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# Crystal structure of the triethylammonium salt of 3-[(4-hydroxy-3-methoxyphenyl)(4-hydroxy-2-oxo-2*H*-chromen-3-yl)methyl]-2-oxo-2*H*-chromen-4-olate

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**Keywords:** crystal structure; 4-hydroxy-3-methoxyphenyl dicoumarol; 4-hydroxycoumarin derivatives; negative charge-assisted hydrogen bonds; short intramolecular hydrogen bonds.

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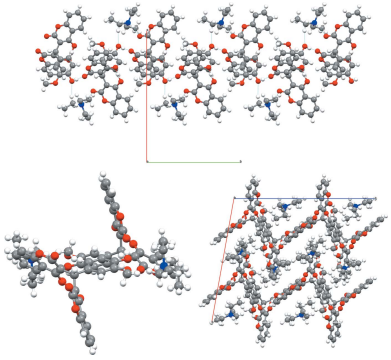
The reaction between 3,3′-[(3-methoxy-4-hydroxyphenyl)methanediyl]bis(4-hydroxy-2*H*-chromen-2-one) and triethylamine in methanol yielded the title compound triethylammonium 3-[(4-hydroxy-3-methoxyphenyl)(4-hydroxy-2-oxo-2*H*-chromen-3-yl)methyl]-2-oxo-2*H*-chromen-4-olate, $C_6H_{16}N^+\cdot C_{26}H_{17}O_8^-$ or $(NHEt_3)^+(C_{26}H_{17}O_8)^-$, which crystallized directly from its methanolic mother liquor. The non-deprotonated coumarol substituent shares its H atom with the deprotonated coumarolate substituent in a short negative charge-assisted hydrogen bond in which the freely refined H atom is moved from its parent O atom towards the acceptor O atom, elongating the covalent O—H bond to 1.18 (3) Å. The respective H atom can therefore be described as being shared by two alcohol O atoms, culminating in the formation of an eight-membered ring.

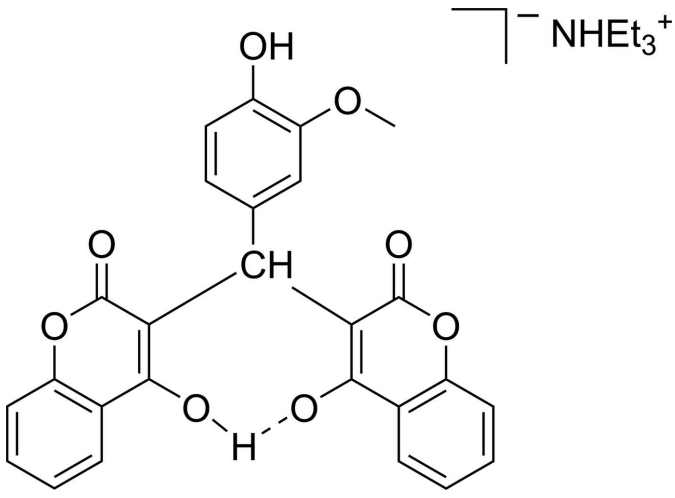
## 1. Chemical context

Requisite chemotherapeutical treatments of cancer and inhibition of bacterial activities encourage the design of drugs that can effectively target the affected cells or respective pathogens (Nolan *et al.*, 2007; Jung & Park, 2009).

4-Hydroxy coumarine and its derivatives have been developed and exploited by various researchers in this context (Nolan *et al.*, 2007; Tavolari *et al.*, 2008; Jung & Park, 2009; Li *et al.*, 2015; David, 2017). In biological tests with 3,3′-[(3-methoxy-4-hydroxyphenyl)methanediyl]bis(4-hydroxy-2*H*-chromen-2-one), much lower than expected cytotoxic activity was found (Rehman *et al.*, 2013), which may be attributed to insufficient solubility. The hydrophobic nature of this compound is most likely due to strong intramolecular hydrogen bonding between the two coumarol moieties *via* two O—H···O=C interactions, which was confirmed for the solid state by X-ray structural analysis of this compound (Bandyopadhyay, 2015) and close relatives (Manolov *et al.*, 2006; Stanchev *et al.*, 2007).

Hydrophobic molecules are not only ineffective inside biological fluids but they may also accumulate inside an organism. Increasing the solubility by increasing the hydrophilicity of potentially bioactive molecules may be achieved by converting them into salts (Smith *et al.*, 2009). Therefore, the synthesis of readily soluble ammonium salts of dicoumarol derivatives is of considerable importance. Herein, a crystallographically characterized example (being only the fourth of its kind) is discussed with a focus on its structural aspects.






## 2. Structural commentary

The molecular structure of the title compound is shown in Fig. 1. The deprotonation of one hydroxy-coumarin substituent but not the other leads to a short intramolecular negative charge-assisted hydrogen bond between the two hydroxy-coumarin substituents. The formation of such intramolecular hydrogen bonds between hydroxy-coumarin substituents is rare though not unprecedented (Kolos *et al.*, 2007; Vijayalakshmi *et al.*, 2001; Waheed & Ahmed, 2016). Recently, Bengiat and coworkers surveyed the occurrence of negative charge-assisted hydrogen bonds (–CAHB) in the Cambridge Structural Database (Groom *et al.*, 2016) in general (Bengiat *et al.*, 2016*a*), covering 19 such compounds although excluding the report by Waheed & Ahmed (2016), which was published later that year. Bengiat *et al.* (2016*b*) also discovered the shortest distance between donor and acceptor oxygen atoms of such intermolecular interactions to be 2.404 (3) Å, whereas in all other examples the distance was given as at least 2.430 Å (Bengiat *et al.*, 2016*a*). The metrical parameters of the intramolecular –CAHB in the title compound are $D\cdots A$ 2.4139 (15) Å and $D$—H$\cdots A$ 169 (2)°. The distance of the freely refined hydrogen atom to its parent atom O3 is elongated to 1.18 (3) Å, while the H$\cdots A$ hydrogen-bond length to O6 is rather short at only 1.24 (3) Å. This interaction is therefore the second shortest such –CAHB overall and the shortest intramolecular one. In the three related deprotonated dicoumarols, the $D\cdots A$ distances range from 2.423 Å (Waheed & Ahmed, 2016) to 2.491 Å (Kolos *et al.*, 2007). Based on the short, and hence strong, intramolecular hydrogen bond, an eight membered ring is formed (C1/C2/C10/O3/H3*O*/O6/C19/C11). The distances between the alcohol oxygen atoms and bound carbon atoms are 1.3005 (16) Å (O3—C10) and 1.2939 (17) Å (O6—C19); *i.e.* both very similar and both significantly shorter than those reported for non-deprotonated derivatives, which range from 1.331 to 1.338 Å (Stanchev *et al.*, 2007). This is in accordance with both alcohol functions being deprotonated and protonated to a certain extent at the same time, as was also found in one related structure of a salt (Vijayalakshmi *et al.*, 2001) but not in the other two analogous structures (Kolos *et al.*, 2007; Waheed & Ahmed, 2016).

