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Two oxazane macrocycles.

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Two oxazane macrocycles

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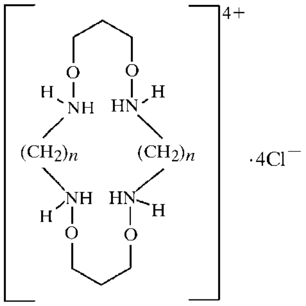
The 20-membered ring in 1,7,11,17-tetraoxa-2,6,12,16-tetraazacycloeicosane tetrahydrochloride, $C_{12}H_{32}N_4O_4^{4+}\cdot 4Cl^-$, adopts an *endo* conformation, while the 18-membered ring in 1,6,10,15-tetraoxa-2,5,11,14-tetraazacyclooctadecane tetrahydrochloride, $C_{10}H_{28}N_4O_4^{4+}\cdot 4Cl^-$, lies about an inversion centre and adopts a symmetrical conformation. In the crystal structures of both compounds, the cations and chloride anions are linked by N—H···Cl hydrogen bonds into planar sheets of molecules; the sheets are linked into three-dimensional networks *via* C—H···Cl hydrogen bonds.

Comment

Heteromacrocyclic systems have for a long time generated great interest in the scientific community because of their huge range of applications. For example, several 1,4,7,10-tetraazacyclododecane (cyclen) derivatives have been used as models for protein–metal binding sites in biological systems (Kimura, 1993; Kimura *et al.*, 1997; Kimura & Koike, 1998). Other cyclic polyamine systems have also been designed and synthesized in order to demonstrate that these systems can act as molecular catalysts capable of effecting reactions on anion substrates, for example, the phosphoryl transfer that plays an essential role in the energetics of all living organisms (Hosseini & Lehn, 1986, 1987). Furthermore, other tetraazamacrocyclic ligands, such as the cyclen, cyclam and bicyclam ligands, have been shown to exhibit antitumour and anti-HIV activity (Inoue & Kimura, 1994, 1996; Kong Thoo Lin *et al.*, 2000). Other areas where macrocyclic systems could have useful applications are in diagnostic and sensor technologies. The free bases of the cation macrocycles described in this work have been used in the assembly of ion-selective electrodes for nitrate detection (Application No./Patent No. 02730426.0-2204-GB0202292). The formation of the tetrahydrochloride salts of the free bases results in protonation of all the N atoms in the macrocycle, thus forming (I) and (II), whose structures are described here.

The 20-membered ring in 1,7,11,17-tetraoxa-2,6,12,16-tetraazacycloeicosane tetrahydrochloride, (I) (Fig. 1*a*), adopts an *endo* conformation, as shown in Fig. 1(*b*). The C—O—N—C, O—N—C—C and C—C—C—N torsion angles (Table 1) are all essentially *trans*, while the O—N—C—C and O—C—C—C torsion angles are mostly *gauche*, except for O7—N6—C5—C4, which has a value of 87.14 (14)°. The N2···N12 separation across this cation ring is 4.870 (2) Å, whereas the O7···O17 separation is 6.377 (2) Å. A related crystallographic study of diaqua(1,7,11,17-tetraoxa-2,6,12,16-tetraazacycloeicosane-*N*,*N*′,*N*″,*N*‴)nickel(II) dichloride has been performed (Kuksa *et al.*, 2002); in this structure, the metal complex has crystallographically imposed 2/*m* symmetry.



(I) $n = 3$
(II) $n = 2$

The 18-membered ring in 1,6,10,15-tetraoxa-2,5,11,14-tetraazacyclooctadecane tetrahydrochloride, (II) (Fig. 2), lies about an inversion centre [chosen for convenience as that at $(\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$] and has a symmetrical conformation. The C—O—N—

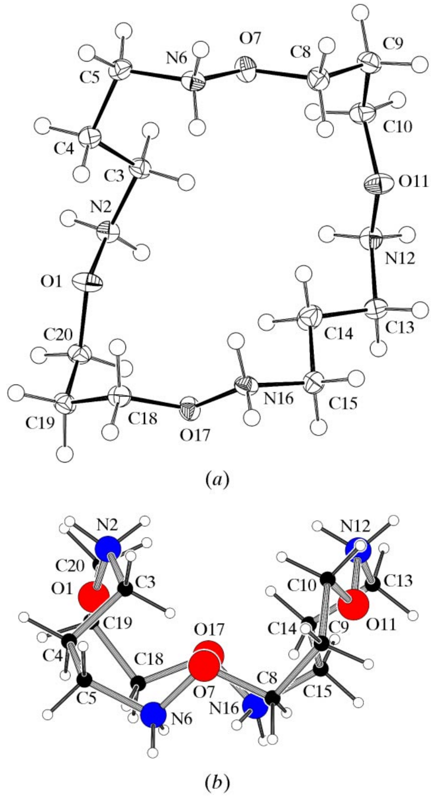


Figure 1
(*a*) The atomic arrangement in the cation of (I). Displacement ellipsoids are shown at the 50% probability level. (*b*) A view showing the *endo* conformation of the cation macrocycle of (I).

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C torsion angles are essentially trans, while the N—C—C—N, O—C—C—C and O—N—C—C torsion angles are gauche; one of the two N—O—C—C angles is gauche and the other is trans (Table 2). In this macrocycle, the shortest transannular contact, O1···O1, is 3.423 (2) Å, whereas the C3···C3 distance is 6.560 (2) Å. An example of an 18-membered oxazane macrocyle with no crystallographically imposed symmetry is found in N,N-dipyridylbisaza-18-crown-6 (Junk & Smith, 2002).

