

C—H...O, C—H... $\pi$  and  $\pi$ — $\pi$  interactions in three benzofuran-2-yl ketone derivativesVeysel T. Yilmaz,<sup>a\*</sup> Canan Kazak,<sup>b</sup> Cumhur Kirilmis,<sup>c</sup> Murat Koca<sup>c</sup> and Frank W. Heinemann<sup>d</sup>

<sup>a</sup>Department of Chemistry, Faculty of Arts and Sciences, Ondokuz Mayıs University, 55139 Kurupelit, Samsun, Turkey, <sup>b</sup>Department of Physics, Faculty of Arts and Sciences, Ondokuz Mayıs University, 55139 Kurupelit, Samsun, Turkey, <sup>c</sup>Department of Chemistry, Faculty of Arts and Sciences, Firat University, 23169 Elazığ, Turkey, and <sup>d</sup>Institut für Anorganische Chemie, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany  
Correspondence e-mail: vtyilmaz@omu.edu.tr

Received 12 May 2005

Accepted 20 May 2005

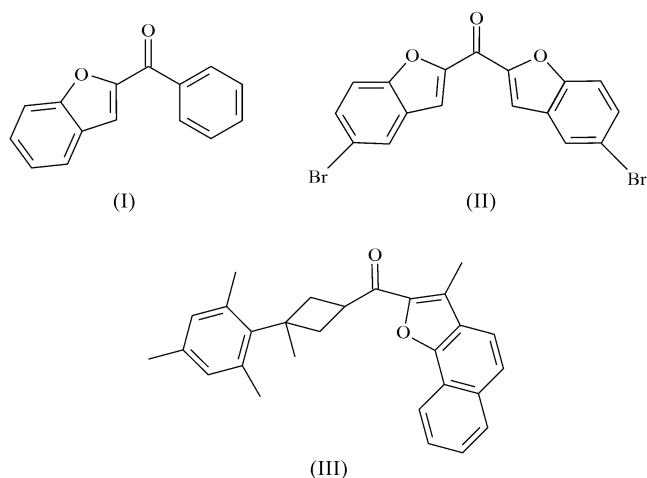
Online 22 June 2005

The molecules of 2-benzoyl-1-benzofuran, C<sub>15</sub>H<sub>10</sub>O<sub>2</sub>, (I), interact through double C—H...O hydrogen bonds, forming dimers that are further linked by C—H...O, C—H... $\pi$  and  $\pi$ — $\pi$  interactions, resulting in a three-dimensional supramolecular network. The dihedral angle between the benzoyl and benzofuran fragments in (I) is 46.15 (3)°. The molecules of bis(5-bromo-1-benzofuran-2-yl) ketone, C<sub>17</sub>H<sub>8</sub>Br<sub>2</sub>O<sub>3</sub>, (II), exhibit C<sub>2</sub> symmetry, with the carbonyl group (C=O) lying along the twofold rotation axis, and are linked by a combination of C—H...O and C—H... $\pi$  interactions and Br...Br contacts to form sheets. The stability of the molecular packing in 3-mesityl-3-methylcyclobutyl 3-methylnaphtho[1,2-*b*]furan-2-yl ketone, C<sub>28</sub>H<sub>28</sub>O<sub>2</sub>, (III), arises from C—H... $\pi$  and  $\pi$ — $\pi$  stacking interactions. The fused naphthofuran moiety in (III) is essentially planar and makes a dihedral angle of 81.61 (3)° with the mean plane of the trimethylbenzene ring.

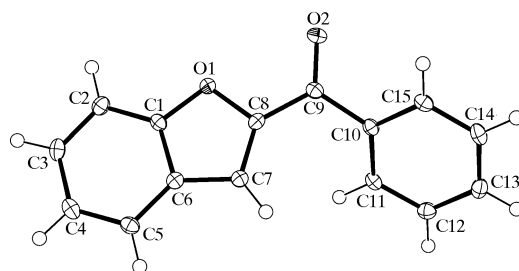
## Comment

Conventional 'strong and directional' hydrogen bonds, such as O—H...O, N—H...O and O—H...N, have long been recognized as being of fundamental importance in determining the supramolecular structure of organic solids (Desiraju & Steiner, 1999). In molecules lacking these hydrogen-bond donors and acceptors, other types of weak and less directional forces, such as C—H...O, C—H... $\pi$  and  $\pi$ — $\pi$  interactions, become important in generating supramolecular architectures (Desiraju & Steiner, 1999; Hunder & Sanders, 1990; Nishio *et al.*, 1998; Umezawa *et al.*, 1998; Calhorda, 2000). Since many natural benzofurans have physiological, pharmacological and toxic properties, there is continuing interest in their synthesis (Kappe *et al.*, 1997). Various benzofuran derivatives have been investigated as estrogen

