

Orthorhombic

Pbca

$a = 9.714 (2) \text{ \AA}$
 $b = 16.742 (2) \text{ \AA}$
 $c = 16.540 (2) \text{ \AA}$
 $V = 2689.9 (7) \text{ \AA}^3$
 $Z = 8$
 $D_x = 1.673 \text{ Mg m}^{-3}$
 D_m not measured

Cell parameters from 25 reflections

$\theta = 10.4\text{--}15.1^\circ$
 $\mu = 2.195 \text{ mm}^{-1}$
 $T = 293 (1) \text{ K}$
 Plate
 $0.70 \times 0.50 \times 0.06 \text{ mm}$
 Light brown

Data collection

Enraf–Nonius CAD-4-MACHS diffractometer
 $R_{\text{int}} = 0.016$
 $\theta_{\text{max}} = 25.98^\circ$
 $\omega/2\theta$ scans
 $h = -1 \rightarrow 11$
 Absorption correction: Gaussian (Sheldrick, 1976)
 $k = -1 \rightarrow 20$
 $l = -1 \rightarrow 20$
 $T_{\text{min}} = 0.343$, $T_{\text{max}} = 0.876$
 3371 measured reflections
 2636 independent reflections
 2158 reflections with $I > 2\sigma(I)$
 3 standard reflections
 frequency: 160 min
 intensity decay: none

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.027$
 $wR(F^2) = 0.074$
 $S = 1.031$
 2636 reflections
 180 parameters
 H atoms: see below
 $w = 1/[\sigma^2(F_o^2) + (0.0408P)^2 + 1.7223P]$
 where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\text{max}} = 0.001$
 $\Delta\rho_{\text{max}} = 0.62 \text{ e \AA}^{-3}$
 $\Delta\rho_{\text{min}} = -0.90 \text{ e \AA}^{-3}$
 Extinction correction: none
 Scattering factors from *International Tables for Crystallography* (Vol. C)

Table 1. Selected geometric parameters (\AA , $^\circ$)

Te—C14	2.120 (4)	N—C8	1.416 (4)
Te—C1	2.122 (3)	C2—C7	1.488 (4)
O—C7	1.230 (3)	C8—C13	1.376 (5)
N—C7	1.341 (4)	C8—C9	1.392 (4)
C14—Te—C1	96.66 (16)	O—C7—C2	120.1 (3)
C7—N—C8	129.0 (3)	N—C7—C2	117.5 (2)
C3—C2—C1	119.6 (3)	C13—C8—C9	119.1 (3)
C3—C2—C7	121.1 (3)	C13—C8—N	117.8 (3)
C1—C2—C7	119.3 (2)	C9—C8—N	123.0 (3)
O—C7—N	122.4 (3)		
C14—Te—C1—C6	19.2 (3)	C1—C2—C7—O	-32.0 (4)
C14—Te—C1—C2	-162.1 (3)	C3—C2—C7—N	-34.4 (4)
C8—N—C7—O	-5.8 (5)	C1—C2—C7—N	147.7 (3)
C8—N—C7—C2	174.5 (3)	C7—N—C8—C13	167.2 (3)
C3—C2—C7—O	145.9 (3)	C7—N—C8—C9	-15.4 (5)

The coordinates of the H atom attached to N were refined [$\text{N—H} = 0.72 (3) \text{ \AA}$]; other H atoms were treated as riding. U_{iso} values of all H atoms were refined.

Data collection: *CAD-4 Software* (Enraf–Nonius, 1989). Cell refinement: *CAD-4 Software*. Data reduction: *PROCESS DATA* (Gable *et al.*, 1993). Program(s) used to solve structure: *SHELXS86* (Sheldrick, 1990). Program(s) used to refine structure: *SHELXL97* (Sheldrick, 1997). Molecular graphics: *ORTEPII* (Johnson, 1976). Software used to prepare material for publication: *SHELXL97*.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: JA1000). Services for accessing these data are described at the back of the journal.