In both (I) and (II), the cations and anions are linked into sheets *via* N—H···Cl hydrogen bonds. In (I), all eight independent N—H bonds take part in N—H···Cl hydrogen bonds (Table 3), which serve to generate sheets in the (001) plane, as shown in Fig. 3, by simple translations in the *a* and *b* directions; these sheets, which lie approximately in the domain $0 < z < 0.5$, are then linked to inversion-related Cl^- ions by C—H···Cl interactions (Table 3), generating a three-dimensional network. In (II), because of the inversion centre, there are only four independent N—H bonds and, as in (I), these all form N—H···Cl hydrogen bonds (Table 4), generating sheets in the (100) plane by a combination of inversions and *b* and *c* translations, as shown in Fig. 4; these sheets lie in the domain $0 > x > 1$. The observed conformation is stabilized by an intramolecular N5—H5*B*···O1 hydrogen bond; there are also C—H···Cl interactions within the sheets (Table 4). The sheets are linked into a three-dimensional network by sets of C3—H3*A*···Cl1(1 + *x*, *y*, *z*) interactions.

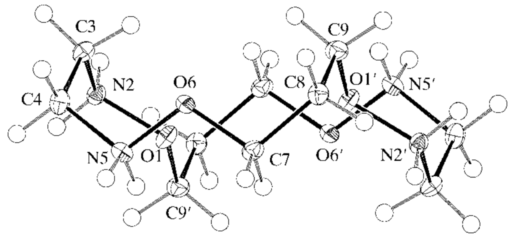

Figure 2
The atomic arrangement in the cation of (II). Displacement ellipsoids are shown at the 50% probability level. Atoms marked with a prime are at the equivalent position (1 − *x*, 1 − *y*, 1 − *z*).

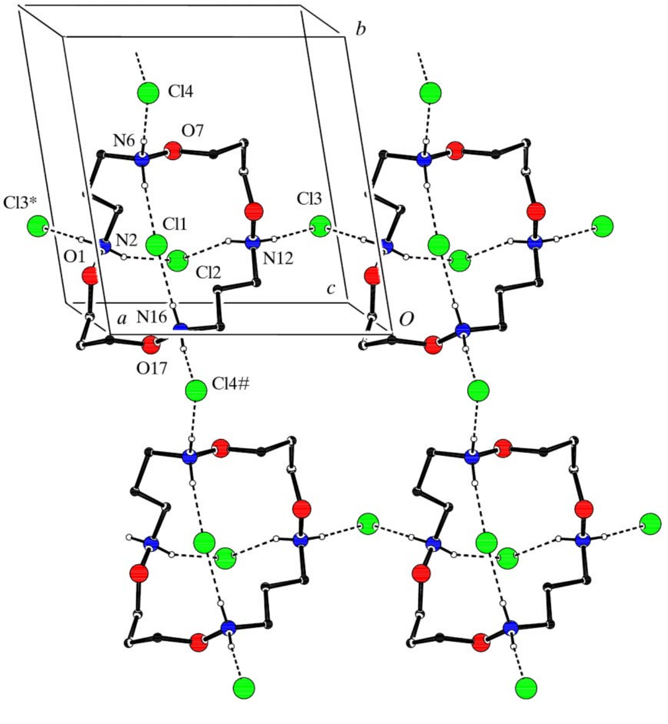

Figure 3
A view of the sheet of cations linked by N—H···Cl hydrogen bonds in (I). Atoms Cl3* and Cl4# are at the equivalent positions (1 + *x*, *y*, *z*) and (*x*, *y* − 1, *z*), respectively.

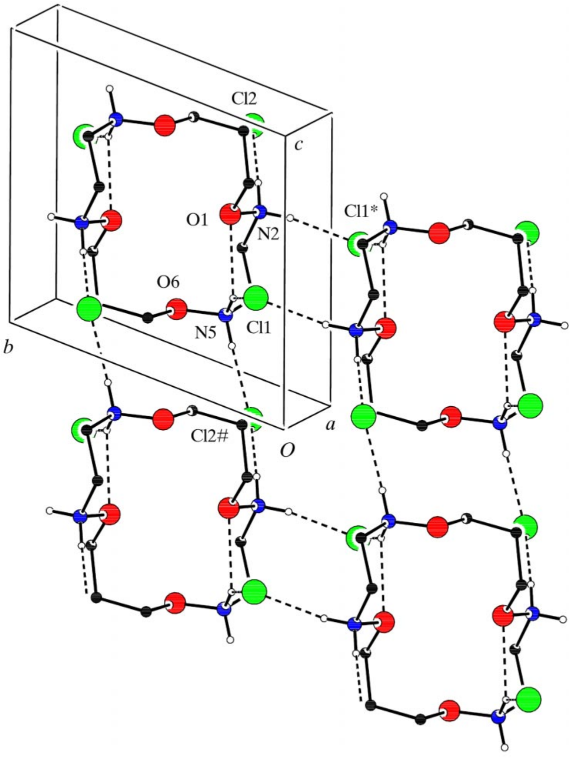

Figure 4
A view of the sheet of cations linked by N—H···Cl hydrogen bonds in (II). Atoms Cl1* and Cl2# are at the equivalent positions (1 − *x*, −*y*, 1 − *z*) and (*x*, *y*, *z* − 1), respectively.

Experimental

The title oxazane macrocycle systems were synthesized according to previously published methods (Kuksa *et al.*, 1999). For (I), ^1H NMR ($CDCl_3$): δ 1.50–1.90 (*m*, 8H, 4 × CH_2), 2.96 (*t*, 8H, 4 × CH_2N), 3.75 (*t*, 8H, 4 × CH_2O), 5.64 (*br*, *s*, 4H, 4 × ONH); ^{13}C NMR ($CDCl_3$): δ 25.4, 28.5, 50.8, 71.1; HRMS–FAB: calculated for $[MH]^+$ $C_{12}H_{28}N_4O_4$: 293.21; found: 293.2197. For (II), ^1H NMR ($CDCl_3$): δ 1.85 (pentet, 4H, 2 × CH_2), 3.15 (doublet, 8H, 4 × CH_2N), 3.85 (*t*, 8H, 4 × CH_2O), 6.00 (*br*, *s*, 4H, 4 × ONH); ^{13}C NMR ($CDCl_3$): δ 28.5, 50.8, 71.1; HRMS–FAB: calculated for $[MH]^+$ $C_{10}H_{24}N_4O_4$: 265.18; found: 265.1877. The tetrahydrochloride salts were prepared by dissolving the free bases in ethanol and adding a few drops of concentrated HCl. The precipitates were filtered off, dried and recrystallized from ethanol–water to give colourless crystals.

