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3-Acetylanilinium bromide, nitrate and dihydrogen phosphate: hydrogen-bonding motifs in one, two and three dimensions

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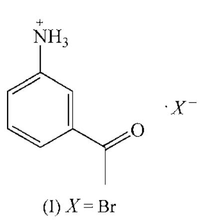
In the title compounds, namely 3-acetylanilinium bromide, $C_8H_{10}NO^+ \cdot Br^-$, (I), 3-acetylanilinium nitrate, $C_8H_{10}NO^+ \cdot NO_3^-$, (II), and 3-acetylanilinium dihydrogen phosphate, $C_8H_{10}NO^+ \cdot H_2PO_4^-$, (III), each asymmetric unit contains a discrete cation, with a protonated amino group, and an anion. In the crystal structure of (I), the ions are connected *via* N—H···Br and N—H···O hydrogen bonds into a chain of spiro-fused $R_2^2(14)$ and $R_4^2(8)$ rings. In compound (II), the non-H atoms of the cation all lie on a mirror plane in the space group *Pnma*, while the nitrate ion lies across a mirror plane. The crystal structures of compounds (II) and (III) are characterized by hydrogen-bonded networks in two and three dimensions, respectively. The ions in (II) are connected *via* N—H···O hydrogen bonds, with three characteristic graph-set motifs, *viz.* $C_2^2(6)$, $R_1^2(4)$ and $R_6^4(14)$. The ions in (III) are connected *via* N—H···O and O—H···O hydrogen bonds, with five characteristic graph-set motifs, *viz.* *D*, *C*(4), $C_2^1(4)$, $R_3^3(10)$ and $R_4^4(12)$. The significance of this study lies in its illustration of the differences between the supramolecular aggregations in the bromide, nitrate and dihydrogen phosphate salts of a small organic molecule. The different geometry of the counter-ions and their different potential for hydrogen-bond formation result in markedly different hydrogen-bonding arrangements.

Comment

The formation of multicomponent ionic crystals, or salts, is of fundamental importance to the development of most active pharmaceutical ingredients (APIs), where the approach is used for both purification and physical property optimization. There is a wide range of acids and bases, with a range of pK_a values, solubilities, molecular weights, geometry and other properties, used for salt formation to increase or decrease solubility, to improve stability or toxicity and to reduce hygroscopicity of APIs (Gould, 1986; Stahl & Wermuth, 2002). The ten most frequently occurring counter-ions of salts of small organic molecules in the Cambridge Structural Database (CSD, Version 5.25; Allen 2002), in order of decreasing occurrence, are chloride, bromide, nitrate, ammonium, sulfate, tosylate, dihydrogen phosphate, tartrate, ethylenediammonium (di-ion) and maleate (mono-ion) (Haynes *et al.*, 2005). Most of these counter-ions are in the pharmaceutical 'Top Ten' list. The aim of this study lies in its illustration of the differences between the supramolecular aggregations in the bromide, nitrate and dihydrogen phosphate salts of a small organic molecule. The different geometry of the counter-ions and their different potential for hydrogen-bond formation result in markedly different hydrogen-bonding arrangements of the ions in the crystal structures.

The title compounds, namely 3-acetylanilinium bromide, (I), 3-acetylanilinium nitrate, (II) and 3-acetylanilinium dihydrogen phosphate, (III), were originally investigated during salt screening of aromatic monoamines and represent part of our research into hydrogen-bonded ionic crystals of acid salts (Cinčić & Kaitner, 2008*a*,*b*). 3-Aminoacetophenone has been much less studied than similar organic molecules, such as 3- and 4-aminobenzoic acid or 4-aminoacetophenone. There are no entries in the CSD for any 3-acetylanilinium salt.



(I) X = Br
(II) X = NO_3
(III) X = H_2PO_4

In compounds (I)–(III), the bond lengths and angles are all normal for their types (Allen *et al.*, 1987). The asymmetric unit of each compound contains an anion and a discrete cation with a protonated amino group (Figs. 1–3).