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The biologically active iron chelators 2-pyridylcarboxaldehyde isonicotinoyl-hydrazone, 2-pyridylcarboxaldehyde benzoylhydrazone monohydrate and 2-furaldehyde isonicotinoylhydrazone

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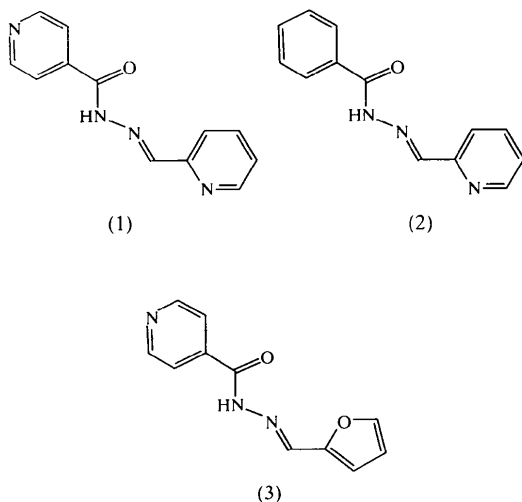
Abstract

In the crystal structures of the respective title compounds, C₁₂H₁₀N₄O, C₁₃H₁₁N₃O·H₂O and C₁₁H₉N₃O₂, variations in the torsion angles of the aromatic pyridyl

and benzoyl groups are observed, and the disposition of the heterocyclic aldehyde is shown to be influenced by the ring size of this group.

Comment

Aroylhydrazone ligands continue to attract interest as potential chelators for the treatment of iron-overload disease and also as agents with considerable antitumour activity (Johnson *et al.*, 1982; Baker *et al.*, 1992; Richardson *et al.*, 1995; Richardson & Milnes, 1997). As part of our research programme examining the development of clinically useful iron chelators, we have synthesized and determined the crystal structures of three aroylhydrazones, namely 2-pyridylcarboxaldehyde isonicotinoylhydrazone, (1), 2-pyridylcarboxaldehyde benzoylhydrazone monohydrate, (2)·H₂O, and 2-furaldehyde (2-furfural) isonicotinoylhydrazone, (3). These chelators were designed to improve upon the aqueous solubility and iron-chelation efficacy of the pyridoxal isonicotinoylhydrazone analogues that were examined previously. Studies assessing the biological activity of compounds (1)–(3) have been completed and will be described elsewhere (Becker & Richardson, 1999). The title compounds have been known for some time [(1), Beyerman *et al.* (1954); (2), Grammaticakis (1956); (3), Fox & Gibas (1953)], but no crystal structures of this series have been published.



In the crystal structure of (1) (Fig. 1), the 2- and 4-pyridyl rings are each twisted slightly about their connecting C—C bonds, defined by the respective C3—C2—C1—N1 and C9—C8—C7—N2 torsion angles of 3.9 (9) and 9.7 (7)°. The 2-pyridyl N atom (N3) is *anti* with respect to the imine N atom (N1), which avoids repulsion between the H atoms attached to C1 and C3. As a consequence, the molecule is unfavourably disposed

to chelate a metal ion in a tridentate configuration. In order for this ligand to bind meridionally (through the donor atoms O1, N1 and N3), the pyridyl group would have to rotate by *ca* 180° about C1—C2.

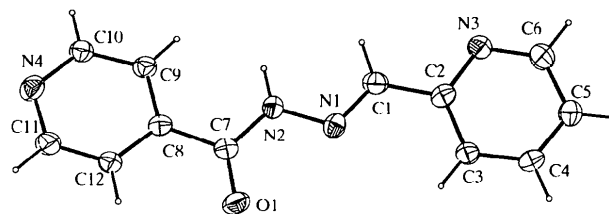


Fig. 1. View of (1) showing 30% probability ellipsoids.