Compound (I)

Crystal data

$C_{12}H_{32}N_4O_4^{4+}\cdot 4Cl^-$
$M_r = 438.22$
Triclinic, $P\overline{1}$
$a = 9.1948$ (2) Å
$b = 9.8341$ (2) Å
$c = 12.2985$ (3) Å
$\alpha = 83.145$ (1)°
$\beta = 82.933$ (1)°
$\gamma = 80.865$ (1)°
$V = 1083.95$ (4) Å^3
$Z = 2$
$D_x = 1.343$ Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 13 890 reflections
$\theta = 2.9$–27.5°
$\mu = 0.57$ mm^{-1}
$T = 120$ (2) K
Block, colourless
0.1 × 0.1 × 0.1 mm

Data collection

Nonius KappaCCD area-detector diffractometer
φ and ω scans to fill Ewald sphere
Absorption correction: multi-scan (*SORTAV*; Blessing, 1997)
$T_{min} = 0.860$, $T_{max} = 0.945$
17 127 measured reflections
4892 independent reflections
4134 reflections with $I > 2\sigma(I)$
$R_{int} = 0.051$
$\theta_{max} = 27.5°$
$h = -11 \rightarrow 11$
$k = -12 \rightarrow 12$
$l = -15 \rightarrow 15$

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.032$
$wR(F^2) = 0.079$
$S = 1.05$
4892 reflections
218 parameters
H-atom parameters constrained
$w = 1/[\sigma^2(F_o^2) + (0.0341P)^2 + 0.2746P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} = 0.001$
$\Delta\rho_{max} = 0.37$ e Å^{-3}
$\Delta\rho_{min} = -0.28$ e Å^{-3}
Extinction correction: *SHELXL*97
Extinction coefficient: 0.0031 (13)

Table 1
Selected torsion angles (°) for (I).

C20—O1—N2—C3	−160.12 (11)	C10—O11—N12—C13	−169.99 (11)
O1—N2—C3—C4	−53.62 (15)	O11—N12—C13—C14	68.59 (14)
N2—C3—C4—C5	−176.99 (12)	N12—C13—C14—C15	−171.99 (13)
C3—C4—C5—N6	−56.12 (17)	C13—C14—C15—N16	179.77 (12)
C4—C5—N6—O7	87.14 (14)	C14—C15—N16—O17	73.33 (14)
C5—N6—O7—C8	179.20 (11)	C15—N16—O17—C18	−165.74 (11)
N6—O7—C8—C9	−177.85 (11)	N16—O17—C18—C19	165.42 (10)
O7—C8—C9—C10	−62.88 (16)	O17—C18—C19—C20	−55.81 (15)
C8—C9—C10—O11	−60.32 (16)	N2—O1—C20—C19	174.63 (11)
C9—C10—O11—N12	176.75 (11)	C18—C19—C20—O1	−52.01 (16)

Table 2
Hydrogen-bonding geometry (Å, °) for (I).

D—H···A	D—H	H···A	D···A	D—H···A
N2—H2A···Cl3^{i}	0.92	2.12	3.0287 (12)	170
N2—H2B···Cl2	0.92	2.15	3.0321 (13)	161
N6—H6A···Cl4	0.92	2.11	3.0199 (13)	171
N6—H6B···Cl1	0.92	2.17	3.0836 (13)	175
N12—H12A···Cl3	0.92	2.09	3.0086 (13)	175
N12—H12B···Cl2	0.92	2.19	3.0683 (13)	159
N16—H16A···Cl4^{ii}	0.92	2.10	3.0210 (13)	174
N16—H16B···Cl1	0.92	2.20	3.1202 (13)	178
C5—H5B···Cl1^{iii}	0.99	2.80	3.7866 (16)	175
C13—H13A···Cl4^{iv}	0.99	2.82	3.6814 (15)	145
C13—H13B···Cl2^{v}	0.99	2.68	3.6315 (15)	161
C15—H15B···Cl4^{iv}	0.99	2.71	3.6013 (15)	150

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

Compound (II)

Crystal data

$C_{10}H_{28}N_4O_4^{4+}\cdot 4Cl^-$
$M_r = 410.16$
Triclinic, $P\overline{1}$
$a = 7.6921$ (2) Å
$b = 8.3920$ (2) Å
$c = 8.6696$ (3) Å
$\alpha = 67.409$ (2)°
$\beta = 68.128$ (2)°
$\gamma = 88.967$ (2)°
$V = 474.37$ (3) Å^3
$Z = 1$
$D_x = 1.436$ Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 3448 reflections
$\theta = 2.9$–27.5°
$\mu = 0.64$ mm^{-1}
$T = 120$ (2) K
Plate, colourless
0.16 × 0.08 × 0.03 mm

Data collection

Nonius KappaCCD area-detector diffractometer
φ and ω scans to fill Ewald sphere
Absorption correction: multi-scan (*SORTAV*; Blessing, 1997)
$T_{min} = 0.941$, $T_{max} = 0.980$
6137 measured reflections
2090 independent reflections
1798 reflections with $I > 2\sigma(I)$
$R_{int} = 0.048$
$\theta_{max} = 27.5°$
$h = -9 \rightarrow 9$
$k = -10 \rightarrow 10$
$l = -11 \rightarrow 11$

Refinement

Refinement on F^2
$R(F) = 0.030$
$wR(F^2) = 0.075$
$S = 1.05$
2090 reflections
101 parameters
H-atom parameters constrained
$w = 1/[\sigma^2(F_o^2) + (0.0262P)^2 + 0.1427P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max} = 0.31$ e Å^{-3}
$\Delta\rho_{min} = -0.26$ e Å^{-3}
Extinction correction: *SHELXL*97
Extinction coefficient: 0.019 (4)

Table 3
Selected torsion angles (°) for (II).