The ammonium hydrogen atom, which was refined freely, exhibits a hydrogen bond to the carbonyl oxygen atom of the deprotonated coumarol substituent (N1—H1*N*$\cdots$O4) with $D\cdots A$ = 2.7727 (19) Å and $D$—H$\cdots A$ = 164.5 (18)°.

All of the C—C1—C angles around the central methine carbon atom [C11—C1—C2 = 116.48 (12), C11—C1—C20 = 114.44 (12), C2—C1—C20 = 110.79 (11)°] are slightly widened compared to the ideal tetrahedral value. As this is most pronounced for the angle involving the two coumarin substituents, it is most likely based on steric strain. The bond lengths involving the two pyran oxygen atoms [O2—C3 = 1.3773 (18), O2—C4 =1.3692 (17), O5—C12 = 1.3789 (18) and O5—C13 = 1.365 (2) Å] are similar as observed previously, indicating conjugation between the six-membered rings in the two benzopyran systems (Alcock & Hough, 1972; Vijayalakshmi *et al.*, 2001). The planarity of the two benzopyran moieties (C2/C3/O2/C4–C10, and C11/C12/O5/C13–C19) support this conclusion, with the largest deviations from the planes found for C2 [0.089 (1) Å; carbon atom binding the central methine carbon C1] and for C18 [0.020 (1) Å]. The dihedral angle between these planes is 50.84 (4)° and they form angles with the phenyl ring plane of 76.24 (5) and 59.40 (5)°, respectively.

Notable differences to the neutral parent molecule (Bandyopadhyay, 2015) comprise (i) the orientation of the hydroxy coumarin substituents (in the neutral structure one is flipped so that the lactone and alcohol moieties face each other, whereas in the present case alcohol faces alcohol and lactone faces lactone), (ii) a contraction [1.516 (2) Å, C1—C11] and elongation [1.5277 (19) Å, C1—C2] of the methine-to-benzopyran-carbon-atom distances of the deprotonated and non-deprotonated substituents compared to the neutral

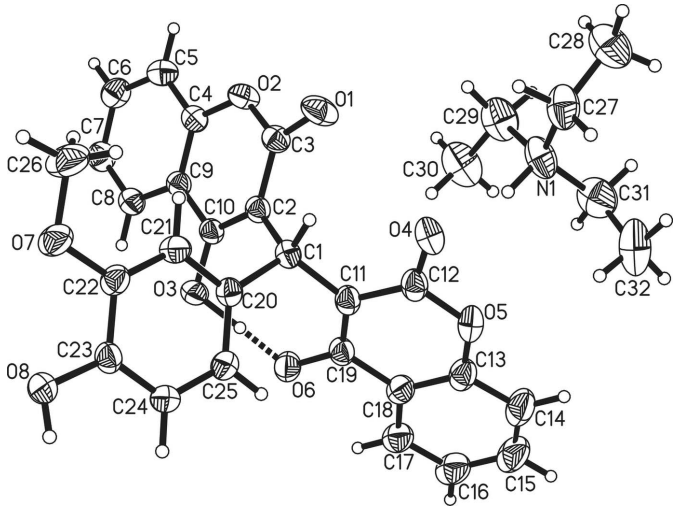



**Figure 1**
The molecular structure of triethylammonium 3-[(4-hydroxy-3-methoxyphenyl)(4-hydroxy-2-oxo-2*H*-chromen-3-yl)methyl]-2-oxo-2*H*-chromen-4-olate. Displacement ellipsoids are shown at the 50% probability level.

**Table 1**
Hydrogen-bond geometry (Å, °).

| $D$—H···$A$ | $D$—H | H···$A$ | $D$···$A$ | $D$—H···$A$ |
|---|---|---|---|---|
| O3—H3$O$···O6 | 1.18 (3) | 1.24 (3) | 2.4139 (15) | 169 (2) |
| O8—H8$O$···O1$^{i}$ | 0.869 (19) | 1.789 (19) | 2.6488 (16) | 170.0 (18) |
| C27—H27$B$···O8$^{ii}$ | 0.99 | 2.31 | 3.257 (2) | 161 |
| N1—H1$N$···O4 | 0.98 (2) | 1.82 (2) | 2.7727 (19) | 164.5 (18) |

Symmetry codes: (i) $-x+\frac{3}{2}, y+\frac{1}{2}, -z+\frac{3}{2}$; (ii) $-x+\frac{3}{2}, y-\frac{1}{2}, -z+\frac{3}{2}$.

structure (1.520 and 1.521 Å) and (iii) a higher molecular symmetry including the orientation of the 4-hydroxy-3-methoxyphenyl substituent of the neutral molecule compared to the anion of the title compound, emphasized by the torsion angles between the phenyl moiety and the two benzopyrane moieties, which are much more distinct in the anion [C2—C1—C20—C25 = 124.22 (15) and C11—C1—C20—C21 = 169.11 (13)° *vs* 153.28 and 163.81° in the neutral molecule].

## 3. Supramolecular features

The crystal packing appears to be dominated by intermolecular hydrogen-bonding interactions. No parallel alignments of the aromatic systems (phenyl, benzopyran) in a stacking fashion are observed, *i.e.* $\pi$–$\pi$ interactions are not present.

