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Three quinolone compounds featuring O⋯I halogen bonding

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Ethyl 1-ethyl-6-iodo-4-oxo-1,4-dihydroquinoline-3-carboxylate, $C_{14}H_{14}INO_3$, (I), and ethyl 1-cyclopropyl-6-iodo-4-oxo-1,4-dihydroquinoline-3-carboxylate, $C_{15}H_{14}INO_3$, (II), have isomorphous crystal structures, while ethyl 1-dimethylamino-6-iodo-4-oxo-1,4-dihydroquinoline-3-carboxylate, $C_{14}H_{15}IN_2O_3$, (III), possesses a different solid-state supramolecular architecture. In all three structures, O⋯I halogen-bonding interactions connect the quinolone molecules into infinite chains parallel to the unique crystallographic b axis. In (I) and (II), these molecular chains are arranged in (101) layers, via π–π stacking and C—H⋯π interactions, and these layers are then interlinked by C—H⋯O interactions. The structural fragments involved in the C—H⋯O interactions differ between (I) and (II), accounting for the observed difference in planarity of the quinolone moieties in the two isomorphous structures. In (III), C—H⋯O and C—H⋯π interactions form (100) molecular layers, which are crosslinked by O⋯I and C—H⋯I interactions.

Comment

Halogen bonding is an interaction between halogen atoms (I, Br and Cl) acting as Lewis acids and neutral or anionic Lewis bases (Karpfen, 2008). The interaction has received a great deal of attention recently as it has frequently been observed in solids (Metrangolo et al., 2008), liquids (Wash et al., 1999) and gases (Legon, 2008). It has also been found in liquid crystals (Nguyen et al., 2004), as well as in biologically important molecules (Metrangolo et al., 2005). For this reason, halogen bonding is considered to be just as important as the analogous hydrogen bonding (Corradi et al., 2000; Aakeröy et al., 2007).

Quinolones have been thoroughly investigated since the early 1960s as potent antibacterial agents (Andriole, 1998). Many quinolone structures have been characterized and

quinolone chemistry has been well explored (Grohe, 1998). A search of the Cambridge Structural Database (CSD; Version 5.30, with May 2009 updates; Allen, 2002) revealed 267 solid-state structures containing the quinolone moiety, 201 of which are halogenated, of which 61 contain Cl, 5 contain Br and only one contains I (CSD refcode BARTIX; Keller et al., 1981). To the best of our knowledge, there has been no report on O⋯I halogen bonding for this class of compounds. We have observed O⋯I halogen bonding in the crystal structures of ethyl 1-ethyl-, (I), 1-cyclopropyl-, (II), and 1-dimethylamino-6-iodo-4-oxo-1,4-dihydroquinoline-3-carboxylate, (III). The solid-state structures of (I) and (II) are isomorphous by substitution at the ring N atom.
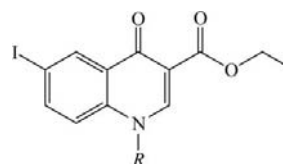
(I) R = Et
(II) R = cyclopropyl
(III) R = NMe₂

The nonsubstituted 4-quinolone molecule (CSD refcode NICJOZ; Nasiri et al., 2006) is planar. Depending on the number, position and type of substituents, as well as the mode of crystal packing, the quinolone moiety (atoms N1/C2–C10/O1 for the structures presented herein; Fig. 1) can significantly deviate from planarity (by up to 0.23 Å in some quinolones; e.g. Polborn et al., 1992; Gulyakevich et al., 1999; Hashimoto et al., 2007). The quinolone moiety in (I) is almost planar [the largest deviation from the mean plane is 0.012 (2) Å for atom C3], whereas the quinolone moieties in (II) and (III) are more distorted from planarity, the largest displacement from the mean plane being that of keto atom O1 [0.072 (2) Å in (II) and 0.102 (2) Å in (III)]. The observed difference in the quinolone (non)planarity between isomorphous structures (I) and (II) could be attributed to slightly different intermolecular interactions (see below). In all three studied structures, the non-H atoms in the ester moiety (C11–C13/O2/O3) are nearly coplanar. The angles between the mean planes of the quinolone and ester moieties are 9.54 (12), 9.88 (11) and 7.72 (13)° for (I), (II) and (III), respectively. The 3-carboxy and quinolone carbonyl groups are mutually in a syn conformation, as was also observed in the crystal structures of several other 4-quinolone-3-carboxylic acid ethyl esters (Barrett et al., 1995, 1996; Al-Hiari et al., 2006; Ukrainets et al., 2007; Abu-Sheaib et al., 2008; Pan et al., 2008). The N-ethyl group in (I) is out of the quinolone plane, with a C9—N1—C14—C15 torsion angle of −78.0 (3)°. The angle between the planes through the N-cyclopropyl group (C14–C16) and the quinolone moiety in (II) is 59.92 (18)°, while the plane of the N-dimethylamino group (N2/C14/C15) is inclined to the mean plane of the quinolone moiety at 83.9 (2)° in (III).