C8^{vi}—C9^{vi}—O1—N2	69.50 (17)	C4—N5—O6—C7	−171.03 (11)
C9^{vi}—O1—N2—C3	173.78 (11)	N5—O6—C7—C8	171.92 (11)
O1—N2—C3—C4	−72.23 (15)	O6—C7—C8—C9	−63.37 (15)
N2—C3—C4—N5	70.57 (17)	C7—C8—C9—O1^{i}	−52.29 (17)
C3—C4—N5—O6	55.80 (15)		

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

Table 4
Hydrogen-bonding geometry (Å, °) for (II).

D—H···A	D—H	H···A	D···A	D—H···A
N2—H2A···Cl1^{v}	0.92	2.12	3.0323 (13)	170
N2—H2B···Cl2	0.92	2.13	3.0214 (13)	163
N5—H5A···Cl2^{vii}	0.92	2.13	3.0340 (13)	168
N5—H5B···Cl1	0.92	2.29	3.1074 (13)	148
N5—H5B···O1	0.92	2.37	2.9007 (16)	117
C3—H3A···Cl1^{i}	0.99	2.66	3.5445 (15)	149
C4—H4B···Cl1^{v}	0.99	2.76	3.5673 (16)	139
C4—H4A···O6^{iii}	0.99	2.60	3.5012 (19)	152

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

All H atoms were resolved clearly in difference maps and were subsequently allowed for as riding atoms using *SHELXL*97 (Sheldrick, 1997) defaults, with N—H distances of 0.92 Å, C—H distances of 0.99 Å and U_{iso} values of $1.2U_{eq}$ of the attached atom.

For both compounds, data collection: *DENZO* (Otwinowski & Minor, 1997) and *COLLECT* (Hooft, 1998); cell refinement: *DENZO* and *COLLECT*; data reduction: *DENZO* and *COLLECT*; program(s) used to solve structure: *SIR*97 (Altomare *et al.*, 1999);

program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *PLATON* (Spek, 2003) and *ORTEP*-3 (Farrugia, 1997); software used to prepare material for publication: *WinGX* (Farrugia, 1999).

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Supplementary data for this paper are available from the IUCr electronic archives (Reference: FG1742). Services for accessing these data are described at the back of the journal.

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supporting information

Acta Cryst. (2004). C**60**, o321–o324 [doi:10.1107/S0108270104006687]

Two oxazane macrocycles

Philip J. Cox and Paul Kong Thoo Lin

Computing details

For both compounds, data collection: *DENZO* (Otwinowski & Minor, 1997) and *COLLECT* (Hooft, 1998); cell refinement: *DENZO* and *COLLECT*; data reduction: *DENZO* and *COLLECT*; program(s) used to solve structure: *SIR97* (Altomare *et al.*,1999); program(s) used to refine structure: *SHELXL97* (Sheldrick, 1997); molecular graphics: *PLATON* (Spek, 2003) and *ORTEP-3* (Farrugia, 1997); software used to prepare material for publication: *WinGX* (Farrugia, 1999).

(I)

Crystal data

$C_{12}H_{32}N_4O_4^{4+}\cdot4Cl^-$
$M_r = 438.22$
Triclinic, $P\overline{1}$
Hall symbol: -P 1
$a = 9.1948$ (2) Å
$b = 9.8341$ (2) Å
$c = 12.2985$ (3) Å
$\alpha = 83.145$ (1)°
$\beta = 82.933$ (1)°
$\gamma = 80.865$ (1)°
$V = 1083.95$ (4) Å^3

$Z = 2$
$F(000) = 464$
$D_x = 1.343$ Mg m^{-3}
Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å
Cell parameters from 13890 reflections
$\theta = 2.9$–$27.5°$
$\mu = 0.57$ mm^{-1}
$T = 120$ K
Block, colourless
0.1 × 0.1 × 0.1 mm

Data collection

Nonius KappaCCD area detector diffractometer
φ and ω scans to fill Ewald sphere
Absorption correction: multi-scan (*SORTAV*; Blessing, 1997)
$T_{min} = 0.860$, $T_{max} = 0.945$
17127 measured reflections

4892 independent reflections
4134 reflections with $I > 2\sigma(I)$
$R_{int} = 0.051$
$\theta_{max} = 27.5°$, $\theta_{min} = 3.0°$
$h = -11 \rightarrow 11$
$k = -12 \rightarrow 12$
$l = -15 \rightarrow 15$

Refinement

Refinement on F^2
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)] = 0.032$
$wR(F^2) = 0.079$
$S = 1.05$
4892 reflections
218 parameters
0 restraints
Primary atom site location: structure-invariant direct methods
Secondary atom site location: difference Fourier map

Hydrogen site location: inferred from neighbouring sites
H-atom parameters constrained
$w = 1/[\sigma^2(F_o^2) + (0.0341P)^2 + 0.2746P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} = 0.001$
$\Delta\rho_{max} = 0.37$ e Å^{-3}
$\Delta\rho_{min} = -0.28$ e Å^{-3}
Extinction correction: *SHELXL97*, $Fc^* = kFc[1+0.001xFc^2\lambda^3/\sin(2\theta)]^{-1/4}$
Extinction coefficient: 0.0031 (13)

Special details

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

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å^2)