The crystal structure of the benzoyl analogue (2)·H₂O (Fig. 2) found the hydrazone and a water of crystallization each located on a general site. The bond lengths are similar to those found in (1). The phenyl ring is somewhat more twisted about the connecting C—C bond [N2—C7—C8—C9 torsion angle 22.6 (3)°] than its 4-pyridyl analogue in (1). The disposition of the 2-pyridyl ring again finds N3 *anti* to N1. Hydrogen bonding with the water O atom (O2) was also identified. The most significant contacts are O2—H2B···N3ⁱ of 1.97 Å [O2···N3ⁱ 2.875 (2) Å] and N2—H2N···O2ⁱⁱ of 2.00 Å [N2···O2ⁱⁱ 2.852 (2) Å] [symmetry codes: (i) $x + \frac{1}{2}, -y + \frac{1}{2}, -z$; (ii) $-x + \frac{1}{2}, y + \frac{1}{2}, z$].

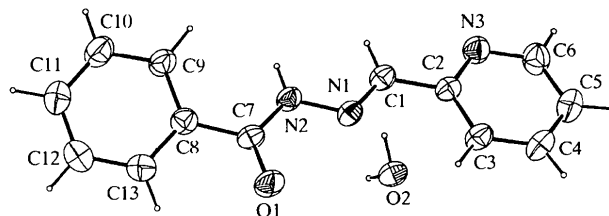


Fig. 2. View of (2)·H₂O showing 30% probability ellipsoids.

The furfural hydrazone (3) (Fig. 3) crystallizes with two independent molecules ($n = A$ and B) in the asymmetric unit, but the structural differences between these molecules are negligible. The furyl O atom (O1 n) is *syn* with respect to the imine N atom (N1 n), in contrast to the structures of (1) and (2) where the heteroatoms were *anti*. In this case, the *ca* 10° more obtuse C1 n —C2 n —C3 n angle enforced by the planar five-membered furyl ring (*ca* 130°) relieves the C1 n —H···H—C3 n repulsion which led to the corresponding *anti* conformers (1) and (2). In (3), the 4-pyridyl ring is twisted significantly about its connecting C—C bond (C8 n —C7 n —C6 n —N2 n *ca* 33°), whereas the furyl ring torsion is relatively small (*ca* 4°).

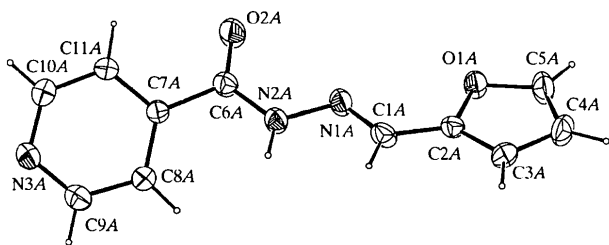


Fig. 3. View of (3) (one independent molecule) showing 30% probability ellipsoids.

We are currently exploring the coordination chemistry and biological activity of these three potential ligands and their analogues.

Experimental

The title compounds were prepared in good yield by Schiff base condensation between the corresponding aldehyde [2-pyridylcarboxaldehyde for (1) and (2), and 2-furfural for (3)] and acid hydrazide [isonicotinic acid hydrazide for (1) and (3), and benzoic acid hydrazide for (2)] in refluxing ethanol. The ¹H NMR and microanalytical results are consistent with their formulation. Crystals of each compound were grown from saturated ethanolic solutions.