receptor ligands, because selective estrogen receptor modulators such as raloxifene have emerged as potential therapeutics for the prevention and treatment of osteoporosis (Sato *et al.*, 1999; Smith *et al.*, 2002). Amiodarone is a well known mitochondrial toxin containing a benzofuran ring. Amiodarone is used in the treatment and prophylaxis of both ventricular and supraventricular arrhythmias, particularly in patients with heart insufficiency, because this compound has no significant negative inotropic effect (Spaniol *et al.*, 2001). Although the synthesis of 2-benzoyl-1-benzofuran, (I), is known (Demirayak *et al.*, 2002), a literature search showed that its structure has not yet been characterized. In addition to (I), we report the molecular and supramolecular structures of two new furan derivatives, namely bis(5-bromo-1-benzofuran-2-yl) ketone, (II), and 3-mesityl-3-methylcyclobutyl 3-methylnaphtho[1,2-*b*]furan-2-yl ketone, (III).



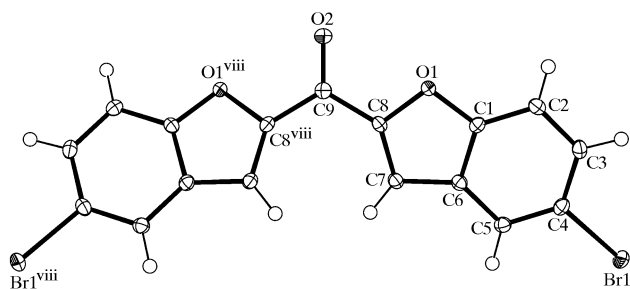
Views of the molecular structures of compounds (I)–(III), including the atom-numbering schemes, are shown in Figs. 1–3. Selected bond distances and angles are listed in Tables 1, 3 and 5. Compounds (I)–(III) consist mainly of a furan-2-yl moiety connected to another fragment by a carbonyl group. The C=O bond distances and the C—C—C bond angles between two fragments are similar in all three compounds. The carbonyl group is known to coordinate to metal ions rather easily, and the presence of the furan O atom adjacent to the carbonyl group in (I)–(III) makes these compounds potential bidentate chelating agents, as reported for lanthanum (Benassi *et al.* 1987). In (I), the fused benzofuran ring is essentially



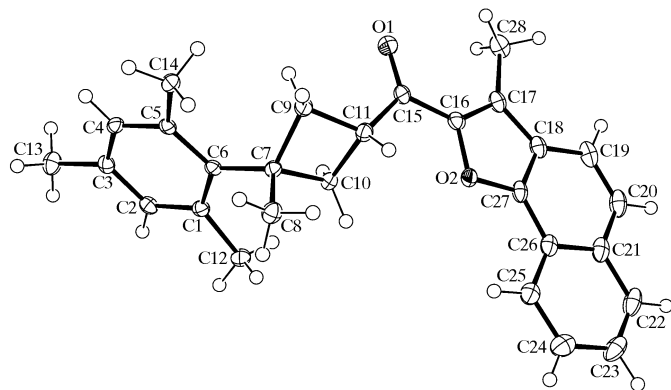
**Figure 1**  
The molecular structure of (I), showing the atom-labeling scheme (50% probability displacement ellipsoids).