	x	y	z	U_{iso}*/U_{eq}
Cl1	0.78182 (4)	0.29749 (4)	0.02612 (3)	0.01915 (10)
Cl2	0.64696 (4)	0.19188 (4)	0.52487 (3)	0.01962 (10)
Cl3	0.11847 (4)	0.30594 (4)	0.54479 (3)	0.02089 (10)
Cl4	0.73572 (4)	0.81739 (4)	−0.05541 (3)	0.01895 (10)
O1	0.99254 (12)	0.16537 (10)	0.29883 (8)	0.0203 (2)
N2	0.92211 (14)	0.25611 (12)	0.37742 (10)	0.0165 (3)
H2A	0.9901	0.2741	0.4208	0.020*
H2B	0.8494	0.2160	0.4221	0.020*
C3	0.85642 (16)	0.38629 (15)	0.31712 (12)	0.0171 (3)
H3A	0.8151	0.4540	0.3704	0.020*
H3B	0.7740	0.3676	0.2790	0.020*
C4	0.96970 (17)	0.44816 (15)	0.23322 (13)	0.0191 (3)
H4A	1.0071	0.3823	0.1778	0.023*
H4B	1.0546	0.4620	0.2709	0.023*
C5	0.90526 (17)	0.58581 (15)	0.17511 (13)	0.0186 (3)
H5A	0.8783	0.6546	0.2295	0.022*
H5B	0.9819	0.6194	0.1191	0.022*
N6	0.77188 (13)	0.57604 (13)	0.12039 (10)	0.0168 (3)
H6A	0.7628	0.6427	0.0614	0.020*
H6B	0.7800	0.4905	0.0951	0.020*
O7	0.64545 (11)	0.59624 (11)	0.20007 (8)	0.0188 (2)
C8	0.51149 (17)	0.58962 (16)	0.15037 (12)	0.0191 (3)
H8A	0.5142	0.4970	0.1255	0.023*
H8B	0.5008	0.6602	0.0862	0.023*
C9	0.38482 (17)	0.61760 (15)	0.23943 (13)	0.0202 (3)
H9A	0.2903	0.6216	0.2075	0.024*
H9B	0.3867	0.7096	0.2639	0.024*
C10	0.38792 (18)	0.51090 (15)	0.33918 (13)	0.0203 (3)
H10A	0.4806	0.5054	0.3739	0.024*
H10B	0.3026	0.5346	0.3944	0.024*
O11	0.37975 (12)	0.38171 (10)	0.29722 (8)	0.0210 (2)
N12	0.38989 (14)	0.26899 (12)	0.38137 (10)	0.0175 (3)
H12A	0.3055	0.2751	0.4302	0.021*
H12B	0.4699	0.2694	0.4194	0.021*
C13	0.40765 (16)	0.14083 (15)	0.32589 (12)	0.0182 (3)
H13A	0.3290	0.1470	0.2766	0.022*
H13B	0.3992	0.0601	0.3814	0.022*
C14	0.55825 (18)	0.12326 (17)	0.25980 (14)	0.0240 (3)
H14A	0.5710	0.2108	0.2133	0.029*

H14B	0.6356	0.1055	0.3112	0.029*
C15	0.58077 (16)	0.00686 (16)	0.18701 (13)	0.0190 (3)
H15A	0.5706	−0.0819	0.2324	0.023*
H15B	0.5051	0.0236	0.1343	0.023*
N16	0.73087 (13)	−0.00011 (13)	0.12633 (10)	0.0171 (3)
H16A	0.7394	−0.0554	0.0699	0.020*
H16B	0.7485	0.0869	0.0968	0.020*
O17	0.83421 (11)	−0.05667 (10)	0.20308 (8)	0.0182 (2)
C18	0.98322 (16)	−0.03550 (15)	0.15841 (12)	0.0180 (3)
H18A	0.9842	0.0607	0.1240	0.022*
H18B	1.0227	−0.0998	0.1021	0.022*
C19	1.07496 (16)	−0.06390 (15)	0.25513 (12)	0.0178 (3)
H19A	1.0800	−0.1629	0.2835	0.021*
H19B	1.1771	−0.0461	0.2292	0.021*
C20	1.01366 (17)	0.02342 (15)	0.34797 (12)	0.0174 (3)
H20A	0.9183	−0.0035	0.3833	0.021*
H20B	1.0840	0.0115	0.4044	0.021*

Atomic displacement parameters (Å^2)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
Cl1	0.0233 (2)	0.01433 (18)	0.01929 (19)	−0.00213 (14)	−0.00157 (14)	−0.00128 (15)
Cl2	0.02013 (19)	0.02069 (19)	0.01824 (19)	−0.00444 (14)	−0.00278 (14)	−0.00006 (15)
Cl3	0.0207 (2)	0.0268 (2)	0.01643 (19)	−0.00656 (15)	−0.00062 (14)	−0.00458 (16)
Cl4	0.0264 (2)	0.01640 (18)	0.01435 (18)	−0.00346 (14)	−0.00417 (14)	−0.00019 (14)
O1	0.0312 (6)	0.0130 (5)	0.0143 (5)	0.0003 (4)	0.0019 (4)	−0.0007 (4)
N2	0.0190 (6)	0.0169 (6)	0.0136 (6)	−0.0023 (5)	−0.0016 (5)	−0.0021 (5)
C3	0.0176 (7)	0.0145 (7)	0.0182 (7)	−0.0010 (6)	−0.0028 (6)	0.0009 (6)
C4	0.0185 (8)	0.0175 (7)	0.0209 (8)	−0.0033 (6)	−0.0022 (6)	0.0007 (6)
C5	0.0200 (8)	0.0161 (7)	0.0199 (8)	−0.0055 (6)	−0.0008 (6)	−0.0006 (6)
N6	0.0202 (7)	0.0148 (6)	0.0140 (6)	−0.0015 (5)	0.0007 (5)	−0.0004 (5)
O7	0.0166 (5)	0.0241 (6)	0.0149 (5)	−0.0013 (4)	0.0001 (4)	−0.0025 (5)
C8	0.0193 (8)	0.0202 (7)	0.0179 (7)	−0.0029 (6)	−0.0049 (6)	0.0005 (6)
C9	0.0207 (8)	0.0166 (7)	0.0220 (8)	−0.0006 (6)	−0.0020 (6)	−0.0006 (6)
C10	0.0244 (8)	0.0173 (7)	0.0193 (8)	−0.0032 (6)	0.0004 (6)	−0.0048 (6)
O11	0.0328 (6)	0.0155 (5)	0.0151 (5)	−0.0048 (4)	−0.0043 (5)	0.0009 (4)
N12	0.0185 (6)	0.0196 (6)	0.0139 (6)	−0.0038 (5)	−0.0005 (5)	0.0009 (5)
C13	0.0206 (8)	0.0155 (7)	0.0185 (7)	−0.0041 (6)	−0.0015 (6)	−0.0001 (6)
C14	0.0227 (8)	0.0245 (8)	0.0264 (8)	−0.0066 (7)	0.0015 (7)	−0.0089 (7)
C15	0.0180 (8)	0.0188 (7)	0.0217 (8)	−0.0029 (6)	−0.0050 (6)	−0.0044 (6)
N16	0.0215 (7)	0.0139 (6)	0.0159 (6)	−0.0004 (5)	−0.0051 (5)	−0.0016 (5)
O17	0.0169 (5)	0.0201 (5)	0.0168 (5)	−0.0021 (4)	−0.0047 (4)	0.0032 (4)
C18	0.0185 (8)	0.0173 (7)	0.0175 (7)	−0.0032 (6)	0.0020 (6)	−0.0016 (6)
C19	0.0172 (7)	0.0156 (7)	0.0191 (8)	−0.0003 (6)	−0.0016 (6)	0.0011 (6)
C20	0.0208 (8)	0.0139 (7)	0.0168 (7)	−0.0020 (6)	−0.0041 (6)	0.0035 (6)

