

Crystals **2012**, *2*, 1366-1373; doi:10.3390/cryst2041366

OPEN ACCESS

crystals

ISSN 2073-4352

www.mdpi.com/journal/crystals

Short Note

A One-Dimensional Coordination Polymer Constructed from Cadmium(II) Cations and Sparfloxacin Anions

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Received: 28 June 2012; in revised form: 22 August 2012 / Accepted: 1 September 2012 /

Published: 28 September 2012

Abstract: The synthesis and crystal structure of the one-dimensional coordination polymer, $[\text{Cd}(\text{spar})_2]_n \cdot n(\text{H}_2\text{O})$, are described, where spar^- is the sparfloxacin anion, $\text{C}_{19}\text{H}_{21}\text{N}_4\text{O}_3\text{F}_2^-$. The Cd^{2+} ion is bonded to four spar^- ligands: Two O,O-chelate with their β -keto carboxylate groupings and two are monodentate-bound through a carboxylate O atom, to result in a distorted CdO_6 octahedral coordination geometry. The bridging ligands lead to [100] polymeric chains in the crystal and N–H \cdots O hydrogen bonds and possible weak aromatic π – π stacking interactions help to consolidate the structure. Crystal data: $\text{C}_{38}\text{H}_{44}\text{CdF}_4\text{N}_8\text{O}_7$, $M_r = 913.21$, triclinic, $P\bar{1}$ (No. 2), $Z = 2$, $a = 9.2256(4)$ Å, $b = 12.8767(5)$ Å, $c = 17.4297(7)$ Å, $\alpha = 89.505(2)^\circ$, $\beta = 85.062(2)^\circ$, $\gamma = 70.757(2)^\circ$, $V = 1947.20(14)$ Å³, $R(F) = 0.036$, $wR(F^2) = 0.082$.

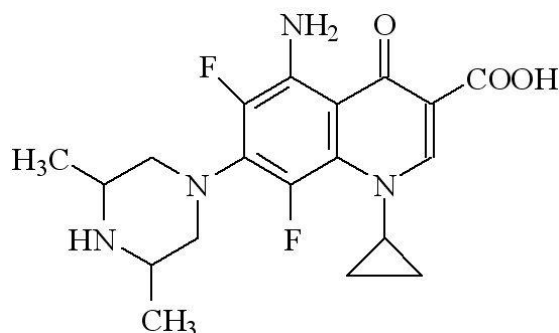
Keywords: one-dimensional coordination polymer; sparfloxacin; cadmium

1. Introduction

Sparfloxacin ($\text{C}_{19}\text{H}_{22}\text{N}_4\text{O}_3\text{F}_2$; Hspar; systematic name: 5-amino-1-cyclopropyl-7-[(3*R**,5*S**)-(3,5-dimethylpiperazin-1-yl)]-6,8-difluoro-4-oxo-quinoline-3-carboxylic acid), is a quinolone derivative (Figure 1) [1] with significant antibiotic properties [2,3], although ironically, the effectiveness of

Hspar and related compounds in treating infections appear to promote the subsequent colonization by “super bugs” such as MRSA [4]. Our own interest in this class of compounds, along with that of others, is focused on their potential as multi-dentate and bridging ligands in the construction of new complexes [5] and coordination polymers [6,7].

Figure 1. Chemical scheme for sparfloxacin ($C_{19}H_{22}N_4O_3F_2$).



The crystal structure of the hydrated, zwitterionic molecule of Hspar has been reported [8] and its hydrate polymorphism demonstrated, which may have important pharmacological consequences [9]. A molecular salt of the H_2spar^+ cation with sulfate counter-ions is known [10]. The crystal structures of its anionic complexes with nickel [11], copper [12,13] and zinc [14] have been reported. As an extension of these studies, we now describe the hydrothermal synthesis and crystal structure of the polymeric title compound, $[Cd(spar)_2]_n \cdot n(H_2O)$, (**1**).

2. Results and Discussion

2.1. Crystal Structure of $[Cd(spar)_2]_n \cdot nH_2O$ (**1**)

Compound **1** is a one-dimensional coordination polymer: The asymmetric unit contains a Cd^{2+} cation, two mono-anionic $spar^-$ ligands and a disordered water molecule of crystallisation (Figure 2).