planar and makes a dihedral angle of  $46.15(3)^\circ$  with the planar benzoyl ring. The conformation of compound (I) is similar to those of previously reported benzoylbenzofuran derivatives (Benassi *et al.*, 1987; Pei *et al.*, 2005). The crystal packing of (I) is governed by a set of weak intermolecular interactions. A dimer is formed *via* a  $C2-H2A \cdots O1^i$  hydrogen bond (see Table 2 for geometry and symmetry code), and the dimeric units are held together by a  $C7-H7A \cdots O2^{ii}$  hydrogen bond (Table 2), two  $C-H \cdots \pi$  interactions [ $C5-H5A \cdots Cg2^{iii} = 3.28 \text{ \AA}$  and  $C15-H15A \cdots Cg1^{iv} = 2.80 \text{ \AA}$ , where  $Cg1$  and  $Cg2$  are the centroids of the  $C1-C6$  and  $C10-C15$  benzene rings; symmetry codes: (iii)  $-x, 1-y, -z$ ; (iv)  $1-x, 1-y, -z$ ] and two  $\pi-\pi$  interactions [ $Cg1 \cdots Cg1^v = 3.561(1) \text{ \AA}$  and  $Cg2 \cdots Cg2^{vi} = 3.776(1) \text{ \AA}$ ; symmetry codes: (v)  $-x, -y, -z$ ; (vi)  $1-x, 1-y, 1-z$ ], resulting in a three-dimensional supramolecular network (Fig. 4).

The molecules of (II) contain two symmetry-related planar bromobenzofuran rings attached to the carbonyl group ( $C9=O2$ ), which is situated on the twofold rotation axis. The dihedral angle between the planes of the two equivalent bromobenzofuran ring moieties is  $32.70(4)^\circ$ . In the packing of (II), the molecules are linked by a combination of a  $C-H \cdots O$  hydrogen bond (Table 4) and a  $C-H \cdots \pi$  interaction [ $C2-H2A \cdots Cg^{viii} = 2.87 \text{ \AA}$ ;  $Cg$  is the centroid of the  $C1-C6$  ring; symmetry code: (viii)  $x, 1-y, -\frac{1}{2}+z$ ]. Each molecule accepts



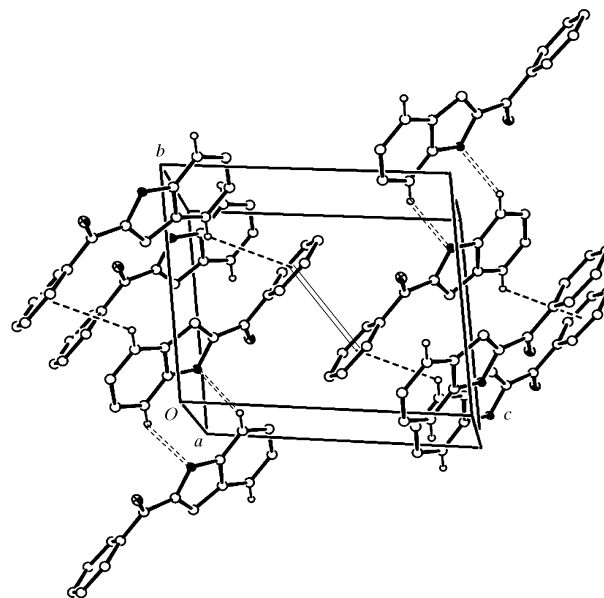
**Figure 2**  
The molecular structure of (II), showing the atom-labeling scheme (50% probability displacement ellipsoids). [Symmetry code: (viii)  $1-x, y, \frac{1}{2}-z$ .]



**Figure 3**  
The molecular structure of (III), showing the atom-labeling scheme (50% probability displacement ellipsoids).

two hydrogen bonds and donates two hydrogen bonds, thus forming chains running parallel to the crystallographic  $b$  axis. These chains are further linked by relatively short  $Br \cdots Br$  contacts [ $Br \cdots Br^{ix} = 3.499(2) \text{ \AA}$ ; symmetry code: (ix)  $\frac{1}{2}-x, \frac{5}{2}-y, -z$ ], resulting in a two-dimensional layer architecture (Fig. 5). The  $C-Br \cdots Br$  angle is  $146.85(12)^\circ$ , and the  $Br \cdots Br$  interactions play a crucial role in determining the crystal packing and compete successfully with other kinds of weak intermolecular interactions.