Geometric parameters (Å, º)

O1—N2	1.4206 (15)	C10—H10B	0.99
O1—C20	1.4467 (17)	O11—N12	1.4233 (16)
N2—C3	1.4805 (18)	N12—C13	1.4809 (19)
N2—H2A	0.92	N12—H12A	0.92
N2—H2B	0.92	N12—H12B	0.92
C3—C4	1.519 (2)	C13—C14	1.513 (2)
C3—H3A	0.99	C13—H13A	0.99
C3—H3B	0.99	C13—H13B	0.99
C4—C5	1.521 (2)	C14—C15	1.509 (2)
C4—H4A	0.99	C14—H14A	0.99
C4—H4B	0.99	C14—H14B	0.99
C5—N6	1.4907 (19)	C15—N16	1.4816 (19)
C5—H5A	0.99	C15—H15A	0.99
C5—H5B	0.99	C15—H15B	0.99
N6—O7	1.4296 (15)	N16—O17	1.4250 (15)
N6—H6A	0.92	N16—H16A	0.92
N6—H6B	0.92	N16—H16B	0.92
O7—C8	1.4544 (18)	O17—C18	1.4492 (18)
C8—C9	1.513 (2)	C18—C19	1.516 (2)
C8—H8A	0.99	C18—H18A	0.99
C8—H8B	0.99	C18—H18B	0.99
C9—C10	1.516 (2)	C19—C20	1.510 (2)
C9—H9A	0.99	C19—H19A	0.99
C9—H9B	0.99	C19—H19B	0.99
C10—O11	1.4430 (18)	C20—H20A	0.99
C10—H10A	0.99	C20—H20B	0.99

N2—O1—C20	111.05 (10)	N12—O11—C10	111.65 (10)
O1—N2—C3	108.16 (10)	O11—N12—C13	106.72 (10)
O1—N2—H2A	110.1	O11—N12—H12A	110.4
C3—N2—H2A	110.1	C13—N12—H12A	110.4
O1—N2—H2B	110.1	O11—N12—H12B	110.4
C3—N2—H2B	110.1	C13—N12—H12B	110.4
H2A—N2—H2B	108.4	H12A—N12—H12B	108.6
N2—C3—C4	111.89 (12)	N12—C13—C14	108.76 (12)
N2—C3—H3A	109.2	N12—C13—H13A	109.9
C4—C3—H3A	109.2	C14—C13—H13A	109.9
N2—C3—H3B	109.2	N12—C13—H13B	109.9
C4—C3—H3B	109.2	C14—C13—H13B	109.9
H3A—C3—H3B	107.9	H13A—C13—H13B	108.3
C3—C4—C5	112.27 (12)	C15—C14—C13	113.52 (13)
C3—C4—H4A	109.1	C15—C14—H14A	108.9
C5—C4—H4A	109.1	C13—C14—H14A	108.9
C3—C4—H4B	109.1	C15—C14—H14B	108.9
C5—C4—H4B	109.1	C13—C14—H14B	108.9
H4A—C4—H4B	107.9	H14A—C14—H14B	107.7

N6—C5—C4	112.82 (12)	N16—C15—C14	108.72 (12)
N6—C5—H5A	109.0	N16—C15—H15A	109.9
C4—C5—H5A	109.0	C14—C15—H15A	109.9
N6—C5—H5B	109.0	N16—C15—H15B	109.9
C4—C5—H5B	109.0	C14—C15—H15B	109.9
H5A—C5—H5B	107.8	H15A—C15—H15B	108.3
O7—N6—C5	107.69 (10)	O17—N16—C15	107.30 (11)
O7—N6—H6A	110.2	O17—N16—H16A	110.3
C5—N6—H6A	110.2	C15—N16—H16A	110.3
O7—N6—H6B	110.2	O17—N16—H16B	110.3
C5—N6—H6B	110.2	C15—N16—H16B	110.3
H6A—N6—H6B	108.5	H16A—N16—H16B	108.5
N6—O7—C8	109.96 (10)	N16—O17—C18	110.78 (10)
O7—C8—C9	105.78 (12)	O17—C18—C19	105.92 (11)
O7—C8—H8A	110.6	O17—C18—H18A	110.6
C9—C8—H8A	110.6	C19—C18—H18A	110.6
O7—C8—H8B	110.6	O17—C18—H18B	110.6
C9—C8—H8B	110.6	C19—C18—H18B	110.6
H8A—C8—H8B	108.7	H18A—C18—H18B	108.7
C8—C9—C10	114.42 (13)	C20—C19—C18	113.23 (12)
C8—C9—H9A	108.7	C20—C19—H19A	108.9
C10—C9—H9A	108.7	C18—C19—H19A	108.9
C8—C9—H9B	108.7	C20—C19—H19B	108.9
C10—C9—H9B	108.7	C18—C19—H19B	108.9
H9A—C9—H9B	107.6	H19A—C19—H19B	107.7
O11—C10—C9	105.11 (12)	O1—C20—C19	106.20 (11)
O11—C10—H10A	110.7	O1—C20—H20A	110.5
C9—C10—H10A	110.7	C19—C20—H20A	110.5
O11—C10—H10B	110.7	O1—C20—H20B	110.5
C9—C10—H10B	110.7	C19—C20—H20B	110.5
H10A—C10—H10B	108.8	H20A—C20—H20B	108.7