Intermolecular halogen O⋯I bonds involving the quinolone keto groups (Table 1) play an important role in the solid-state supramolecular architectures of all three title quinolone esters. In all of these structures, molecules connected by O⋯I

bonds form zigzag chains parallel to the crystallographic *b* axis (Figs. 2 and 3). The mean quinolone planes of the two halogen-bonded molecules in (III) make an angle of 10.93 (5)°, while this angle is much larger in the structures of (I) and (II) [63.39 (5) and 70.37 (5)°, respectively]. As found by a search of the CSD, refcodes EVINIG (Song *et al.*, 2004) and BAKSUC (Mphahlele *et al.*, 2002) are the only two other quinolone structures with halogen bonds involving the quinolone keto group. In EVINIG (7-chloro-1-ethyl-6-fluoro-4-quinolone-3-carboxylic acid), O···Cl interactions connect the molecules into infinite chains. In contrast to the zigzag chains in (I), (II) and (III), the molecular chains formed by halogen bonding in EVINIG are straight, the quinolone moieties of the linked molecules being coplanar. In BAKSUC [3-bromo-2-(4-fluorophenyl)-4-quinolone], six quinolone mol-ecules are joined *via* O···Br bonds into a ring with $R_6^6(24)$ topology (Etter *et al.*, 1990; Bernstein *et al.*, 1995) and crystallographic $\bar{3}$ symmetry. There is only one example of iodine halogen bonding for the quinolone compounds (CSD refcode BARTIX; Keller *et al.*, 1981), where a 6-iodo-4-quinolonium cation makes a discrete N···I interaction with a 7,7,8,8-tetra-cyanoquinodimethane molecule.