The alcohol oxygen atom of the 4-hydroxy-3-methoxyphenyl substituent (O8) bridges the adjacent cation and anion by hydrogen bonding as a classical donor [O8—H8$O$···O1($-x+\frac{3}{2}, y+\frac{1}{2}, -z+\frac{3}{2}$); $D$···$A$ = 2.4139 (15) Å] and as acceptor [O8···H27$B$—C27($-x+\frac{3}{2}, y+\frac{1}{2}, -z+\frac{3}{2}$); $D$···$A$ = 3.257 (2) Å] in a non-classical hydrogen bond from an amine methyl group (Table 1; Fig. 2, top). The ammonium cations bridge adjacent anions by the intra-formula classical hydrogen bond (N1—H1$N$···O4; see above) and the non-classical donation towards O8 [C27—H27$B$···O8($-x+\frac{3}{2}, y-\frac{1}{2}, -z+\frac{3}{2}$; $D$···$A$ = 3.257 (2) (19) Å]. Supported by the hydrogen bond with the carbonyl oxygen atom O1 as acceptor [O1···H8$O$—

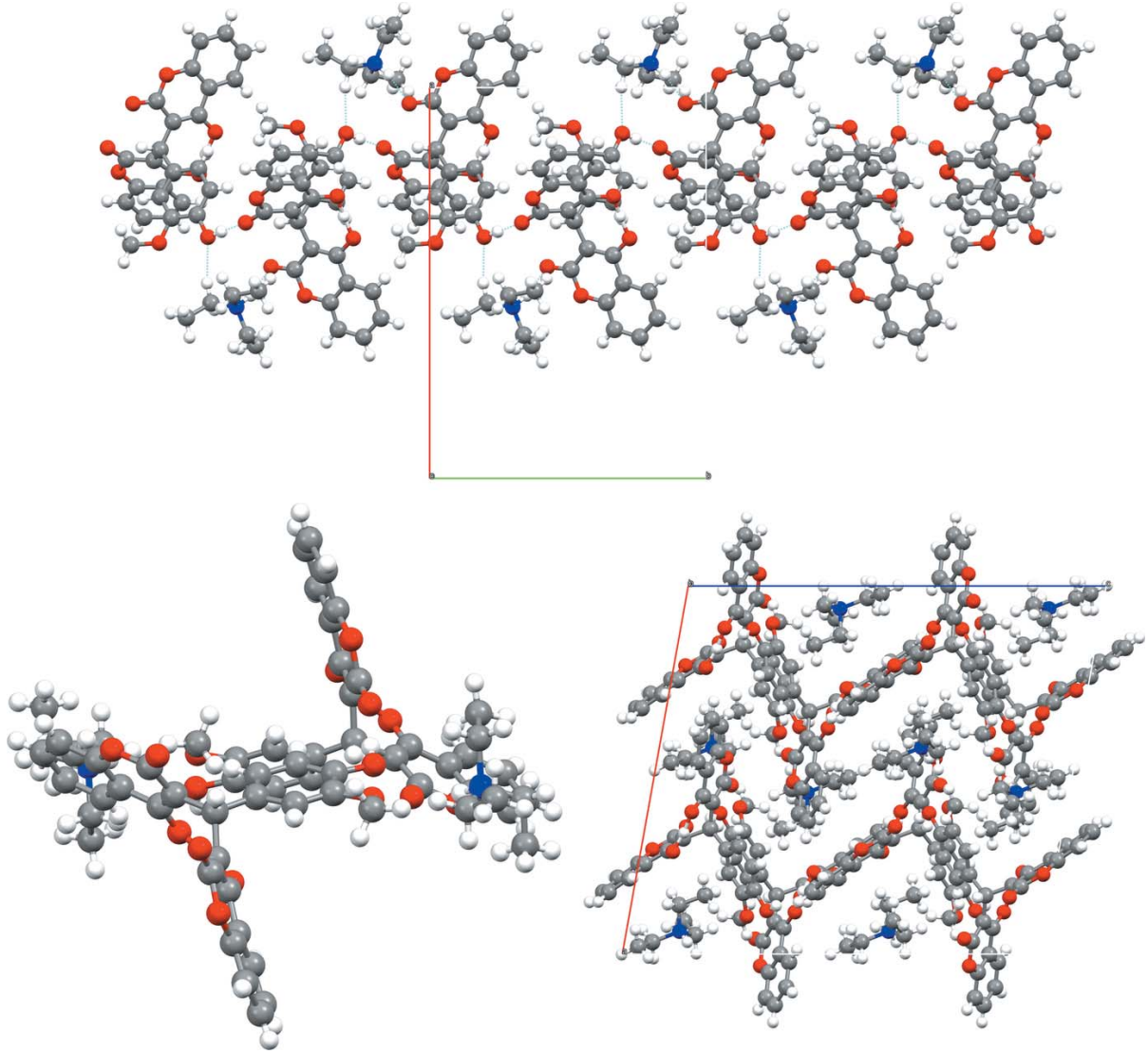


**Figure 2**
Hydrogen-bonding interactions forming infinite flat chains protruding along $b$ viewed along $c$ (top) and along $b$ (bottom, left; showing the benzopyran moieties sticking out up and down). The crystal packing exhibiting a zigzag pattern viewed along $b$ (bottom, right).

O8($-x+\frac{3}{2}$, $y-\frac{1}{2}$, $-z+\frac{3}{2}$); $D\cdots A$ = 2.6488 (16) Å], these interactions form infinite flat chains with 'up and down'-pointing benzopyrane moieties protruding along **b** (Fig. 2, bottom left). The packing diagram exhibits a zigzag pattern along **b** in which adjacent chains are aligned in a zipper-like fashion (Fig. 2, bottom right).