Compound (1)

Crystal data

C₁₂H₁₀N₄O
M_r = 226.24
 Orthorhombic
Fdd2
a = 43.749 (10) Å
b = 20.984 (2) Å
c = 4.5980 (10) Å
V = 4221.1 (14) Å³
Z = 16
D_x = 1.424 Mg m⁻³
D_m not measured

Mo *Kα* radiation
 λ = 0.71073 Å
 Cell parameters from 25 reflections
 θ = 9.3–14.1°
 μ = 0.097 mm⁻¹
T = 296 (2) K
 Prism
 0.50 × 0.13 × 0.10 mm
 Colourless

Data collection

Enraf–Nonius CAD-4 diffractometer
 ω -2 θ scans
 Absorption correction: none
 2163 measured reflections
 1060 independent reflections
 625 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.068$
 $\theta_{\text{max}} = 24.98^\circ$
 $h = -51 \rightarrow 51$
 $k = 0 \rightarrow 24$
 $l = -2 \rightarrow 5$
 3 standard reflections
 frequency: 120 min
 intensity decay: <5%

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.050$
 $wR(F^2) = 0.122$
S = 1.034

$(\Delta/\sigma)_{\text{max}} < 0.001$
 $\Delta\rho_{\text{max}} = 0.19 \text{ e \AA}^{-3}$
 $\Delta\rho_{\text{min}} = -0.20 \text{ e \AA}^{-3}$
 Extinction correction: none

1060 reflections
 154 parameters
 H atoms constrained
 $w = 1/[\sigma^2(F_o^2) + (0.0532P)^2]$
 where $P = (F_o^2 + 2F_c^2)/3$

Compound (2)

Crystal data

C₁₃H₁₁N₃O·H₂O
M_r = 243.26
 Orthorhombic
Pbca
a = 7.1468 (6) Å
b = 11.994 (7) Å
c = 29.493 (5) Å
V = 2528.1 (16) Å³
Z = 8
D_x = 1.278 Mg m⁻³
D_m not measured

Data collection

Enraf–Nonius CAD-4 diffractometer
 ω -2 θ scans
 Absorption correction: none
 2250 measured reflections
 2220 independent reflections
 1548 reflections with $I > 2\sigma(I)$

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.034$
 $wR(F^2) = 0.127$
S = 1.059
 2220 reflections
 158 parameters
 H atoms constrained
 $w = 1/[\sigma^2(F_o^2) + (0.0743P)^2 + 0.2126P]$
 where $P = (F_o^2 + 2F_c^2)/3$

Scattering factors from *International Tables for Crystallography* (Vol. C)

Mo *Kα* radiation
 λ = 0.71073 Å
 Cell parameters from 25 reflections
 θ = 11.3–13.4°
 μ = 0.089 mm⁻¹
T = 296 (2) K
 Prism
 0.60 × 0.60 × 0.50 mm
 Colourless

$R_{\text{int}} = 0.008$
 $\theta_{\text{max}} = 24.97^\circ$
 $h = -4 \rightarrow 8$
 $k = -4 \rightarrow 14$
 $l = -14 \rightarrow 35$
 3 standard reflections
 frequency: 120 min
 intensity decay: <5%

$(\Delta/\sigma)_{\text{max}} < 0.001$
 $\Delta\rho_{\text{max}} = 0.15 \text{ e \AA}^{-3}$
 $\Delta\rho_{\text{min}} = -0.13 \text{ e \AA}^{-3}$
 Extinction correction: *SHELXL97*
 Extinction coefficient: 0.0039 (9)
 Scattering factors from *International Tables for Crystallography* (Vol. C)

Compound (3)

Crystal data

C₁₁H₉N₃O₂
M_r = 215.21
 Monoclinic
P2₁/c
a = 14.188 (3) Å
b = 5.2850 (3) Å
c = 26.954 (6) Å
 β = 93.550 (10)°
V = 2017.2 (6) Å³
Z = 8
D_x = 1.417 Mg m⁻³
D_m not measured

Mo *Kα* radiation
 λ = 0.71073 Å
 Cell parameters from 25 reflections
 θ = 11.6–16.0°
 μ = 0.101 mm⁻¹
T = 296 (2) K
 Plate
 0.30 × 0.20 × 0.07 mm
 Colourless