In (I), the ions are connected *via* N—H···Br and N—H···O hydrogen bonds (Table 1) into one-dimensional hydrogen-bonded chains which run parallel to the [1$\bar{1}$1] direction. All

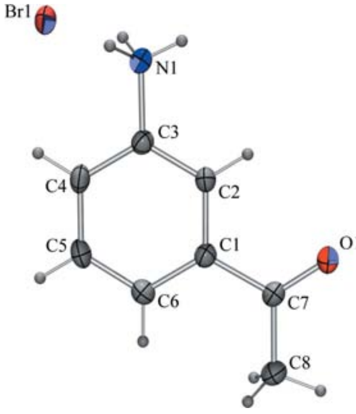


Figure 1
The asymmetric unit of (I), showing the crystallographic numbering scheme. Displacement ellipsoids are drawn at the 50% probability level and H atoms are shown as small spheres of arbitrary radii.

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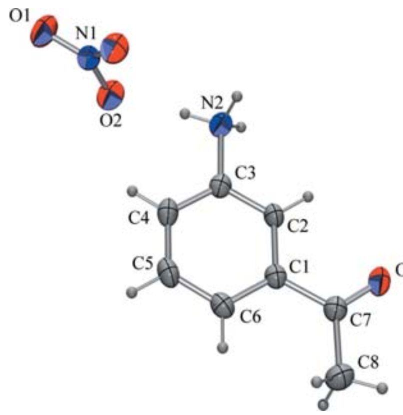


Figure 2
The asymmetric unit of (II), showing the crystallographic numbering scheme. Displacement ellipsoids are drawn at the 30% probability level and H atoms are shown as small spheres of arbitrary radii. Only one set of disordered methyl and ammonium H atoms is shown.

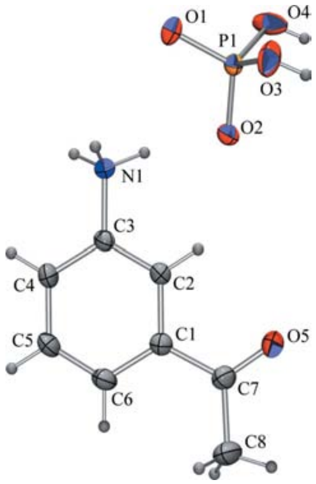


Figure 3
The asymmetric unit of (III), showing the crystallographic numbering scheme. Displacement ellipsoids are drawn at the 30% probability level and H atoms are shown as small spheres of arbitrary radii.

ammonium H atoms are involved in hydrogen bonds with two different Br^- ions and with the carbonyl O atom of a neighbouring cation, while each anion accepts two hydrogen bonds. The centrosymmetric hydrogen-bonded rings formed by adjacent 3-acetylanilinium cations and two Br^- anions can be described by the graph-set motif $R_4^2(8)$ (Bernstein *et al.*, 1995). The carbonyl O atom participates in hydrogen bonding with a neighbouring cation through an N—H···O hydrogen bond. This interaction links cations into another centrosymmetric hydrogen-bonded ring which can be described by the graph-set motif $R_2^2(14)$. The aggregation of two ring motifs results in an overall one-dimensional hydrogen-bonded chain structure along the $[1\bar{1}1]$ direction (Fig. 4).