In the isomorphous structures of (I) and (II), each quinolone molecule is stacked between two neighbouring molecules, both belonging to the same molecular chain formed by halogen bonding (Fig. 2). Molecules from different chains are connected into centrosymmetric dimers by C—H···π interactions (Table 2), and packing along the crystallographic *b* axis is achieved by π–π interactions (Desiraju & Gavezzotti, 1989) between adjacent molecular dimers (Table 3). Therefore, each molecular chain forms zipper-like motifs with two adjacent
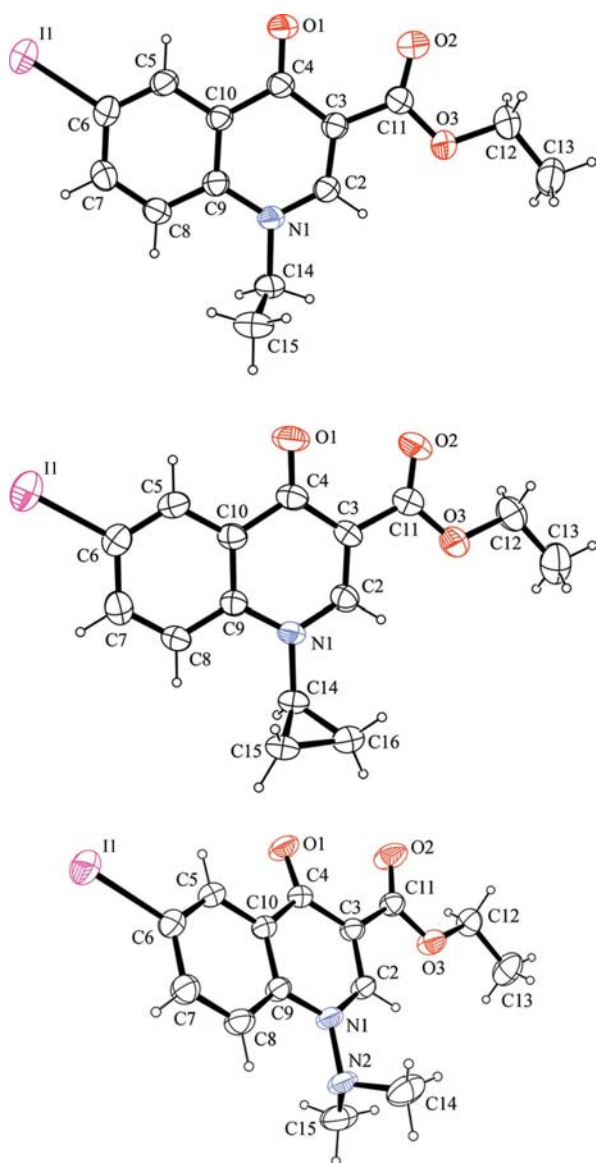
Figure 1
The molecular structures of (I) (top), (II) (middle) and (III) (bottom), showing the atom-numbering schemes. Displacement ellipsoids are drawn at the 50% probability level and H atoms are shown as small spheres of arbitrary radii.
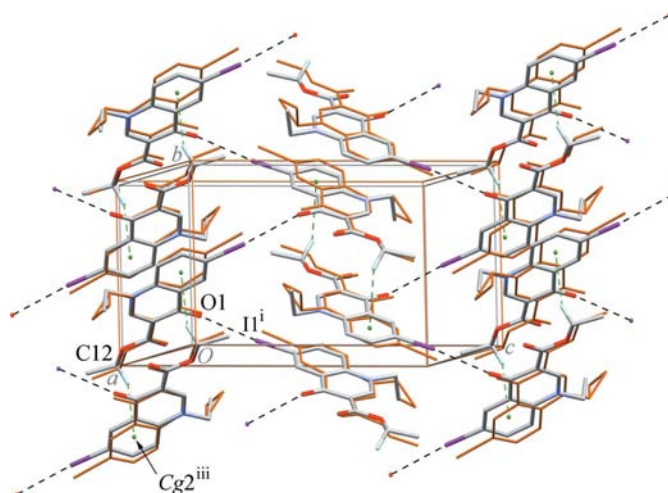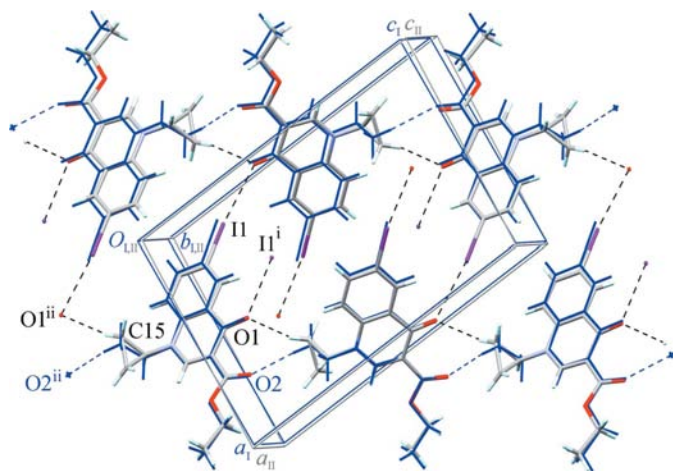