The metal ion in **1** is coordinated by two bidentate $spar^-$ anions, with the ketone O-atom and its *syn*-carboxylate O atom (O3 and O2, respectively, in the C1-containing ion and O6 and O5, respectively, in the C20-ion) serving as the donors, which generates a six-membered chelate ring in each case. The metal coordination sphere is completed by two monodentate-O bonded $spar^-$ species: In each case the carboxylate O-atom anti to the ketone O-atom is involved. Together, these lead to a moderately distorted octahedral geometry for the CdO_6 polyhedron (Table 1, Figure 3), with the monodentate O-atoms in a *cis* disposition. The mean Cd–O separation is 2.293 Å, the angular variance [15] for the O–Cd–O bond angles is 105.2° and the bond-valence-sum (BVS) for the metal ion, calculated by the Brown–Altermatt formalism [16], is 2.11 (expected value = 2.00). The –O2–C1–C2–C3–O3–Cd1– six-membered chelate ring approximates to a distorted half-chair, with O2 and Cd1 displaced by 0.320(5) Å and –0.702(7) Å, respectively, from the plane of the other four atoms (r.m.s. deviation = 0.026 Å). The –O5–C20–C21–C22–O6–Cd1– ring can be described in the same way, with O5 and Cd1 displaced by 0.190(5) Å and –1.013(7) Å, respectively, from the other atoms (r.m.s. deviation = 0.008 Å). The dihedral angle between the near-planar segments of the chelate rings is $32.0(3)^\circ$.

Table 1. Selected geometrical data (Å,°) for **1**.

Cd1–O4	2.264(2)	Cd1–O1 ⁱ	2.269(2)
Cd1–O5 ⁱⁱ	2.280(2)	Cd1–O2	2.292(2)
Cd1–O6 ⁱⁱ	2.304(2)	Cd1–O3	2.3466(19)
O4–Cd1–O1 ⁱ	87.58(8)	O4–Cd1–O5 ⁱⁱ	90.75(8)
O1 ⁱ –Cd1–O5 ⁱⁱ	102.81(8)	O4–Cd1–O2	104.12(8)
O1 ⁱ –Cd1–O2	98.16(7)	O5 ⁱⁱ –Cd1–O2	154.76(7)
O4–Cd1–O6 ⁱⁱ	164.30(7)	O1 ⁱ –Cd1–O6 ⁱⁱ	100.15(8)
O5 ⁱⁱ –Cd1–O6 ⁱⁱ	74.28(8)	O2–Cd1–O6 ⁱⁱ	88.40(8)
O4–Cd1–O3	92.27(7)	O1 ⁱ –Cd1–O3	170.82(8)
O5 ⁱⁱ –Cd1–O3	86.37(7)	O2–Cd1–O3	72.97(7)
O6 ⁱⁱ –Cd1–O3	82.26(8)		

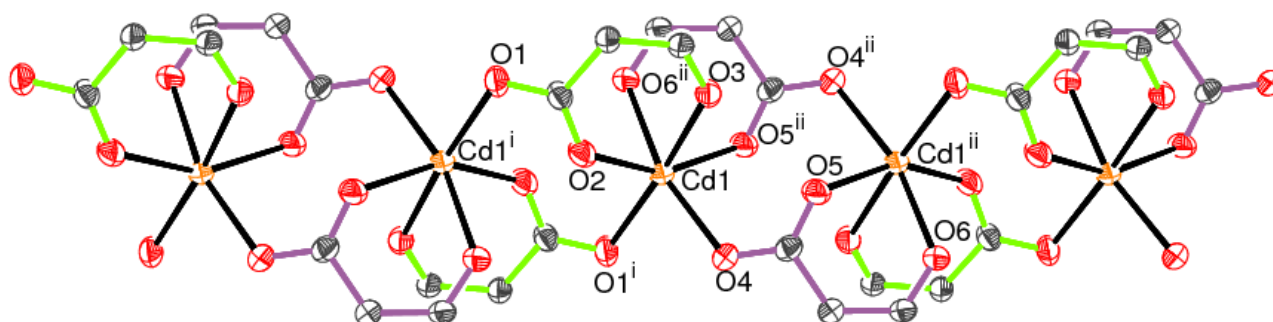
Symmetry codes: ⁱ 2 – x, 1 – y, 1 – z; ⁱⁱ 1 – x, 1 – y, 1 – z.