C20—O1—N2—C3	−160.12 (11)	C10—O11—N12—C13	−169.99 (11)
O1—N2—C3—C4	−53.62 (15)	O11—N12—C13—C14	68.59 (14)
N2—C3—C4—C5	−176.99 (12)	N12—C13—C14—C15	−171.99 (13)
C3—C4—C5—N6	−56.12 (17)	C13—C14—C15—N16	179.77 (12)
C4—C5—N6—O7	87.14 (14)	C14—C15—N16—O17	73.33 (14)
C5—N6—O7—C8	179.20 (11)	C15—N16—O17—C18	−165.74 (11)
N6—O7—C8—C9	−177.85 (11)	N16—O17—C18—C19	165.42 (10)
O7—C8—C9—C10	−62.88 (16)	O17—C18—C19—C20	−55.81 (15)
C8—C9—C10—O11	−60.32 (16)	N2—O1—C20—C19	174.63 (11)
C9—C10—O11—N12	176.75 (11)	C18—C19—C20—O1	−52.01 (16)

Hydrogen-bond geometry (Å, º)

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
N2—H2*A*···Cl3$^{\mathrm{i}}$	0.92	2.12	3.0287 (12)	170
N2—H2*B*···Cl2	0.92	2.15	3.0321 (13)	161

N6—H6*A*···Cl4	0.92	2.11	3.0199 (13)	171
N6—H6*B*···Cl1	0.92	2.17	3.0836 (13)	175
N12—H12*A*···Cl3	0.92	2.09	3.0086 (13)	175
N12—H12*B*···Cl2	0.92	2.19	3.0683 (13)	159
N16—H16*A*···Cl4^{ii}	0.92	2.10	3.0210 (13)	174
N16—H16*B*···Cl1	0.92	2.20	3.1202 (13)	178
C5—H5*B*···Cl1^{iii}	0.99	2.80	3.7866 (16)	175
C13—H13*A*···Cl4^{iv}	0.99	2.82	3.6814 (15)	145
C13—H13*B*···Cl2^{v}	0.99	2.68	3.6315 (15)	161
C15—H15*B*···Cl4^{iv}	0.99	2.71	3.6013 (15)	150

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

(II)

Crystal data

$C_{10}H_{28}N_4O_4^{4+}\cdot 4Cl^-$
$M_r = 410.16$
Triclinic, $P\overline{1}$
Hall symbol: -P 1
$a = 7.6921$ (2) Å
$b = 8.3920$ (2) Å
$c = 8.6696$ (3) Å
$\alpha = 67.409$ (2)°
$\beta = 68.128$ (2)°
$\gamma = 88.967$ (2)°
$V = 474.37$ (3) Å^3
$Z = 1$
$F(000) = 216$
$D_x = 1.436$ Mg m^{-3}
Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å
Cell parameters from 3448 reflections
$\theta = 2.9$–27.5°
$\mu = 0.64$ mm^{-1}
$T = 120$ K
Plate, colourless
0.16 × 0.08 × 0.03 mm

Data collection

Nonius KappaCCD area detector diffractometer
φ and ω scans to fill Ewald sphere
Absorption correction: multi-scan (*SORTAV*; Blessing, 1997)
$T_{min} = 0.941$, $T_{max} = 0.980$
6137 measured reflections
2090 independent reflections
1798 reflections with $I > 2\sigma(I)$
$R_{int} = 0.048$
$\theta_{max} = 27.5°$, $\theta_{min} = 3.0°$
$h = -9 \rightarrow 9$
$k = -10 \rightarrow 10$
$l = -11 \rightarrow 11$

Refinement

Refinement on F^2
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)] = 0.030$
$wR(F^2) = 0.075$
$S = 1.05$
2090 reflections
101 parameters
0 restraints
Primary atom site location: structure-invariant direct methods
Secondary atom site location: difference Fourier map
Hydrogen site location: inferred from neighbouring sites
H-atom parameters constrained
$w = 1/[\sigma^2(F_o^2) + (0.0262P)^2 + 0.1427P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max} = 0.31$ e Å^{-3}
$\Delta\rho_{min} = -0.26$ e Å^{-3}
Extinction correction: *SHELXL97*, $Fc^* = kFc[1+0.001xFc^2\lambda^3/\sin(2\theta)]^{-1/4}$
Extinction coefficient: 0.019 (4)