Compound (III) consists of a fused naphthofuran moiety ( $O2/C16-C27$ ), a cyclobutane ring ( $C7/C9-C11$ ) and a mesityl group ( $C1-C6/C12-C14$ ). The naphthofuran and mesityl ring systems are essentially planar, and the dihedral angle between their planes is  $81.86(3)^\circ$ , differing from the values reported for 1-(1-benzofuran-2-yl)-2-mesitylketone [ $89.08(4)^\circ$ ; Arici *et al.*, 2004] and (benzofuran-2-yl)(3-methyl-3-phenylcyclobutyl)methanone [ $73.63(6)^\circ$ ; Yüseketepe *et al.*, 2004]. These differences may be explained by the presence of the different substituents in these compounds. The cyclobutane ring deviates significantly from planarity, with a puckering parameter ( $q_2$ ) of  $0.3972(4) \text{ \AA}$ , and this finding is consistent with a similar benzofuran derivative containing a cyclobutane ring (Yüseketepe *et al.*, 2004). However, a nearly planar cyclobutane ring was also reported by Özdemir *et al.* (2004). The dihedral angles between the planes of the naphthofuran/cyclobutane and mesityl/cyclobutane ring systems are  $52.15(5)^\circ$  and  $38.26(8)^\circ$ , respectively. In contrast to compounds (I) and (II), compound (III) does not exhibit  $C-H \cdots O$  hydrogen bonds, and molecules of (III) are held together by  $C-H \cdots \pi$  and  $\pi-\pi$  interactions (Fig. 6). There are three  $C-H \cdots \pi$  interactions between the H atoms of the



**Figure 4**  
A packing diagram of (I).  $C-H \cdots O$  interactions are indicated by double dashed lines and  $C-H \cdots \pi$  interactions by single dashed lines, while  $\pi-\pi$  interactions are shown as double thin lines. O atoms are shown with octant shading.



Figure 5

A packing diagram of (II). C—H...O interactions are represented as double dashed lines and Br...Br contacts are indicated by single dashed lines. O atoms are shown with octant shading.

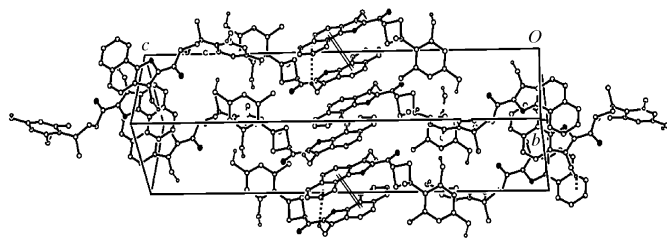


Figure 6

A packing diagram of (III), viewed along the crystallographic *b* axis. C—H... $\pi$  interactions are indicated by double dashed lines, while  $\pi$ — $\pi$  interactions are shown as double thin lines. O atoms are shown with octant shading.

methyl groups and the benzene rings [C13—H13A...Cg1<sup>x</sup> = 3.20 Å, C14—H14B...Cg1<sup>xi</sup> = 2.73 Å and C28—H28A...Cg2<sup>iii</sup> = 2.87 Å, where Cg1 and Cg2 are the centroids of the C1—C6 and C21—C26 rings, respectively; symmetry codes: (x)  $-x, \frac{1}{2} + y, \frac{1}{2} - z$ ; (xi)  $1 - x, -\frac{1}{2} + y, \frac{1}{2} - z$ ]. In (III), the packing of the molecules is additionally reinforced by a  $\pi$ — $\pi$  stacking interaction between adjacent naphthalene rings, with a Cg1...Cg1<sup>iii</sup> distance of 3.695 (1) Å.

## Experimental

For the preparation of (I), a mixture of salicylaldehyde (12.21 g, 0.1 mol) and potassium carbonate (20.70 g, 0.15 mol) was stirred in dry acetone (250 ml) at room temperature for 2 h. A solution of phenacyl bromide (19.90 g, 0.1 mol) in dry acetone (20 ml) was added to this mixture. The resulting solution was poured into water (250 ml) and reprecipitated twice from water. Suitable crystals of (I) were obtained by recrystallizing the precipitate from acetone (yield 19.60 g, 89.1%). For the preparation of (II), a mixture of 5-bromo-2-hydroxybenzaldehyde (20.10 g, 0.1 mol) and potassium carbonate