## 4. Synthesis and crystallization

3,3′-[(3-Methoxy-4-hydroxyphenyl)methanediyl]bis(4-hydroxy-2*H*-chromen-2-one) was synthesized following essentially the reported procedure (Rehman *et al.*, 2013). 20 mmol of 3-methoxy-4-hydroxybenzaldehyde dissolved in anyhydrous ethanol was added to 50 mmol of an ethanolic solution of 4-hydroxycoumarin. The resulting mixture was refluxed at 393 K for 3 h. Upon cooling, a solid white powder was obtained, which was washed with 10% copious ethanolic/*n*-hexane solution. The subsequent deprotonation of 3,3′-[(3-methoxy-4-hydroxyphenyl)methanediyl]bis(4-hydroxy-2*H*-chromen-2-one) was carried out by adding 1 mL of triethylamine to its methanolic solution. The resulting transparent yellowish solution was left standing overnight to grow transparent crystals of triethylammonium 3-[(4-hydroxy-3-methoxyphenyl)(4-hydroxy-2-oxo-2*H*-chromen-3-yl)methyl]-2-oxo-2*H*-chromen-4-olate.

## 5. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 2. The three hydrogen atoms bound to heteroatoms (N1, O3, O8) were freely refined. Carbon-bound hydrogen atoms were placed in calculated positions, and refined with a riding-model approximation: C—H = 0.95–1.00 Å with $U_{iso}$(H) = 1.5$U_{eq}$(C-methyl) and 1.2$U_{eq}$(C) for other H atoms.

Hydrogen-bonding interactions were identified and analysed using *PLATON* (Spek, 2009) and finally calculated using the HTAB instruction in *SHELXL* (together with EQIV) (Sheldrick, 2015*b*).

**Table 2**
Experimental details.

| | |
|---|---|
| Crystal data | |
| Chemical formula | $C_6H_{16}N^+\cdot C_{26}H_{17}O_8^-$ |
| $M_r$ | 559.59 |
| Crystal system, space group | Monoclinic, *C*2/*c* |
| Temperature (K) | 170 |
| *a*, *b*, *c* (Å) | 19.408 (4), 13.518 (3), 21.714 (4) |
| $\beta$ (°) | 100.16 (3) |
| *V* (Å$^3$) | 5607 (2) |
| *Z* | 8 |
| Radiation type | Mo *K*$\alpha$ |
| $\mu$ (mm$^{-1}$) | 0.10 |
| Crystal size (mm) | 0.44 × 0.39 × 0.37 |
| | |
| Data collection | |
| Diffractometer | Stoe IPDS2T |
| Absorption correction | Numerical (*X-RED32* and *X-SHAPE*; Stoe & Cie, 2010) |
| $T_{min}$, $T_{max}$ | 0.784, 0.927 |
| No. of measured, independent and observed [$I > 2\sigma(I)$] reflections | 31033, 7726, 4433 |
| $R_{int}$ | 0.054 |
| (sin $\theta/\lambda)_{max}$ (Å$^{-1}$) | 0.695 |
| | |
| Refinement | |
| $R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, *S* | 0.044, 0.122, 0.90 |
| No. of reflections | 7726 |
| No. of parameters | 386 |
| H-atom treatment | H atoms treated by a mixture of independent and constrained refinement |
| $\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å$^{-3}$) | 0.44, −0.27 |

Computer programs: *X-AREA* (Stoe & Cie, 2010), *SHELXT2016* (Sheldrick, 2015*a*), *SHELXL2016* (Sheldrick, 2015*b*), *XP* in *SHELXTL* (Sheldrick, 2008), *CIFTAB* (Sheldrick, 2008) and *Mercury* (Macrae *et al.*, 2006).

## Acknowledgements

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# supporting information

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# Crystal structure of the triethylammonium salt of 3-[(4-hydroxy-3-methoxyphenyl)(4-hydroxy-2-oxo-2*H*-chromen-3-yl)methyl]-2-oxo-2*H*-chromen-4-olate

**Muhammad Ikram, Sadia Rehman, Afzal Khan and Carola Schulzke**

## Computing details

Data collection: *X-AREA* (Stoe & Cie, 2010); cell refinement: *X-AREA* (Stoe & Cie, 2010); data reduction: *X-AREA* (Stoe & Cie, 2010); program(s) used to solve structure: SHELXT2016 (Sheldrick, 2015a); program(s) used to refine structure: *SHELXL2016* (Sheldrick, 2015b); molecular graphics: *XP* in *SHELXTL* (Sheldrick, 2008); software used to prepare material for publication: *CIFTAB* (Sheldrick, 2008) and *Mercury* (Macrae *et al.*, 2006).

## Triethylammonium 3-[(4-hydroxy-3-methoxyphenyl)(4-hydroxy-2-oxo-2*H*-chromen-3-yl)methyl]-2-oxo-2*H*-chromen-4-olate

*Crystal data*

$C_6H_{16}N^+·C_{26}H_{17}O_8^-$
$M_r$ = 559.59
Monoclinic, *C*2/*c*
*a* = 19.408 (4) Å
*b* = 13.518 (3) Å
*c* = 21.714 (4) Å
*β* = 100.16 (3)°
*V* = 5607 (2) Å$^3$
*Z* = 8
*F*(000) = 2368
$D_x$ = 1.326 Mg m$^{-3}$
Mo *Kα* radiation, *λ* = 0.71073 Å
Cell parameters from 31667 reflections
*θ* = 6.3–59.2°
*μ* = 0.10 mm$^{-1}$
*T* = 170 K
Prism, colourless
0.44 × 0.39 × 0.37 mm

*Data collection*

Stoe IPDS2T diffractometer
Radiation source: fine-focus sealed tube
Detector resolution: 6.67 pixels mm$^{-1}$
*ω* scans
Absorption correction: numerical (X-RED32 and X-SHAPE; Stoe & Cie, 2010)
$T_{min}$ = 0.784, $T_{max}$ = 0.927
31033 measured reflections
7726 independent reflections
4433 reflections with $I > 2\sigma(I)$
$R_{int}$ = 0.054
$\theta_{max}$ = 29.6°, $\theta_{min}$ = 3.2°
*h* = −26→26
*k* = −18→18
*l* = −29→30

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.044
$wR(F^2)$ = 0.122
*S* = 0.90
7726 reflections
386 parameters
0 restraints
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0718P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 0.44 e Å$^{-3}$
$\Delta\rho_{min}$ = −0.26 e Å$^{-3}$