The supramolecular structure of (II) differs markedly from that of (I). Atoms C7, C8 and O3 are coplanar with the benzene ring and, together with atoms N1 and O1, lie on a mirror plane of symmetry where the two O atoms of the anion are crystallographically equivalent. The H atoms of the methyl and ammonium groups display symmetry-induced disorder over two sets of positions. The ions are connected *via* N—H···O hydrogen bonds (Table 2) into a two-dimensional hydrogen-bonded network parallel to the (100) plane. As in (I), all ammonium H atoms are involved in hydrogen bonds, but this time with three different nitrate ions, while each anion accepts four hydrogen bonds. Only two O atoms of the anion are involved in strong hydrogen bonds, while the third does not participate in any strong interaction. The anions and cations are connected *via* a three-centred hydrogen bond into a ring which can be described by the graph-set motif $R_1^2(4)$ (Fig. 5). Another ammonium–anion interaction links the anions and cations in an alternating fashion into extended chains along the [010] direction which can be described by the graph-set motif $C_2^2(6)$ (Fig. 5). There are no centrosymmetric hydrogen-bonded dimers of adjacent 3-acetylanilinium cations, as in (I). Also, the carbonyl O atom does not participate in any strong intermolecular interaction. The noncen-

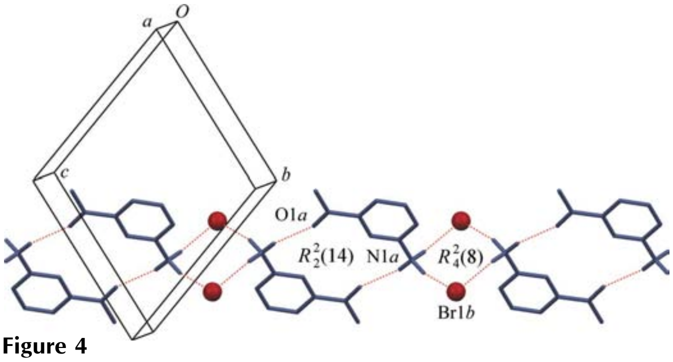


Figure 4
A view of the one-dimensional hydrogen-bonded chain of (I), showing the aggregation of two hydrogen-bonding motifs, *viz.* $R_2^2(14)$ and $R_4^2(8)$. Hydrogen bonds are drawn as dotted lines and C-bound H atoms have been omitted. Atoms marked with the suffixes *a* and *b* are at the symmetry positions ($x - 1$, $y + 1$, $z - 1$) and ($-x - 1$, $-y + 3$, $-z$), respectively.

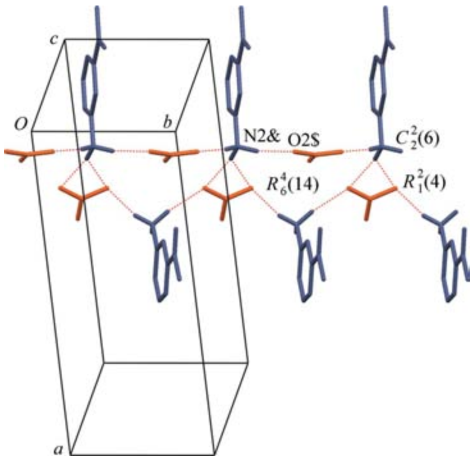


Figure 5
A view of part of the crystal structure of (II), showing the aggregation of three hydrogen-bonding motifs, *viz.* $C_2^2(6)$, $R_1^2(4)$ and $R_6^4(14)$. Hydrogen bonds are drawn as dotted lines. Atoms marked with an ampersand (&) or a dollar sign ($) are at the symmetry positions (x, $y + 1$, z) and ($-x + \frac{1}{2}$, $y + \frac{3}{2}$, $z + \frac{1}{2}$), respectively. One set of disordered ammonium H atoms and C-bound H atoms have been omitted.