The important geometrical features of the first spar^- anion (containing C1) are as follows: The C1–O1 and C1–O2 bond lengths of 1.266(4) Å and 1.250(3) Å, respectively, are typical for a delocalised carboxylate group and the dihedral angle between C1/O1/O2 and the adjacent N2-containing ring (r.m.s. deviation = 0.051 Å) is 11.5(5)°. The dihedral angle between the cyclopropane ring and the N2 ring is 66.4(2)°. The dihedral angle between the N2 ring and the C5 ring (r.m.s. deviation = 0.021 Å), which are fused at the C4–C9 bond, is 7.50(15)°, indicating a significant puckering to the quinolone system. The piperazine ring adopts a typical chair conformation with the N–C_q (q = quinolone) bond in an equatorial orientation. Its geometry is complicated by disorder of the C atoms bearing the terminal methyl groups over two orientations, in a 0.766(10):0.234(10) ratio, but both of these maintain the (3*R**,5*S**) relative configurations of these stereogenic atoms.

The second spar^- anion (containing C20) has a broadly similar geometry: The C20–O4 and C20–O5 bond lengths are 1.273(3) Å and 1.250(3) Å, respectively, and the dihedral angle between C20/O4/O5 and the N6 ring (r.m.s. deviation = 0.037°) is 4.0(4)°. The dihedral angle between the N6 ring and the pendent three-membered ring is 73.5(2)°. The N6 and C24 rings (r.m.s. deviation for the latter = 0.041 Å), fused at the C23–C28 bond, are tilted by 4.38(16)°. The piperazine ring in the second anion shows the same type of positional disorder as the first, in a 0.908(8):0.092(8) ratio for the two orientations.

The extended structure of **1** features polymeric chains in the [100] direction (Figure 4), such that each spar^- anion links two cadmium metal ions. Adjacent metal ions are fused via eight-membered loops, generated by crystallographic inversion symmetry.

Figure 4. Fragment of a [100] polymeric chain in **1** showing only the O atoms and linking C atoms of the ligands (50% displacement ellipsoids; symmetry codes as in Table 1). The bonds of the C1 and C20 spar^- anions are colored mint and plum, respectively.



To complete the structure of **1**, several N–H \cdots O hydrogen bonds occur of varying strengths, including a bifurcated N–H \cdots (O,O) link (Table 2). All of these bonds are intra-chain interactions. It is notable that neither of the piperazine H atoms (attached to N4 and N8) participates in a hydrogen bond, perhaps due in part to the steric crowding of the two adjacent methyl groups. Weak aromatic π – π stacking (centroid–centroid separation = 3.7164(17) Å between the N6 and C24 rings) might also play some role in consolidating the structure of **1**.

Table 2. Hydrogen-Bond geometries for **1**.

N1–H1A \cdots O1 ⁱⁱⁱ	0.86	2.33	3.021(3)	138
N1–H1B \cdots O3	0.86	1.96	2.598(3)	130
N1–H1B \cdots O5	0.86	2.35	3.061(3)	141
N5–H5A \cdots O4 ⁱⁱⁱ	0.86	2.59	3.221(3)	131
N5–H5B \cdots O6	0.86	1.98	2.609(3)	129

The four columns specify the D–H, H \cdots A and D \cdots A separations (Å) and the D–H \cdots A angle ($^\circ$), respectively. Symmetry code: ⁱⁱⁱ $x - 1, y, z$.

2.2. Spectroscopy

By analogy with data from related compounds [9], the 1629 cm^{-1} band is assigned as a C=O(pyridone) stretch and the 1570 cm^{-1} and 1364 cm^{-1} signals correspond to the carboxylate $-\text{CO}_2$ asymmetric and symmetric stretches, respectively.

3. Experimental Section

3.1. Synthesis and Characterization

A mixture of cadmium acetate trihydrate (0.25 mmol), sparfloxacin (0.5 mmol), 1,4-benzenedicarboxylic acid (0.25 mmol), sodium hydroxide (1 mmol), and water (15 mL) was stirred for 30 min at room temperature. The mixture was then transferred to a 25-mL Teflon-lined reactor and heated to 423 K for 72 h under autogenous pressure. Upon cooling, colorless prisms of **1** were recovered from the reaction mixture by vacuum filtration. The role of the 1,4-benzenedicarboxylic acid in the synthesis is unknown, but it has not proved possible to prepare **1** if it is not present.

