-bonded dimer was observed in crystals of 2′-methyl-3-hydroxyflavone. The crystal structure of 2′-methyl-3-hydroxyflavone shows an antiparallel-overlapped molecular arrangement. For 3′-methyl-3-hydroxyflavone, a centrosymmetric hydrogen-bonded dimer was formed. It seems that the steric hindrance between the hydroxy and 2′-methyl groups interferes with the formation of mutual hydrogen bonds between adjacent molecules in the crystal. The dihedral angle between the phenyl ring and the chromane ring is 5.5°, 60.5°, and 23.1° for 3-hydroxyflavone, 2′-methyl-, and 3′-methyl-, respectively.[7] For **1a** and **1b**, this angle is 29.1° and 30.5°, 33.9° which are comparable to that for 3′-methyl-3-hydroxyflavone. It is worth noting that a centrosymmetric dimeric structure composed of hydrogen bonds was observed in the crystal structures of **1**. A similar hydrogen-bonded dimer has also been reported in the crystal structure of 4′-fluoro-[8] and 4′-bromo-3-hydroxyflavone.[9] Very recently, we found that the excitation of crystals **1a** and **1b** at 77 K using UV light provided unique emission spectra, where five peaks appeared in the 440–570 nm region.

Table 5. Crystallographic Data for Polymorphic Crystals **1a** and **1b**

	1a	**1b**
Chemical formula	$C_{17}H_{15}NO_3$	$C_{17}H_{15}NO_3$
Formula weight	281.30	281.30
Crystal system	Monoclinic	Triclinic
Space group	$P2_1/c$	$P\bar{1}$
a/Å	7.6180(3)	9.8050(3)
b/Å	7.1072(2)	12.1655(3)
c/Å	26.2302(9)	13.1840(3)
α/°	90.00	67.2890(10)
β/°	90.7300(10)	75.5060(10)
γ/°	90.00	78.7790(10)
V/Å^3	1420.06(8)	1396.04(6)
Z	4	4
T/K	298(2)	298(2)
μ(Mo Kα)/mm^{-1}	0.091	0.092
Crystal size/mm^3	0.30 × 0.30 × 0.02	0.50 × 0.30 × 0.25
Number of measured/ independent reflections	14046/3253	14699/6369
R_{int}	0.0487	0.0273
$R1(F_o)$ for observed data/ $wR2(F_o^2)$ for all data	0.0669/0.1368	0.0533/0.1255
Goodness of fit	1.096	1.069

These peaks may be associated with local minima on the S_1 excited-state potential surface, which arise from the suppression of the torsional motion of the dimethylamino group and/or the torsional motion of the C–C bond that connects the two aromatic rings of 3-hydroxyflavone due to strong intermolecular interactions in crystal.

Experimental

Preparation of Two Polymorphic Crystals 1a and 1b. **1** was prepared as follows, according to a modified Algar–Flynn–Oyamada method.[10] *p*-Dimethylaminobenzaldehyde was condensed with *o*-hydroxyacetophenone to yield crystals of chalcone, which were filtered and recrystallized from ethyl acetate. The chalcone was oxidized with hydrogen peroxide in ethanol under basic conditions, and cyclized. The product was recrystallized from ethanol; yellow platelets of **1a** formed first, and then orange prisms of **1b** formed more slowly.

X-ray Structural Determinations. Single-crystal X-ray diffraction measurements for **1a** and **1b** were made on a Rigaku SCXmini CCD area detector with graphite monochromated Mo Kα radiation (Table 5). The intensity data were collected by the ω scan mode. The intensities were corrected for Lorentz and polarization effects. Numerical absorption corrections were also applied. The structures were solved by direct methods (SHELXS-97)[11] and expanded using Fourier techniques. The structures were refined with full-matrix least-squares on F^2. The non-hydrogen atoms were refined anisotropically. Hydrogen atoms were refined isotropically. All calculations were performed using the CrystalStructure crystallographic software package[12] except for the refinement, which was performed using SHELXL-97.[13] Crystallographic data have been deposited with Cambridge Crystallographic Data Centre: Deposition numbers CCDC 834953 and 834954. Copies of the data can be obtained free of charge via http://www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, U.K.; Fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk).

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