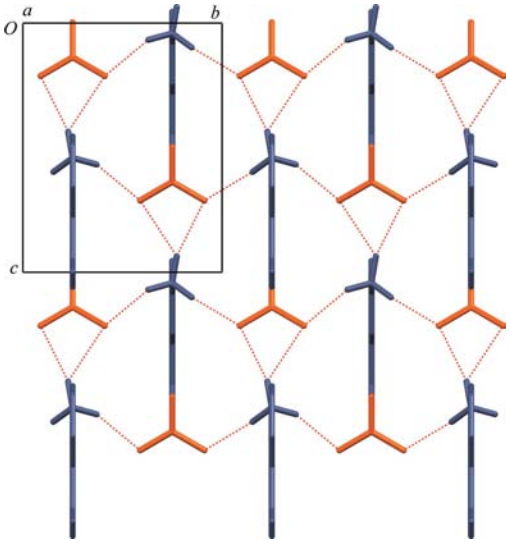


Figure 6
A view of the two-dimensional hydrogen-bonded network of (II) parallel to the (100) plane. Hydrogen bonds are drawn as dotted lines. One set of disordered ammonium H atoms and C-bound H atoms has been omitted.

trosymmetric hydrogen-bonded ring formed by three adjacent 3-acetylanilinium cations and three nitrate anions can be described by the graph-set motif $R_6^4(14)$ (Fig. 5). The aggregation of ring and chain motifs results in an overall two-dimensional hydrogen-bonded sheet-like structure (Fig. 6). Adjacent sheets are stacked in the [100] direction to give a three-dimensional framework, where the interplanar distance between the aromatic rings of each sheet is *ca* 3.30 Å.

In (III), the ions are connected into a three-dimensional hydrogen-bonded network *via* N—H···O and O—H···O hydrogen bonds (Table 3). All ammonium H atoms are involved in hydrogen bonds with three $H_2PO_4^-$ ions, while each anion accepts six hydrogen bonds. Similar to (II), the two ammonium–anion interactions link the anions and cations in an alternating fashion into extended chains along the [100] direction which can be described by the graph-set motif $C_2^1(4)$ (Fig. 7). The anions themselves are linked *via* an O—H···O interaction into chains, also along the [100] direction, which can be described by the graph-set motif $C(4)$. The combination of these two chain motifs generates noncentrosymmetric fused rings which can be described by the graph-set motif $R_3^3(10)$ (Fig. 7). The centrosymmetric hydrogen-bonded ring formed by two adjacent 3-acetylanilinium cations and two $H_2PO_4^-$ anions can be described by the graph-set motif $R_4^4(12)$ (Fig. 8).

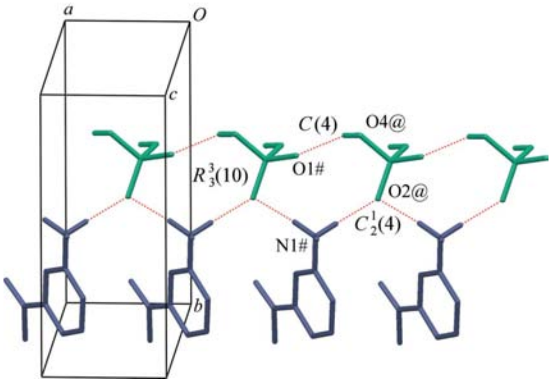


Figure 7
A view of part of the crystal structure of (III), showing the aggregation of three hydrogen-bonding motifs, *viz.* $C(4)$, $C_2^1(4)$ and $R_3^3(10)$. Hydrogen bonds are drawn as dotted lines and C-bound H atoms have been omitted. Atoms marked with a hash (#) or an 'at' symbol (@) are at the symmetry positions ($x - 1$, y, z) and ($x - 2$, y, z), respectively.