*Special details*

**Geometry**. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

*Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å²)*

| | *x* | *y* | *z* | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| O1 | 0.65404 (7) | 0.33340 (8) | 0.59806 (5) | 0.0450 (3) |
| O2 | 0.71609 (6) | 0.37291 (7) | 0.52747 (5) | 0.0351 (2) |
| O3 | 0.72176 (6) | 0.66489 (7) | 0.57698 (5) | 0.0349 (2) |
| O4 | 0.54117 (6) | 0.42562 (8) | 0.68855 (5) | 0.0392 (3) |
| O5 | 0.46745 (5) | 0.54780 (8) | 0.66496 (5) | 0.0413 (3) |
| O6 | 0.61390 (6) | 0.72322 (8) | 0.60507 (5) | 0.0380 (3) |
| O7 | 0.89787 (6) | 0.52052 (8) | 0.78148 (5) | 0.0432 (3) |
| O8 | 0.88267 (5) | 0.69683 (8) | 0.82643 (5) | 0.0382 (3) |
| C1 | 0.65911 (7) | 0.52333 (10) | 0.65646 (6) | 0.0283 (3) |
| H1 | 0.653226 | 0.456518 | 0.674616 | 0.034* |
| C2 | 0.68601 (7) | 0.50216 (10) | 0.59576 (6) | 0.0274 (3) |
| C3 | 0.68308 (8) | 0.40112 (10) | 0.57585 (6) | 0.0307 (3) |
| C4 | 0.75438 (8) | 0.43890 (10) | 0.49954 (7) | 0.0304 (3) |
| C5 | 0.79254 (9) | 0.40104 (12) | 0.45636 (7) | 0.0380 (3) |
| H5 | 0.791402 | 0.332382 | 0.446889 | 0.046* |
| C6 | 0.83190 (9) | 0.46504 (12) | 0.42771 (7) | 0.0397 (4) |
| H6 | 0.859256 | 0.440327 | 0.398885 | 0.048* |
| C7 | 0.83193 (9) | 0.56603 (12) | 0.44068 (7) | 0.0391 (4) |
| H7 | 0.858278 | 0.609993 | 0.419785 | 0.047* |
| C8 | 0.79410 (8) | 0.60231 (11) | 0.48347 (7) | 0.0340 (3) |
| H8 | 0.794209 | 0.671288 | 0.491881 | 0.041* |
| C9 | 0.75550 (7) | 0.53842 (10) | 0.51466 (6) | 0.0282 (3) |
| C10 | 0.71880 (7) | 0.57089 (10) | 0.56401 (6) | 0.0280 (3) |
| C11 | 0.58739 (7) | 0.57065 (11) | 0.64990 (6) | 0.0306 (3) |
| C12 | 0.53443 (8) | 0.51111 (11) | 0.66936 (7) | 0.0334 (3) |
| C13 | 0.45011 (8) | 0.64011 (12) | 0.64179 (7) | 0.0384 (4) |
| C14 | 0.38105 (9) | 0.66885 (15) | 0.63775 (9) | 0.0515 (4) |
| H14 | 0.347869 | 0.626144 | 0.651362 | 0.062* |
| C15 | 0.36156 (10) | 0.76085 (16) | 0.61355 (10) | 0.0577 (5) |
| H15 | 0.314319 | 0.781672 | 0.610423 | 0.069* |
| C16 | 0.40959 (9) | 0.82347 (15) | 0.59370 (9) | 0.0517 (5) |
| H16 | 0.395311 | 0.886758 | 0.577164 | 0.062* |
| C17 | 0.47810 (9) | 0.79387 (12) | 0.59795 (8) | 0.0420 (4) |
| H17 | 0.511084 | 0.836923 | 0.584344 | 0.050* |
| C18 | 0.49943 (8) | 0.70091 (11) | 0.62216 (7) | 0.0352 (3) |
| C19 | 0.57071 (7) | 0.66420 (11) | 0.62576 (7) | 0.0313 (3) |
| C20 | 0.71563 (7) | 0.57348 (10) | 0.70423 (6) | 0.0282 (3) |
| C21 | 0.77965 (8) | 0.52424 (10) | 0.72074 (7) | 0.0315 (3) |
| H21 | 0.785784 | 0.461518 | 0.702725 | 0.038* |