(20.70 g, 0.15 mol) was stirred in dry acetone (250 ml) at room temperature for 2 h. A solution of 1,3-dichloroacetone (6.35 g, 0.05 mol) in dry acetone (20 ml) was added and this mixture was poured into water (250 ml). The separated solid was filtered off, washed with water and recrystallized from tetrahydrofuran to give (II) (yield 33.8 g, 80.5%). For the preparation of (III), hydroxynaphthophenone (1.86 g, 10 mmol), potassium carbonate (2.07 g, 15 mmol) and dry tetrahydrofuran (100 ml) were placed in a 500 ml two-necked flask fitted with a reflux condenser, and the mixture was stirred for 1 h at room temperature. To this solution, a solution of 3-(2-chloro-1-oxoethyl)-1-mesityl-1-methylcyclobutane (2.64 g, 10 mmol) in acetonitrile (100 ml) was added dropwise over a period of about 30 min and the mixture was subsequently refluxed for 4 h. The progress of the reaction was monitored by IR spectroscopy. The mixture was allowed to cool to room temperature, and was then poured into water (500 ml) and reprecipitated twice from water. The solid was filtered off and recrystallized from tetrahydrofuran to obtain crystals of (III) (yield 2.85 g, 71.96%).

## Compound (I)

### Crystal data

C<sub>15</sub>H<sub>10</sub>O<sub>2</sub>  
*M<sub>r</sub>* = 222.23  
 Triclinic, *P* $\bar{1}$   
*a* = 6.1028 (5) Å  
*b* = 8.8010 (4) Å  
*c* = 10.1195 (6) Å  
 $\alpha$  = 97.700 (4)°  
 $\beta$  = 93.710 (6)°  
 $\gamma$  = 101.073 (6)°  
*V* = 526.31 (6) Å<sup>3</sup>

*Z* = 2  
*D<sub>x</sub>* = 1.402 Mg m<sup>-3</sup>  
 Mo *K* $\alpha$  radiation  
 Cell parameters from 36 reflections  
 $\theta$  = 6.0–20.0°  
 $\mu$  = 0.09 mm<sup>-1</sup>  
*T* = 100 (2) K  
 Prism, colorless  
 0.34 × 0.31 × 0.28 mm

### Data collection

Bruker–Nonius KappaCCD diffractometer  
 $\varphi$  and  $\omega$  scans  
 17534 measured reflections  
 2498 independent reflections  
 2049 reflections with *I* > 2 $\sigma$ (*I*)

*R*<sub>int</sub> = 0.070  
 $\theta_{\max}$  = 27.9°  
*h* = −8 → 8  
*k* = −11 → 11  
*l* = −13 → 13

### Refinement

Refinement on *F*<sup>2</sup>  
*R* [*F*<sup>2</sup> > 2 $\sigma$ (*F*<sup>2</sup>)] = 0.040  
*wR*(*F*<sup>2</sup>) = 0.098  
*S* = 1.06  
 2498 reflections  
 154 parameters  
 H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0496P)^2 + 0.1374P]$   
 where  $P = (F_o^2 + 2F_c^2)/3$   
 ( $\Delta/\sigma$ )<sub>max</sub> = 0.001  
 $\Delta\rho_{\max} = 0.23$  e Å<sup>-3</sup>  
 $\Delta\rho_{\min} = -0.30$  e Å<sup>-3</sup>

Table 1

Selected geometric parameters (Å, °) for (I).

O2—C9	1.2257 (14)	C9—C10	1.4932 (16)
C8—C9	1.4678 (17)		
C8—C9—C10	118.74 (10)		

Table 2

Hydrogen-bond geometry (Å, °) for (I).

<i>D</i> —H... <i>A</i>	<i>D</i> —H	H... <i>A</i>	<i>D</i> ... <i>A</i>	<i>D</i> —H... <i>A</i>
C2—H2A...O1 <sup>i</sup>	0.95	2.57	3.4182 (14)	149
C7—H7A...O2 <sup>ii</sup>	0.95	2.55	3.1449 (14)	121