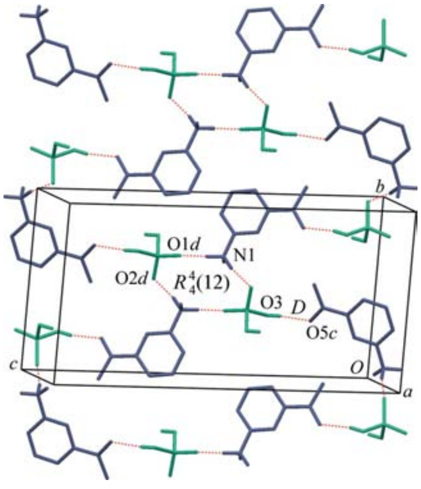
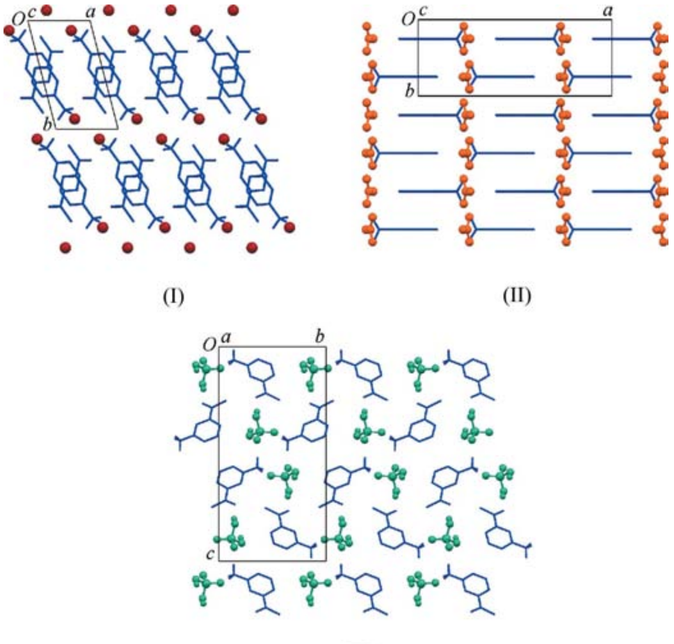


Figure 8
A view of part of the crystal structure of (III), showing a sheet parallel to (100). Hydrogen bonds are drawn as dotted lines and C-bound H atoms have been omitted. Atoms marked with the suffixes *c* and *d* are at the symmetry positions ($-x + 1$, $y - \frac{1}{2}$, $-z + \frac{1}{2}$) and ($-x$, $-y + 1$, $-z + 1$), respectively.



(I)

(II)

(III)

Figure 9
Packing diagrams for compounds (I), (II) and (III), viewed along the *c* axes for (I) and (II) and along the *a* axis for (III). The anions are shown as ball-and-stick models and C-bound H atoms have been omitted.

The carbonyl O atom of the cation participates in a finite hydrogen-bonding motif, *D*, with a neighbouring anion through an O—H$\cdots$O hydrogen bond. The combination of this finite motif and the $R_4^4(12)$ motif generates a sheet parallel to (100) (Fig. 8). The aggregation of all these ring and chain motifs results in an overall three-dimensional hydrogen-bonded framework.

Fig. 9 compares the packing arrangements of (I)–(III). The crystal packings of all three compounds are characterized by layers of 3-acetylanilinium cations which are embedded between ionic layers of anions, forming an alternating hydrocarbon–ionic layer structure. No intermolecular π–π interactions are evident in the hydrocarbon layer in any of the crystal structures. The shortest centroid-to-centroid distances between adjacent cations in (I), (II) and (III) are *ca* 4.65, 4.00 and 4.67 Å, respectively.

Experimental

For the preparation of (I), 3-aminoacetophenone (100 mg, 0.74 mmol) was dissolved in a hot mixture of ethanol and propan-2-ol (3 ml, 2:1 *v*/*v*). The resulting clear solution was added to aqueous hydrobromic acid (2 ml, 2 *M*) and cooled to room temperature, and colourless crystals were grown by slow evaporation. For the preparation of (II), 3-aminoacetophenone (100 mg, 0.74 mmol) was dissolved in hot ethanol (2 ml). The clear solution was added to aqueous nitric acid (1 ml, 2 *M*) and cooled to room temperature, and colourless crystals of (II) were grown by slow evaporation. For the preparation of (III), 3-aminoacetophenone (100 mg, 0,74 mmol) was dissolved in a hot mixture of ethanol and propan-2-ol (3 ml, 2:1 *v*/*v*). The clear solution was added to aqueous phosphoric acid (2 ml, 2 *M*) and cooled to room temperature, and colourless crystals of (III) were grown by slow evaporation. Crystals of (I)–(III) were collected by vacuum filtration, washed with cold acetone and dried in air. Under a nitrogen atmosphere, compounds (I), (II) and (III) melt at 459, 425 and 447 K, respectively.