| | | | | |
|---|---|---|---|---|
| C22 | 0.83384 (7) | 0.56465 (11) | 0.76247 (6) | 0.0313 (3) |
| C23 | 0.82595 (7) | 0.65759 (11) | 0.78824 (6) | 0.0303 (3) |
| C24 | 0.76243 (8) | 0.70469 (11) | 0.77388 (7) | 0.0338 (3) |
| H24 | 0.756016 | 0.766884 | 0.792446 | 0.041* |
| C25 | 0.70744 (8) | 0.66260 (11) | 0.73256 (7) | 0.0331 (3) |
| H25 | 0.663662 | 0.695791 | 0.723776 | 0.040* |
| C26 | 0.90262 (10) | 0.41779 (13) | 0.76835 (9) | 0.0543 (5) |
| H26A | 0.865134 | 0.382110 | 0.783783 | 0.081* |
| H26B | 0.948123 | 0.392467 | 0.789170 | 0.081* |
| H26C | 0.897890 | 0.408094 | 0.723074 | 0.081* |
| H3O | 0.6704 (13) | 0.6889 (17) | 0.5951 (11) | 0.085 (7)* |
| H8O | 0.8688 (10) | 0.7456 (14) | 0.8472 (9) | 0.047 (5)* |
| N1 | 0.43844 (8) | 0.30039 (12) | 0.62696 (7) | 0.0470 (4) |
| C27 | 0.44835 (9) | 0.20824 (14) | 0.66564 (9) | 0.0509 (5) |
| H27A | 0.431136 | 0.220287 | 0.705272 | 0.061* |
| H27B | 0.499039 | 0.193640 | 0.676315 | 0.061* |
| C28 | 0.41125 (13) | 0.11883 (15) | 0.63391 (11) | 0.0694 (6) |
| H28A | 0.360606 | 0.130354 | 0.626276 | 0.104* |
| H28B | 0.422180 | 0.060744 | 0.660876 | 0.104* |
| H28C | 0.426885 | 0.107345 | 0.593994 | 0.104* |
| C29 | 0.46749 (11) | 0.28595 (16) | 0.56641 (9) | 0.0583 (5) |
| H29A | 0.512240 | 0.249257 | 0.576127 | 0.070* |
| H29B | 0.434245 | 0.244931 | 0.537270 | 0.070* |
| C30 | 0.47967 (13) | 0.38019 (16) | 0.53470 (9) | 0.0651 (6) |
| H30A | 0.434859 | 0.413819 | 0.520966 | 0.098* |
| H30B | 0.501585 | 0.366045 | 0.498311 | 0.098* |
| H30C | 0.510589 | 0.422827 | 0.563915 | 0.098* |
| C31 | 0.36666 (10) | 0.34013 (16) | 0.61423 (10) | 0.0604 (5) |
| H31A | 0.334931 | 0.289439 | 0.591806 | 0.072* |
| H31B | 0.365407 | 0.398452 | 0.586472 | 0.072* |
| C32 | 0.34037 (11) | 0.3698 (2) | 0.67264 (10) | 0.0723 (7) |
| H32A | 0.331448 | 0.310448 | 0.695904 | 0.108* |
| H32B | 0.296877 | 0.407609 | 0.661328 | 0.108* |
| H32C | 0.375635 | 0.410813 | 0.698784 | 0.108* |
| H1N | 0.4677 (11) | 0.3515 (15) | 0.6501 (10) | 0.064 (6)* |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| O1 | 0.0646 (8) | 0.0275 (5) | 0.0459 (6) | −0.0090 (5) | 0.0180 (6) | 0.0021 (5) |
| O2 | 0.0467 (6) | 0.0250 (5) | 0.0350 (5) | −0.0026 (4) | 0.0105 (5) | −0.0019 (4) |
| O3 | 0.0372 (6) | 0.0243 (5) | 0.0460 (6) | −0.0043 (4) | 0.0146 (5) | −0.0036 (4) |
| O4 | 0.0366 (6) | 0.0435 (6) | 0.0367 (5) | −0.0117 (5) | 0.0039 (4) | 0.0044 (5) |
| O5 | 0.0263 (5) | 0.0525 (7) | 0.0458 (6) | −0.0047 (5) | 0.0080 (5) | 0.0017 (5) |
| O6 | 0.0306 (6) | 0.0333 (5) | 0.0511 (6) | 0.0003 (4) | 0.0094 (5) | 0.0053 (5) |
| O7 | 0.0334 (6) | 0.0446 (6) | 0.0470 (6) | 0.0127 (5) | −0.0056 (5) | −0.0110 (5) |
| O8 | 0.0284 (6) | 0.0417 (6) | 0.0427 (6) | −0.0011 (5) | 0.0011 (5) | −0.0143 (5) |
| C1 | 0.0270 (7) | 0.0281 (7) | 0.0295 (7) | −0.0029 (5) | 0.0042 (5) | 0.0015 (5) |