Figure 2
The (101) molecular layers in the isomorphous structures of (I) (thick bonds) and (II) (thin bonds) formed by O···I and C—H···π interactions [dashed lines; for the sake of clarity, they are represented only for (I)]. H atoms [except for H12A in (I)] are not shown. *Cg*2 (small dots) represent the centroids of the C5–C10 benzene rings. [Symmetry codes: (i) $-x + \frac{1}{2}$, $y - \frac{1}{2}$, $-z + \frac{1}{2}$; (iii) $-x + 1$, $-y$, $-z$.]
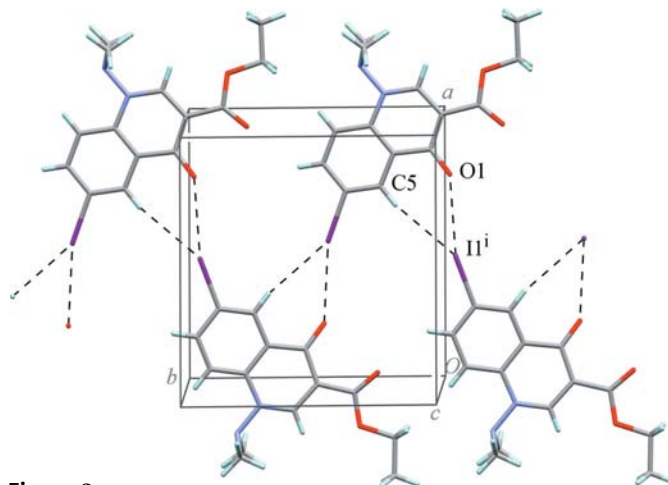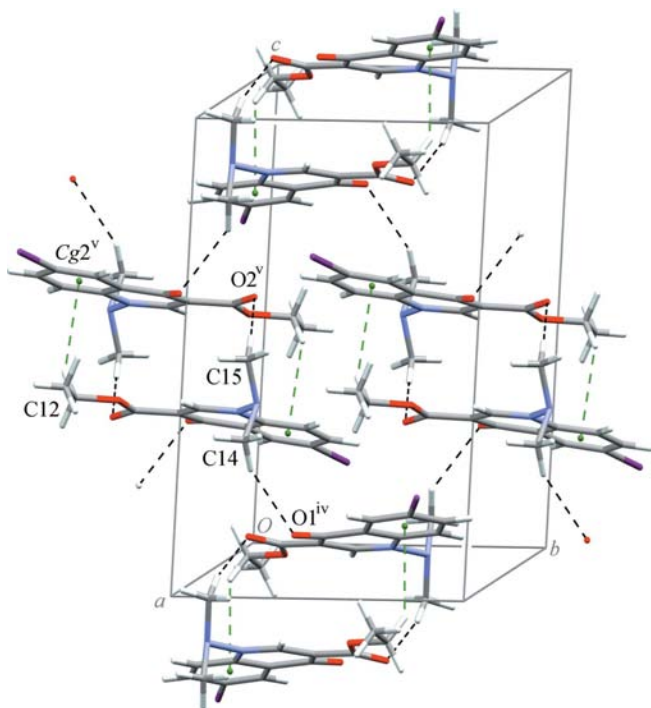

Figure 3
The molecular chains in (III), formed by O···I and C—H···I interactions (dashed lines). [Symmetry code: (i) $-x + 1$, $y - \frac{1}{2}$, $-z + \frac{1}{2}$.]

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chains, resulting in (101) molecular layers (Fig. 2). These layers are crosslinked by C—H···O interactions, but these are different in the two isomorphous structures (illustrated in Fig. 4 and Table 2). In the structure of (I), C—H···O interactions engage the *N*-ethyl and ester carbonyl groups. By contrast, molecules of (II) are linked by C—H···O interactions between the *N*-cyclopropyl and quinolone keto groups,

Figure 4
Packing differences between (I) and (II). Molecules of (I) (thin bonds) are linked by C15—H15*A*···O2[ii] interactions, while molecules of (II) (thick bonds) form C15—H15*A*···O1[ii] interactions. For clarity, O···I halogen bonding is shown only for (II). Interactions are indicated by dashed lines. [Symmetry codes: (i) $-x + \frac{1}{2}, y - \frac{1}{2}, -z + \frac{1}{2}$; (ii) $x - \frac{1}{2}, -y + \frac{1}{2}, z - \frac{1}{2}$.]

Figure 5
The (100) molecular layers in (III), with C—H···O and C—H···π interactions shown as dashed lines. *Cg*2 (small dots) represent the centroids of the C5–C10 benzene rings. [Symmetry codes: (iv) $-x + 2, y + \frac{1}{2}, -z + \frac{1}{2}$; (v) $-x + 2, -y, -z + 1$.]

thus accounting for the considerable displacement of keto atom O1 from the quinolone mean plane in (II) noted above. The molecular chains formed *via* the C—H···O interactions run in the [101] direction, and for both isomorphs can be described by graph-set motif *C*(8) (Fig. 4).