Compound (I)

Crystal data

$C_8H_{10}NO^+\cdot Br^-$
$M_r = 216.08$
Triclinic, $P\overline{1}$
$a = 5.0530$ (4) Å
$b = 9.4145$ (9) Å
$c = 9.5169$ (9) Å
$\alpha = 75.239$ (8)°
$\beta = 89.253$ (9)°
$\gamma = 75.757$ (10)°
$V = 423.74$ (7) Å^3
$Z = 2$
Mo $K\alpha$ radiation
$\mu = 4.79$ mm^{-1}
$T = 295$ K
0.47 × 0.36 × 0.10 mm

Data collection

Oxford Diffraction Xcalibur CCD diffractometer
Absorption correction: analytical (Alcock, 1970)
$T_{\min} = 0.155$, $T_{\max} = 0.631$
5468 measured reflections
1809 independent reflections
1668 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.011$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.018$
$wR(F^2) = 0.049$
$S = 1.12$
1809 reflections
114 parameters
H atoms treated by a mixture of independent and constrained refinement
$\Delta\rho_{\max} = 0.33$ e Å^{-3}
$\Delta\rho_{\min} = -0.40$ e Å^{-3}

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

D—H$\cdots A$	D—H	H$\cdots A$	$D\cdots A$	D—H$\cdots A$
N1—H1*B*$\cdots$Br1	0.94 (3)	2.45 (3)	3.322 (2)	156 (2)
N1—H1*C*$\cdots$O1$^{\rm i}$	0.86 (3)	2.17 (3)	2.974 (2)	157 (2)
N1—H1*A*$\cdots$Br1$^{\rm ii}$	0.94 (3)	2.38 (2)	3.284 (1)	163 (2)

Symmetry codes: (i) $-x+1, -y+1, -z+2$; (ii) $-x, -y+2, -z+1$.

Table 2
Hydrogen-bond geometry (Å, °) for (II).

D—H$\cdots A$	D—H	H$\cdots A$	$D\cdots A$	D—H$\cdots A$
N2—H2*A*$\cdots$O2	0.89	2.26	2.979 (2)	137
N2—H2*A*$\cdots$O2$^{\rm i}$	0.89	2.12	2.979 (2)	163
N2—H2*B*$\cdots$O2$^{\rm ii}$	0.89	2.02	2.857 (2)	157
N2—H2*C*$\cdots$O2$^{\rm iii}$	0.89	1.97	2.857 (2)	172

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

Compound (II)

Crystal data

$C_8H_{10}NO^+\cdot NO_3^-$
$M_r = 198.18$
Orthorhombic, *Pnma*
$a = 16.7754$ (4) Å
$b = 6.6044$ (2) Å
$c = 8.2683$ (2) Å
$V = 916.06$ (4) Å^3
$Z = 4$
Mo $K\alpha$ radiation
$\mu = 0.12$ mm^{-1}
$T = 295$ K
0.31 × 0.26 × 0.13 mm

Data collection

Oxford Diffraction Xcalibur CCD diffractometer
Absorption correction: analytical (Alcock, 1970)
$T_{\min} = 0.968$, $T_{\max} = 0.987$
9987 measured reflections
1086 independent reflections
824 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.020$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.042$
$wR(F^2) = 0.129$
$S = 1.12$
1086 reflections
85 parameters
H-atom parameters constrained
$\Delta\rho_{\max} = 0.22$ e Å^{-3}
$\Delta\rho_{\min} = -0.16$ e Å^{-3}