| | | | | | | |
|---|---|---|---|---|---|---|
| C2 | 0.0250 (7) | 0.0277 (6) | 0.0282 (6) | −0.0012 (5) | 0.0012 (5) | 0.0000 (5) |
| C3 | 0.0330 (8) | 0.0278 (7) | 0.0300 (7) | −0.0009 (6) | 0.0023 (6) | 0.0018 (5) |
| C4 | 0.0316 (7) | 0.0284 (7) | 0.0299 (7) | −0.0019 (6) | 0.0021 (6) | 0.0012 (5) |
| C5 | 0.0440 (9) | 0.0333 (8) | 0.0368 (8) | 0.0032 (7) | 0.0074 (7) | −0.0039 (6) |
| C6 | 0.0410 (9) | 0.0470 (9) | 0.0326 (8) | 0.0028 (7) | 0.0104 (7) | −0.0022 (6) |
| C7 | 0.0401 (9) | 0.0413 (9) | 0.0373 (8) | −0.0039 (7) | 0.0105 (7) | 0.0012 (6) |
| C8 | 0.0344 (8) | 0.0315 (7) | 0.0362 (7) | −0.0028 (6) | 0.0068 (6) | 0.0004 (6) |
| C9 | 0.0266 (7) | 0.0275 (6) | 0.0289 (7) | −0.0003 (5) | 0.0002 (5) | 0.0008 (5) |
| C10 | 0.0255 (7) | 0.0258 (6) | 0.0311 (7) | −0.0009 (5) | 0.0008 (5) | −0.0003 (5) |
| C11 | 0.0256 (7) | 0.0362 (7) | 0.0292 (7) | −0.0039 (6) | 0.0031 (5) | −0.0028 (6) |
| C12 | 0.0283 (7) | 0.0427 (8) | 0.0284 (7) | −0.0058 (6) | 0.0031 (6) | −0.0041 (6) |
| C13 | 0.0278 (8) | 0.0513 (9) | 0.0352 (8) | −0.0002 (7) | 0.0032 (6) | −0.0065 (7) |
| C14 | 0.0292 (8) | 0.0706 (12) | 0.0546 (10) | 0.0016 (8) | 0.0072 (7) | −0.0067 (9) |
| C15 | 0.0303 (9) | 0.0755 (13) | 0.0647 (12) | 0.0120 (9) | 0.0010 (8) | −0.0129 (10) |
| C16 | 0.0396 (10) | 0.0584 (11) | 0.0526 (10) | 0.0135 (9) | −0.0045 (8) | −0.0088 (8) |
| C17 | 0.0366 (9) | 0.0457 (9) | 0.0414 (8) | 0.0059 (7) | 0.0003 (7) | −0.0054 (7) |
| C18 | 0.0285 (8) | 0.0433 (8) | 0.0318 (7) | 0.0017 (6) | −0.0001 (6) | −0.0067 (6) |
| C19 | 0.0271 (7) | 0.0347 (7) | 0.0313 (7) | −0.0037 (6) | 0.0032 (6) | −0.0034 (6) |
| C20 | 0.0268 (7) | 0.0301 (7) | 0.0280 (6) | −0.0018 (6) | 0.0055 (5) | 0.0003 (5) |
| C21 | 0.0345 (8) | 0.0289 (7) | 0.0302 (7) | 0.0038 (6) | 0.0028 (6) | −0.0027 (5) |
| C22 | 0.0266 (7) | 0.0355 (7) | 0.0307 (7) | 0.0043 (6) | 0.0023 (5) | −0.0012 (6) |
| C23 | 0.0260 (7) | 0.0351 (7) | 0.0288 (7) | −0.0037 (6) | 0.0025 (5) | −0.0033 (6) |
| C24 | 0.0315 (8) | 0.0311 (7) | 0.0385 (8) | 0.0007 (6) | 0.0056 (6) | −0.0081 (6) |
| C25 | 0.0261 (7) | 0.0340 (7) | 0.0384 (8) | 0.0030 (6) | 0.0037 (6) | −0.0033 (6) |
| C26 | 0.0536 (11) | 0.0461 (10) | 0.0575 (11) | 0.0231 (9) | −0.0055 (9) | −0.0063 (8) |
| N1 | 0.0418 (8) | 0.0546 (8) | 0.0391 (7) | −0.0160 (7) | −0.0081 (6) | 0.0083 (6) |
| C27 | 0.0362 (9) | 0.0638 (12) | 0.0495 (10) | −0.0042 (8) | −0.0010 (8) | 0.0164 (9) |
| C28 | 0.0777 (15) | 0.0541 (12) | 0.0745 (14) | −0.0127 (11) | 0.0082 (12) | 0.0119 (10) |
| C29 | 0.0603 (12) | 0.0710 (13) | 0.0402 (9) | −0.0151 (10) | −0.0002 (8) | −0.0013 (9) |
| C30 | 0.0820 (15) | 0.0759 (14) | 0.0356 (9) | −0.0231 (12) | 0.0051 (9) | 0.0010 (9) |
| C31 | 0.0511 (11) | 0.0590 (12) | 0.0622 (12) | −0.0008 (9) | −0.0145 (9) | 0.0007 (10) |
| C32 | 0.0476 (12) | 0.1114 (19) | 0.0579 (12) | −0.0237 (12) | 0.0092 (10) | 0.0128 (12) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| O1—C3 | 1.2183 (17) | C16—C17 | 1.376 (2) |
| O2—C4 | 1.3692 (17) | C16—H16 | 0.9500 |
| O2—C3 | 1.3773 (18) | C17—C18 | 1.396 (2) |
| O3—C10 | 1.3005 (16) | C17—H17 | 0.9500 |
| O3—H3O | 1.18 (3) | C18—C19 | 1.459 (2) |
| O4—C12 | 1.2275 (18) | C20—C25 | 1.375 (2) |
| O5—C13 | 1.365 (2) | C20—C21 | 1.399 (2) |
| O5—C12 | 1.3789 (18) | C21—C22 | 1.375 (2) |
| O6—C19 | 1.2939 (17) | C21—H21 | 0.9500 |
| O6—H3O | 1.24 (3) | C22—C23 | 1.395 (2) |
| O7—C22 | 1.3745 (17) | C23—C24 | 1.374 (2) |
| O7—C26 | 1.424 (2) | C24—C25 | 1.389 (2) |
| O8—C23 | 1.3634 (17) | C24—H24 | 0.9500 |

| | | | |
|---|---|---|---|
| O8—H8O | 0.869 (19) | C25—H25 | 0.9500 |
| C1—C11 | 1.516 (2) | C26—H26A | 0.9800 |
| C1—C2 | 1.5277 (19) | C26—H26B | 0.9800 |
| C1—C20 | 1.5287 (19) | C26—H26C | 0.9800 |
| C1—H1 | 1.0000 | N1—C31 | 1.473 (2) |
| C2—C10 | 1.3779 (19) | N1—C27 | 1.496 (2) |
| C2—C3 | 1.4307 (19) | N1—C29 | 1.532 (3) |
| C4—C9 | 1.384 (2) | N1—H1N | 0.98 (2) |
| C4—C5 | 1.391 (2) | C27—C28 | 1.510 (3) |
| C5—C6 | 1.374 (2) | C27—H27A | 0.9900 |
| C5—H5 | 0.9500 | C27—H27B | 0.9900 |
| C6—C7 | 1.394 (2) | C28—H28A | 0.9800 |
| C6—H6 | 0.9500 | C28—H28B | 0.9800 |
| C7—C8 | 1.372 (2) | C28—H28C | 0.9800 |
| C7—H7 | 0.9500 | C29—C30 | 1.487 (3) |
| C8—C9 | 1.395 (2) | C29—H29A | 0.9900 |
| C8—H8 | 0.9500 | C29—H29B | 0.9900 |
| C9—C10 | 1.455 (2) | C30—H30A | 0.9800 |
| C11—C19 | 1.385 (2) | C30—H30B | 0.9800 |
| C11—C12 | 1.427 (2) | C30—H30C | 0.9800 |
| C13—C14 | 1.383 (2) | C31—C32 | 1.503 (3) |
| C13—C18 | 1.385 (2) | C31—H31A | 0.9900 |
| C14—C15 | 1.377 (3) | C31—H31B | 0.9900 |
| C14—H14 | 0.9500 | C32—H32A | 0.9800 |
| C15—C16 | 1.383 (3) | C32—H32B | 0.9800 |
| C15—H15 | 0.9500 | C32—H32C | 0.9800 |