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

## Compound (II)

## Crystal data

$C_{17}H_8Br_2O_3$	$D_x = 1.994 \text{ Mg m}^{-3}$
$M_r = 420.05$	Mo $K\alpha$ radiation
Monoclinic, $C2/c$	Cell parameters from 89 reflections
$a = 29.644 (2) \text{ \AA}$	$\theta = 6.0\text{--}20.0^\circ$
$b = 6.2536 (5) \text{ \AA}$	$\mu = 5.80 \text{ mm}^{-1}$
$c = 7.8188 (8) \text{ \AA}$	$T = 100 (2) \text{ K}$
$\beta = 105.091 (6)^\circ$	Irregular, colorless
$V = 1399.5 (2) \text{ \AA}^3$	$0.25 \times 0.24 \times 0.16 \text{ mm}$
$Z = 4$	

## Data collection

Bruker–Nonius KappaCCD diffractometer	1814 independent reflections
$\varphi$ and $\omega$ scans	1604 reflections with $I > 2\sigma(I)$
Absorption correction: multi-scan (SADABS; Bruker, 2002)	$R_{\text{int}} = 0.046$
$T_{\text{min}} = 0.262$ , $T_{\text{max}} = 0.398$	$\theta_{\text{max}} = 28.7^\circ$
19777 measured reflections	$h = -40 \rightarrow 40$
	$k = -8 \rightarrow 8$
	$l = -10 \rightarrow 10$

## Refinement

Refinement on $F^2$	$w = 1/[\sigma^2(F_o^2) + (0.0084P)^2 + 2.8382P]$
$R[F^2 > 2\sigma(F^2)] = 0.019$	where $P = (F_o^2 + 2F_c^2)/3$
$wR(F^2) = 0.043$	$(\Delta/\sigma)_{\text{max}} = 0.001$
$S = 1.08$	$\Delta\rho_{\text{max}} = 0.43 \text{ e \AA}^{-3}$
1814 reflections	$\Delta\rho_{\text{min}} = -0.32 \text{ e \AA}^{-3}$
101 parameters	
H-atom parameters constrained	

Table 3

Selected geometric parameters ( $\text{\AA}$ ,  $^\circ$ ) for (II).

Br1—C4	1.9010 (16)	C8—C9	1.473 (2)
O2—C9	1.223 (3)		
O2—C9—C8	120.81 (10)	C8 <sup>vii</sup> —C9—C8	118.4 (2)

Symmetry code: (vii)  $-x + 1, y, -z + \frac{1}{2}$ .

Table 4

Hydrogen-bond geometry ( $\text{\AA}$ ,  $^\circ$ ) for (II).

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
C7—H7A $\cdots$ O2 <sup>xii</sup>	0.95	2.56	3.429 (2)	151

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

## Compound (III)

## Crystal data

$C_{28}H_{28}O_2$	$D_x = 1.250 \text{ Mg m}^{-3}$
$M_r = 396.50$	Mo $K\alpha$ radiation
Monoclinic, $P2_1/c$	Cell parameters from 134 reflections
$a = 7.3816 (3) \text{ \AA}$	$\theta = 6.0\text{--}20.0^\circ$
$b = 8.2874 (6) \text{ \AA}$	$\mu = 0.08 \text{ mm}^{-1}$
$c = 34.591 (2) \text{ \AA}$	$T = 100 (2) \text{ K}$
$\beta = 95.487 (5)^\circ$	Block, colorless
$V = 2106.4 (2) \text{ \AA}^3$	$0.34 \times 0.25 \times 0.16 \text{ mm}$
$Z = 4$	

## Data collection

Bruker–Nonius KappaCCD diffractometer	4182 independent reflections
$\varphi$ and $\omega$ scans	3360 reflections with $I > 2\sigma(I)$
Absorption correction: multi-scan (SADABS; Bruker, 2002)	$R_{\text{int}} = 0.032$
$T_{\text{min}} = 0.970$ , $T_{\text{max}} = 0.988$	$\theta_{\text{max}} = 26.4^\circ$
20365 measured reflections	$h = -9 \rightarrow 9$
	$k = -10 \rightarrow 10$
	$l = -43 \rightarrow 43$

## Refinement

Refinement on $F^2$	$w = 1/[\sigma^2(F_o^2) + (0.0429P)^2 + 1.2434P]$
$R[F^2 > 2\sigma(F^2)] = 0.044$	where $P = (F_o^2 + 2F_c^2)/3$
$wR(F^2) = 0.106$	$(\Delta/\sigma)_{\text{max}} = 0.004$
$S = 1.03$	$\Delta\rho_{\text{max}} = 0.26 \text{ e \AA}^{-3}$
4182 reflections	$\Delta\rho_{\text{min}} = -0.25 \text{ e \AA}^{-3}$
276 parameters	
H-atom parameters constrained	

Table 5

Selected interatomic distances ( $\text{\AA}$ ) for (III).