Special details

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

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

	x	y	z	$U_{\rm iso}$*/$U_{\rm eq}$
Cl1	0.32480 (5)	0.15909 (5)	0.36436 (5)	0.01571 (13)
Cl2	0.84740 (5)	0.26379 (5)	0.87007 (5)	0.01947 (14)
O1	0.54871 (14)	0.29156 (14)	0.58324 (14)	0.0143 (3)
N2	0.70790 (17)	0.21150 (16)	0.60752 (17)	0.0123 (3)
H2A	0.6895	0.0952	0.6308	0.015*
H2B	0.7236	0.2206	0.7041	0.015*
C3	0.8764 (2)	0.3029 (2)	0.4382 (2)	0.0145 (3)
H3A	0.9912	0.2701	0.4616	0.017*
H3B	0.8798	0.4302	0.4033	0.017*
C4	0.8817 (2)	0.2629 (2)	0.2805 (2)	0.0151 (3)
H4A	1.0095	0.3075	0.1816	0.018*
H4B	0.8609	0.1347	0.3210	0.018*
N5	0.73925 (18)	0.33915 (16)	0.20681 (17)	0.0127 (3)
H5A	0.7546	0.3175	0.1065	0.015*
H5B	0.6189	0.2908	0.2932	0.015*
O6	0.76719 (14)	0.52168 (13)	0.15796 (14)	0.0135 (2)
C7	0.6143 (2)	0.6011 (2)	0.1116 (2)	0.0136 (3)
H7A	0.4899	0.5393	0.2097	0.016*
H7B	0.6200	0.5973	−0.0029	0.016*
C8	0.6429 (2)	0.7871 (2)	0.0894 (2)	0.0139 (3)
H8A	0.5483	0.8502	0.0472	0.017*
H8B	0.7701	0.8441	−0.0060	0.017*
C9	0.6255 (2)	0.8042 (2)	0.2626 (2)	0.0158 (3)
H9A	0.7345	0.7610	0.2924	0.019*
H9B	0.6314	0.9291	0.2409	0.019*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
Cl1	0.0148 (2)	0.0153 (2)	0.0167 (2)	0.00085 (15)	−0.00585 (17)	−0.00649 (16)
Cl2	0.0181 (2)	0.0280 (3)	0.0153 (2)	−0.00110 (17)	−0.00643 (17)	−0.01186 (18)
O1	0.0106 (5)	0.0201 (6)	0.0128 (5)	0.0053 (4)	−0.0053 (4)	−0.0068 (5)
N2	0.0123 (6)	0.0146 (7)	0.0123 (6)	0.0044 (5)	−0.0062 (5)	−0.0066 (5)
C3	0.0103 (7)	0.0175 (8)	0.0135 (8)	0.0012 (6)	−0.0039 (6)	−0.0048 (6)
C4	0.0154 (8)	0.0165 (8)	0.0121 (7)	0.0054 (6)	−0.0043 (6)	−0.0056 (6)
N5	0.0147 (6)	0.0113 (7)	0.0116 (6)	−0.0002 (5)	−0.0043 (5)	−0.0050 (5)
O6	0.0144 (5)	0.0099 (5)	0.0181 (6)	0.0015 (4)	−0.0084 (5)	−0.0055 (4)
C7	0.0138 (8)	0.0163 (8)	0.0137 (7)	0.0033 (6)	−0.0082 (7)	−0.0065 (6)
C8	0.0134 (8)	0.0139 (8)	0.0125 (7)	0.0020 (6)	−0.0037 (6)	−0.0050 (6)

C9	0.0110 (7)	0.0189 (8)	0.0180 (8)	0.0008 (6)	−0.0027 (7)	−0.0107 (7)

Geometric parameters (Å, º)

O1—N2	1.4314 (15)	N5—H5A	0.92
O1—C9$^{\rm i}$	1.4518 (18)	N5—H5B	0.92
N2—C3	1.4752 (19)	O6—C7	1.4516 (17)
N2—H2A	0.92	C7—C8	1.508 (2)
N2—H2B	0.92	C7—H7A	0.99
C3—C4	1.514 (2)	C7—H7B	0.99
C3—H3A	0.99	C8—C9	1.519 (2)
C3—H3B	0.99	C8—H8A	0.99
C4—N5	1.4836 (19)	C8—H8B	0.99
C4—H4A	0.99	C9—H9A	0.99
C4—H4B	0.99	C9—H9B	0.99
N5—O6	1.4204 (15)		

N2—O1—C9$^{\rm i}$	110.47 (10)	O6—N5—H5B	110.2
O1—N2—C3	107.54 (11)	C4—N5—H5B	110.2
O1—N2—H2A	110.2	H5A—N5—H5B	108.5
C3—N2—H2A	110.2	N5—O6—C7	110.34 (10)
O1—N2—H2B	110.2	O6—C7—C8	105.61 (12)
C3—N2—H2B	110.2	O6—C7—H7A	110.6
H2A—N2—H2B	108.5	C8—C7—H7A	110.6
N2—C3—C4	113.76 (12)	O6—C7—H7B	110.6
N2—C3—H3A	108.8	C8—C7—H7B	110.6
C4—C3—H3A	108.8	H7A—C7—H7B	108.7
N2—C3—H3B	108.8	C7—C8—C9	113.82 (13)
C4—C3—H3B	108.8	C7—C8—H8A	108.8
H3A—C3—H3B	107.7	C9—C8—H8A	108.8
N5—C4—C3	114.03 (12)	C7—C8—H8B	108.8
N5—C4—H4A	108.7	C9—C8—H8B	108.8
C3—C4—H4A	108.7	H8A—C8—H8B	107.7
N5—C4—H4B	108.7	O1$^{\rm i}$—C9—C8	113.05 (12)
C3—C4—H4B	108.7	O1$^{\rm i}$—C9—H9A	109.0
H4A—C4—H4B	107.6	C8—C9—H9A	109.0
O6—N5—C4	107.37 (11)	O1$^{\rm i}$—C9—H9B	109.0
O6—N5—H5A	110.2	C8—C9—H9B	109.0
C4—N5—H5A	110.2	H9A—C9—H9B	107.8

C8$^{\rm i}$—C9$^{\rm i}$—O1—N2	69.50 (17)	C4—N5—O6—C7	−171.03 (11)
C9$^{\rm i}$—O1—N2—C3	173.78 (11)	N5—O6—C7—C8	171.92 (11)
O1—N2—C3—C4	−72.23 (15)	O6—C7—C8—C9	−63.37 (15)
N2—C3—C4—N5	70.57 (17)	C7—C8—C9—O1$^{\rm i}$	−52.29 (17)
C3—C4—N5—O6	55.80 (15)		

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

Hydrogen-bond geometry (Å, º)

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
N2—H2*A*···Cl1^{ii}	0.92	2.12	3.0323 (13)	170
N2—H2*B*···Cl2	0.92	2.13	3.0214 (13)	163
N5—H5*A*···Cl2^{iii}	0.92	2.13	3.0340 (13)	168
N5—H5*B*···Cl1	0.92	2.29	3.1074 (13)	148
N5—H5*B*···O1	0.92	2.37	2.9007 (16)	117
C3—H3*A*···Cl1^{iv}	0.99	2.66	3.5445 (15)	149
C4—H4*B*···Cl1^{ii}	0.99	2.76	3.5673 (16)	139
C4—H4*A*···O6^{v}	0.99	2.60	3.5012 (19)	152

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