| | | | |
|---|---|---|---|
| C4—O2—C3 | 121.30 (11) | C25—C20—C21 | 118.02 (13) |
| C10—O3—H3O | 109.5 (11) | C25—C20—C1 | 124.51 (13) |
| C13—O5—C12 | 121.49 (12) | C21—C20—C1 | 117.47 (12) |
| C19—O6—H3O | 118.4 (11) | C22—C21—C20 | 121.43 (13) |
| C22—O7—C26 | 116.76 (13) | C22—C21—H21 | 119.3 |
| C23—O8—H8O | 108.6 (12) | C20—C21—H21 | 119.3 |
| C11—C1—C2 | 116.48 (12) | O7—C22—C21 | 124.85 (13) |
| C11—C1—C20 | 114.44 (12) | O7—C22—C23 | 115.34 (12) |
| C2—C1—C20 | 110.79 (11) | C21—C22—C23 | 119.80 (13) |
| C11—C1—H1 | 104.5 | O8—C23—C24 | 123.63 (13) |
| C2—C1—H1 | 104.5 | O8—C23—C22 | 117.41 (13) |
| C20—C1—H1 | 104.5 | C24—C23—C22 | 118.96 (13) |
| C10—C2—C3 | 119.32 (13) | C23—C24—C25 | 120.88 (13) |
| C10—C2—C1 | 124.31 (12) | C23—C24—H24 | 119.6 |
| C3—C2—C1 | 115.99 (12) | C25—C24—H24 | 119.6 |
| O1—C3—O2 | 113.83 (12) | C20—C25—C24 | 120.78 (13) |
| O1—C3—C2 | 126.45 (14) | C20—C25—H25 | 119.6 |
| O2—C3—C2 | 119.72 (12) | C24—C25—H25 | 119.6 |
| O2—C4—C9 | 121.00 (13) | O7—C26—H26A | 109.5 |
| O2—C4—C5 | 117.01 (12) | O7—C26—H26B | 109.5 |
| C9—C4—C5 | 121.98 (14) | H26A—C26—H26B | 109.5 |

| | | | |
|---|---|---|---|
| C6—C5—C4 | 118.58 (14) | O7—C26—H26C | 109.5 |
| C6—C5—H5 | 120.7 | H26A—C26—H26C | 109.5 |
| C4—C5—H5 | 120.7 | H26B—C26—H26C | 109.5 |
| C5—C6—C7 | 120.38 (15) | C31—N1—C27 | 115.64 (15) |
| C5—C6—H6 | 119.8 | C31—N1—C29 | 111.38 (15) |
| C7—C6—H6 | 119.8 | C27—N1—C29 | 110.21 (15) |
| C8—C7—C6 | 120.37 (15) | C31—N1—H1N | 106.5 (12) |
| C8—C7—H7 | 119.8 | C27—N1—H1N | 107.2 (12) |
| C6—C7—H7 | 119.8 | C29—N1—H1N | 105.2 (12) |
| C7—C8—C9 | 120.32 (14) | N1—C27—C28 | 114.01 (15) |
| C7—C8—H8 | 119.8 | N1—C27—H27A | 108.8 |
| C9—C8—H8 | 119.8 | C28—C27—H27A | 108.8 |
| C4—C9—C8 | 118.30 (14) | N1—C27—H27B | 108.8 |
| C4—C9—C10 | 118.59 (13) | C28—C27—H27B | 108.8 |
| C8—C9—C10 | 123.06 (13) | H27A—C27—H27B | 107.6 |
| O3—C10—C2 | 123.86 (13) | C27—C28—H28A | 109.5 |
| O3—C10—C9 | 116.45 (12) | C27—C28—H28B | 109.5 |
| C2—C10—C9 | 119.63 (12) | H28A—C28—H28B | 109.5 |
| C19—C11—C12 | 119.64 (13) | C27—C28—H28C | 109.5 |
| C19—C11—C1 | 124.77 (13) | H28A—C28—H28C | 109.5 |
| C12—C11—C1 | 115.57 (13) | H28B—C28—H28C | 109.5 |
| O4—C12—O5 | 113.87 (13) | C30—C29—N1 | 113.64 (17) |
| O4—C12—C11 | 126.33 (14) | C30—C29—H29A | 108.8 |
| O5—C12—C11 | 119.74 (13) | N1—C29—H29A | 108.8 |
| O5—C13—C14 | 116.94 (15) | C30—C29—H29B | 108.8 |
| O5—C13—C18 | 121.14 (14) | N1—C29—H29B | 108.8 |
| C14—C13—C18 | 121.90 (16) | H29A—C29—H29B | 107.7 |
| C15—C14—C13 | 118.40 (18) | C29—C30—H30A | 109.5 |
| C15—C14—H14 | 120.8 | C29—C30—H30B | 109.5 |
| C13—C14—H14 | 120.8 | H30A—C30—H30B | 109.5 |
| C14—C15—C16 | 121.12 (17) | C29—C30—H30C | 109.5 |
| C14—C15—H15 | 119.4 | H30A—C30—H30C | 109.5 |
| C16—C15—H15 | 119.4 | H30B—C30—H30C | 109.5 |
| C17—C16—C15 | 119.84 (18) | N1—C31—C32 | 112.94 (17) |
| C17—C16—H16 | 120.1 | N1—C31—H31A | 109.0 |
| C15—C16—H16 | 120.1 | C32—C31—H31A | 109.0 |
| C16—C17—C18 | 120.38 (18) | N1—C31—H31B | 109.0 |
| C16—C17—H17 | 119.8 | C32—C31—H31B | 109.0 |
| C18—C17—H17 | 119.8 | H31A—C31—H31B | 107.8 |
| C13—C18—C17 | 118.36 (15) | C31—C32—H32A | 109.5 |
| C13—C18—C19 | 118.82 (14) | C31—C32—H32B | 109.5 |
| C17—C18—C19 | 122.80 (15) | H32A—C32—H32B | 109.5 |
| O6—C19—C11 | 124.88 (13) | C31—C32—H32C | 109.5 |
| O6—C19—C18 | 115.97 (13) | H32A—C32—H32C | 109.5 |
| C11—C19—C18 | 119.14 (13) | H32B—C32—H32C | 109.5 |

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O3—H3*O*···O6 | 1.18 (3) | 1.24 (3) | 2.4139 (15) | 169 (2) |
| O8—H8*O*···O1$^{i}$ | 0.869 (19) | 1.789 (19) | 2.6488 (16) | 170.0 (18) |
| C27—H27*B*···O8$^{ii}$ | 0.99 | 2.31 | 3.257 (2) | 161 |
| N1—H1*N*···O4 | 0.98 (2) | 1.82 (2) | 2.7727 (19) | 164.5 (18) |

Symmetry codes: (i) −*x*+3/2, *y*+1/2, −*z*+3/2; (ii) −*x*+3/2, *y*−1/2, −*z*+3/2.