Molecules in (III) are arranged into (100) layers *via* C—H···π and C—H···O interactions (Table 2 and Fig. 5). C12—H12*B*···*Cg*2[v] and C15—H15*A*···O2[v] interactions form centrosymmetric dimers, similar to those observed in the structures of (I) and (II), which are then linked by C14—H14*C*···O1[iv] interactions (symmetry codes as in Table 2). If each molecular dimer is represented by a node, then the pattern created by the C14—H14*C*···O1[iv] interactions can be described as a two-dimensional network with (4,4) topology (Wells, 1977; Batten & Robson 1998; Fig. 5). As found in (II), the C14—H14*C*···O1[iv] interaction affects the planarity of the quinolone moiety by displacing keto atom O1 significantly from the mean quinolone plane. The (100) molecular layers are crosslinked by O···I and C—H···I interactions (Table 2).

Experimental

Compound (I)

Crystal data

$C_{14}H_{14}INO_3$	$V = 1380.61$ (6) Å^3
$M_r = 371.05$	$Z = 4$
Monoclinic, $P2_1/n$	Mo $K\alpha$ radiation
$a = 10.8169$ (3) Å	$\mu = 2.32$ mm^{-1}
$b = 8.0588$ (2) Å	$T = 295$ K
$c = 15.8422$ (4) Å	$0.50 \times 0.35 \times 0.30$ mm
$\beta = 91.326$ (3)°	

Data collection

Oxford Diffraction Xcalibur CCD diffractometer	21815 measured reflections
Absorption correction: multi-scan (*CrysAlis RED*; Oxford Diffraction, 2007)	4010 independent reflections
	3045 reflections with $I > 2\sigma(I)$
$T_{min} = 0.396$, $T_{max} = 0.498$	$R_{int} = 0.015$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.026$	175 parameters
$wR(F^2) = 0.080$	H-atom parameters constrained
$S = 1.07$	$\Delta\rho_{max} = 0.74$ e Å^{-3}
4010 reflections	$\Delta\rho_{min} = -0.69$ e Å^{-3}

Compound (II)

Crystal data

$C_{15}H_{14}INO_3$	$V = 1428.21$ (5) Å^3
$M_r = 383.17$	$Z = 4$
Monoclinic, $P2_1/n$	Mo $K\alpha$ radiation
$a = 10.8406$ (2) Å	$\mu = 2.25$ mm^{-1}
$b = 8.2843$ (2) Å	$T = 295$ K
$c = 15.9269$ (3) Å	$0.60 \times 0.35 \times 0.20$ mm
$\beta = 93.127$ (2)°	

Data collection

Oxford Diffraction Xcalibur CCD diffractometer	13158 measured reflections
Absorption correction: multi-scan (*CrysAlis RED*; Oxford Diffraction, 2007) $T_{min} = 0.313$, $T_{max} = 0.638$	4146 independent reflections 2708 reflections with $I > 2\sigma(I)$ $R_{int} = 0.017$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.029$	183 parameters
$wR(F^2) = 0.079$	H-atom parameters constrained
$S = 1.01$	$\Delta\rho_{max} = 0.82$ e Å^{-3}
4146 reflections	$\Delta\rho_{min} = -0.59$ e Å^{-3}

Compound (III)

Crystal data

$C_{14}H_{15}IN_2O_3$	$V = 1481.26$ (7) Å^3
$M_r = 386.18$	$Z = 4$
Monoclinic, $P2_1/c$	Mo $K\alpha$ radiation
$a = 10.8437$ (3) Å	$\mu = 2.17$ mm^{-1}
$b = 9.9660$ (3) Å	$T = 295$ K
$c = 14.4482$ (4) Å	$0.60 \times 0.50 \times 0.15$ mm
$\beta = 108.436$ (3)°	

Data collection

Oxford Diffraction Xcalibur CCD diffractometer	13165 measured reflections
Absorption correction: multi-scan (*CrysAlis RED*; Oxford Diffraction, 2007) $T_{min} = 0.296$, $T_{max} = 0.722$	4265 independent reflections 3414 reflections with $I > 2\sigma(I)$ $R_{int} = 0.015$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.030$	184 parameters
$wR(F^2) = 0.079$	H-atom parameters constrained
$S = 1.09$	$\Delta\rho_{max} = 1.08$ e Å^{-3}
4265 reflections	$\Delta\rho_{min} = -0.85$ e Å^{-3}

Table 1
Halogen-bond geometry (Å, °) in (I), (II), and (III).