Compound (III)

Crystal data

$C_8H_{10}NO^+\cdot H_2O_4P^-$
$M_r = 233.16$
Monoclinic, $P2_1/c$
$a = 4.6733$ (2) Å
$b = 10.5962$ (4) Å
$c = 21.1801$ (9) Å
$\beta = 93.631$ (3)°
$V = 1046.72$ (7) Å^3
$Z = 4$
Mo $K\alpha$ radiation
$\mu = 0.26$ mm^{-1}
$T = 295$ K
0.52 × 0.08 × 0.07 mm

Data collection

Oxford Diffraction Xcalibur CCD diffractometer
Absorption correction: analytical (Alcock, 1970)
$T_{\min} = 0.879$, $T_{\max} = 0.986$
10065 measured reflections
2270 independent reflections
1593 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.028$

Refinement

$R[F^2 > 2\sigma(F^2)] = 0.047$
$wR(F^2) = 0.150$
$S = 1.16$
2270 reflections
141 parameters
H-atom parameters constrained
$\Delta\rho_{\max} = 0.48$ e Å^{-3}
$\Delta\rho_{\min} = -0.38$ e Å^{-3}

Table 3
Hydrogen-bond geometry (Å, °) for (III).

D—H···A	D—H	H···A	D···A	D—H···A
N1—H1C···O2	0.96	1.93	2.878 (3)	170
N1—H1A···O1$^{\rm i}$	0.96	1.76	2.707 (3)	168
N1—H1B···O2$^{\rm ii}$	0.91	1.85	2.746 (3)	169
O3—H3A···O5$^{\rm iii}$	0.82	1.86	2.665 (3)	165
O4—H4A···O1$^{\rm iv}$	0.82	2.05	2.504 (3)	115

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

For (I) and (III), N-bound H atoms were located in difference Fourier maps. For (I), the positions and isotropic displacement parameters of N-bound H atoms were refined [N—H = 0.86 (3)–0.94 (3) Å]. The N-bound H atoms in (III) were fixed in their as-found positions (N—H = 0.91–0.96 Å). The H atoms of the methyl and ammonium groups in (II) display symmetry-induced disorder and were each modelled using two sets of half-occupancy H atoms. The N—H distance and C—N—H angles for N-bound H atoms were fixed, but the group was allowed to rotate around the C—N bound, with N—H = 0.89 Å and $U_{\rm iso}$(H) = $1.5U_{\rm eq}$(N). For (III), hydroxyl H atoms were placed in calculated positions and treated as riding on their parent O atoms, with O—H = 0.82 Å and $U_{\rm iso}$(H) = $1.5U_{\rm eq}$(O). Aromatic H atoms were placed in calculated positions and treated as riding on their parent C atoms [C—H = 0.93 Å and $U_{\rm iso}$(H) = $1.2U_{\rm eq}$(C)]. For all three compounds, the C—H distances and C—C—H angles for the methyl H atoms were fixed, but the group was allowed to rotate around the C—C bound, with C—H = 0.96 Å and $U_{\rm iso}$(H) = $1.5U_{\rm eq}$(C).

For all three compounds, data collection: *CrysAlis CCD* (Oxford Diffraction, 2003); cell refinement: *CrysAlis RED* (Oxford Diffraction, 2003); data reduction: *CrysAlis RED*; program(s) used to solve structure: *SHELXS97* (Sheldrick, 2008); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *ORTEP-3* (Farrugia, 1997); software used to prepare material for publication: *WinGX* (Farrugia, 1999), *PARST97* (Nardelli, 1995), *Mercury* (Version 1.4; Macrae *et al.*, 2006) and *POVRay* (Persistence of Vision Team, 2004).

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Supplementary data for this paper are available from the IUCr electronic archives (Reference: GD3241). Services for accessing these data are described at the back of the journal.

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