Data collection

Enraf–Nonius CAD-4 diffractometer

$R_{\text{int}} = 0.032$
 $\theta_{\text{max}} = 24.96^\circ$

ω -2 θ scans $h = -1 \rightarrow 16$
 Absorption correction: none $k = -4 \rightarrow 6$
 3731 measured reflections $l = -32 \rightarrow 31$
 3533 independent reflections 3 standard reflections
 1403 reflections with frequency: 120 min
 $I > 2\sigma(I)$ intensity decay: <5%

Refinement

Refinement on F^2 $(\Delta/\sigma)_{\max} < 0.001$
 $R[F^2 > 2\sigma(F^2)] = 0.047$ $\Delta\rho_{\max} = 0.20 \text{ e } \text{\AA}^{-3}$
 $wR(F^2) = 0.143$ $\Delta\rho_{\min} = -0.22 \text{ e } \text{\AA}^{-3}$
 $S = 0.971$ Extinction correction: none
 3533 reflections Scattering factors from
 289 parameters *International Tables for*
 H atoms constrained *Crystallography* (Vol. C)
 $w = 1/[\sigma^2(F_o^2) + (0.0553P)^2]$
 where $P = (F_o^2 + 2F_c^2)/3$

For (1), the direction of the polar axis could not be determined reliably as the heaviest atom in the structure was oxygen. For structure (3), the presence of a pseudo-*b*-glide plane (perpendicular to **a**) was noted, but no alternative cell could be identified.

For all compounds, data collection: *CAD-4 Software* (Enraf-Nonius, 1989); cell refinement: *SET4* in *CAD-4 Software*; data reduction: *Xtal3.2* (Hall *et al.*, 1992); program(s) used to solve structures: *SHELXS86* (Sheldrick, 1990); program(s) used to refine structures: *SHELXL97* (Sheldrick, 1997); molecular graphics: *PLATON* (Spek, 1990); software used to prepare material for publication: *SHELXL97*.

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Supplementary data for this paper are available from the IUCr electronic archives (Reference: TA1264). Services for accessing these data are described at the back of the journal.

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4,4'-Bipyridinium diperchlorate

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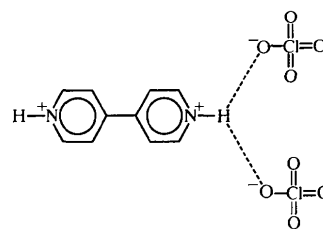
Abstract

In 4,4'-bipyridinium diperchlorate, $\text{C}_{10}\text{H}_{10}\text{N}_2^{2+} \cdot 2\text{ClO}_4^-$, the centrosymmetric dication and the anions are linked by three $\text{N} \cdots \text{O}$ hydrogen bonds [$\text{N} \cdots \text{O} = 2.893(3)$, $2.915(3)$ and $2.972(3)$ Å] into a two-dimensional network.

Comment

The two pyridyl moieties of the 4,4'-bipyridinium dication are coplanar in the diiodide (Iyere *et al.*, 1998) and in the monoclinic modification of the dinitrate (Weakley, 1987), but are twisted by 39° in the orthorhombic modification of the dinitrate (Barker *et al.*, 1990). For the dinitrate, the cation lies on a centre-of-inversion in the orthorhombic modification and on a twofold axis in the monoclinic modifications; both modifications display only one $\text{N} \cdots \text{O}$ hydrogen bond [2.77(1) Å (Weakley, 1987); 2.674 Å (Barker *et al.*, 1990)]. However, $\text{C}-\text{H} \cdots \text{X}$ interactions [3.163(6)–3.239(4) Å] are present in the two modifications as well as in the centrosymmetric diiodide [$\text{C}-\text{H} \cdots \text{I} = 3.740(5)$ – $3.818(5)$ Å] (Iyere *et al.*, 1998).

The two rings in the diperchlorate, (I) (Fig. 1), are also exactly coplanar, a feature that is predicted



(I)