O1—C15	1.2237 (19)	C15—C16	1.473 (2)
C11—C15	1.505 (2)		

All H atoms were refined using a riding model, with C—H distances of 0.95–1.00  $\text{\AA}$  and  $U_{\text{iso}}(\text{H})$  values of  $1.2U_{\text{eq}}(\text{C})$ .

For all compounds, data collection: *COLLECT* (Bruker, 2002); cell refinement: *EVALCCD* (Duisenberg *et al.*, 2003); data reduction: *EVALCCD*; program(s) used to solve structure: *SHELXTL* (Bruker, 2002); program(s) used to refine structure: *SHELXTL*; molecular graphics: *SHELXTL*; software used to prepare material for publication: *SHELXTL*.

The authors thank Ondokuz Mayıs and Firat Universities for the financial support given to the study.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: SQ1211). Services for accessing these data are described at the back of the journal.

## References

- Arıcı, C., Ülkü, D., Kirilmis, C., Koca, M. & Ahmedzade, M. (2004). *Acta Cryst.* **E60**, o941–o942.
- Benassi, R., Folli, U., Iarossi, D., Schenetti, L., Taddei, F., Musatti, A. & Nardelli, M. (1987). *J. Chem. Soc. Perkin Trans. 2*, pp. 1443–1454.
- Bruker (2002). *SADABS* (Version 2.06), *COLLECT* and *SHELXTL* (Version 6.12). Bruker AXS Inc., Madison, Wisconsin, USA.
- Calhorda, M. J. (2000). *Chem. Commun.* pp. 801–810.
- Demirayak, S., Ucucu, U., Benkli, K., Gundogdu-Karaburun, N., Gundogdu-Karaburun, A., Akar, D., Karabacak, M. & Kiraz, N. (2002). *Il Farmaco*, **57**, 609–612.
- Desiraju, G. R. & Steiner, T. (1999). In *The Weak Hydrogen Bond in Structural Chemistry and Biology*. Oxford University Press.
- Duisenberg, A. J. M., Kroon-Batenburg, L. M. J. & Schreurs, A. M. M. (2003). *J. Appl. Cryst.* **36**, 220–229.
- Hunder, C. A. & Sanders, J. K. M. (1990). *J. Am. Chem. Soc.* **112**, 5525–5534.
- Kappe, C. O., Murphree, S. S. & Padwa, A. (1997). *Tetrahedron*, **53**, 14179–14233.
- Nishio, M., Hirota, M. & Umezawa, Y. (1998). In *The C—H $\cdots\pi$  Interaction (Evidence, Nature and Consequences)*. New York: Wiley-VCH.
- Özdemir, N., Dinçer, M., Yilmaz, I. & Çukurovali, A. (2004). *Acta Cryst.* **E60**, o14–o16.
- Pei, L.-X., Bu, X.-Z., Gu, L.-Q. & Ng, S. W. (2005). *Acta Cryst.* **E61**, o1081–o1082.
- Sato, M., Grese, T. A., Dodge, J. A., Bryant, H. U. & Turner, C. H. (1999). *J. Med. Chem.* **42**, 1–24.
- Smith, R. A., Chen, J., Mader, M. M., Muegge, I., Moehler, U., Katti, S., Marrero, D., Stirtan, W. G., Weaver, D. R., Xiao, H. & Carley, W. (2002). *Bioorg. Med. Chem. Lett.* **12**, 2875–2878.
- Spaniol, M., Bracher, R., Ha, H. R., Follath, F. & Krahenbuhl, S. (2001). *J. Hepatol.* **35**, 628–636.
- Umezawa, Y., Tsuboyama, S., Honda, K., Uzawa, J. & Nishio, M. (1998). *Bull. Chem. Soc. Jpn.*, **71**, 1207–1213.
- Yüksektepe, Ç., Saraçoğlu, H., Koca, M., Çukurovali, A. & Çaliskan, N. (2004). *Acta Cryst.* **C60**, o509–o510.