	O1···I1^i	θ_1(O1···I1^i—C6^i)	θ_2(C4=O1···I1^i)
(I)	3.0857 (15)	169.86 (7)	137.69 (13)
(II)	3.1715 (15)	171.31 (7)	138.69 (13)
(III)	3.218 (2)	163.07 (6)	145.90 (15)

Symmetry code: (i) $-x + \frac{1}{2}, y - \frac{1}{2}, -z + \frac{1}{2}$ for (I) and (II); $-x + 1, y - \frac{1}{2}, -z + \frac{1}{2}$ for (III).

Reflections (202) and (004) in the data set of (II) were omitted as outliers. H atoms were constrained to ideal geometry using an appropriate riding model [C—H = 0.96 (methyl), 0.97 (methylene), 0.98 (methine) or 0.93 Å (aromatic)]. Methyl H atoms were refined with U_{iso}(H) values set at $1.5U_{eq}$(C); all other H atoms were refined with U_{iso}(H) values set at $1.2U_{eq}$(C).

For all compounds, data collection: *CrysAlis CCD* (Oxford Diffraction, 2007); cell refinement: *CrysAlis RED* (Oxford Diffraction, 2007); data reduction: *CrysAlis RED*; program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008) integrated in *WinGX* (Farrugia, 1999); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008) integrated in *WinGX*; molecular graphics: *ORTEP-3* (Farrugia, 1997) and *Mercury* (Macrae *et al.*, 2006); software used to prepare material for publication: *PLATON* (Spek, 2009).

Table 2
C—H···A interactions (Å, °) in (I), (II), and (III).

$Cg2$ is the centroid of the C5–C10 benzene ring.

	D—H···A	D—H	H···A	D···A	D—H···A
(I)	C15—H15A···O2^{ii}	0.96	2.62	3.543 (4)	160
	C12—H12A···$Cg2^{iii}$	0.97	2.92	3.677 (3)	136
(II)	C15—H15A···O1^{ii}	0.97	2.41	3.236 (3)	143
	C12—H12A···$Cg2^{iii}$	0.97	3.05	3.749 (3)	130
(III)	C14—H14C···O1^{iv}	0.96	2.53	3.286 (3)	136
	C15—H15A···O2^{v}	0.96	2.57	3.504 (4)	166
	C5—H5···I1^i	0.93	3.11	4.023 (2)	167
	C12—H12B···$Cg2^{v}$	0.97	2.86	3.675 (3)	142

Symmetry codes: (i) $-x + 1, y - \frac{1}{2}, -z + \frac{1}{2}$; (ii) $x - \frac{1}{2}, -y + \frac{1}{2}, z - \frac{1}{2}$; (iii) $-x + 1, -y, -z$; (iv) $-x + 2, y + \frac{1}{2}, -z + \frac{1}{2}$; (v) $-x + 2, -y, -z + 1$.

Table 3
π–π interactions (Å, °) in (I) and (II).

$Cg1$ and $Cg2$ are the centroids of the N1/C2–C4/C9/C10 ring (ring 1) and the C5–C10 benzene ring (ring 2), respectively; α is the dihedral angle between the mean planes of the two interacting rings.

	Ring m···ring n^{vi}	Cgm···Cgn^{vi}	α	Mean plane of ring m···Cgn^{vi}	Ring offset
(I)	Ring 1···ring 1^{vi}	3.6198 (9)	0	3.4380 (7)	*ca* 1.13
	Ring 1···ring 2^{vi}	3.6625 (11)	0.63 (9)	3.4269 (9)	
(II)	Ring 1···ring 1^{vi}	3.6883 (11)	0	3.4703 (8)	*ca* 1.25
	Ring 1···ring 2^{vi}	3.6373 (12)	0.94 (10)	3.4341 (9)	

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

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