Elemental analysis: calc (%) for $C_{38}H_{44}CdF_4N_8O_7$: C 49.98, H 4.86, N 12.27; found (%): C 49.76, H 4.49, N 12.04. IR (cm^{-1} , KBr): 3450 (br, m), 1629 (s), 1570 (s), 1449 (s), 1364 (w), 1290 (s).

3.2. Single-Crystal Data Collection and Analysis

The single-crystal data for **1** (colorless prism $0.20 \times 0.20 \times 0.18$ mm) were collected using a Bruker APEX II CCD diffractometer (graphite monochromated $MoK\alpha$ radiation, $\lambda = 0.71073$ Å) at room temperature. Data reduction with SAINT [17] then proceeded and the structure was solved by direct methods with SHELXS-97 [18]. The resulting atomic model was developed and refined against $|F|^2$ with SHELXL-97 [18] and the “observed data” threshold for calculating the $R(F)$ residuals was set as $I > 2\sigma(I)$. The C-bound H atoms were placed in idealised locations (C–H = 0.93–0.98 Å) and refined as riding atoms. The N-bound H atoms were located in difference maps: Those attached to N1 and N5 were relocated to idealised locations (N–H = 0.86 Å) and refined as riding and those attached to N4 and N8 were refined as riding in their as-found relative locations. Due to the disorder of the piperazine rings, the location of the N4 and N8 H atoms are perhaps less certain, although they appeared reasonably distinctly in difference maps. The constraint $U_{iso}(H) = 1.2U_{eq}(\text{carrier})$ or $1.5U_{eq}(\text{methyl carrier})$ was applied as appropriate. The H atoms associated with the disordered water molecule could not be located; based on geometrical considerations, one of the water molecules may form a hydrogen bond to N4. The structural model was analysed and validated with PLATON [19] and full refinement details are given in the deposited cif.

Crystal data for **1**: $C_{38}H_{44}CdF_4N_8O_7$, $M_r = 913.21$, triclinic, $P\bar{1}$ (No. 2), $Z = 2$, $a = 9.2256(4)$ Å, $b = 12.8767(5)$ Å, $c = 17.4297(7)$ Å, $\alpha = 89.505(2)^\circ$, $\beta = 85.062(2)^\circ$, $\gamma = 70.757(2)^\circ$, $V = 1947.20(14)$ Å³, $F(000) = 936$, $T = 296(2)$ K, $\rho_{calc} = 1.558$ g·cm⁻³, $\mu = 0.640$ mm⁻¹, 27884 reflections recorded ($3.4^\circ \leq 2\theta \leq 50.0^\circ$; $-10 \leq h \leq 10$, $-15 \leq k \leq 15$, $-20 \leq l \leq 20$), $R_{int} = 0.039$, 6848 merged reflections, 6225 with $I > 2\sigma(I)$, 541 variable parameters, $R(F) = 0.036$, $wR(F^2) = 0.082$, min./max. $\Delta\rho = -0.58/0.46$ e Å⁻³. Cambridge Structural Database deposition number: CCDC-888200.

4. Conclusions

The synthesis and crystal structure of the title one-dimensional coordination polymer have been described, in which the metal atom adopts a distorted octahedral geometry arising from its coordination by two O,O-bidentate and two O-monodentate $spar^-$ anions. The linkages in the polymeric chain are centrosymmetric eight-membered rings. The structure of **1** is completely different to that of $Cd_2(\text{enro})_4(\text{H}_2\text{O})_2 \cdot 4\text{H}_2\text{O}$ (Henro = enrofloxacin; $C_{19}H_{22}N_3O_3F$), in which isolated binuclear complexes occur and the metal coordination geometry is a CdO_6 trigonal prism [5]. In $[Cd(\text{cipro})_2]_n \cdot 2.5n\text{H}_2\text{O}$ (Hcipro = ciprofloxacin; $C_{17}H_{18}FN_3O_4$) [6], the Cd^{2+} ion is coordinated by O,O-bidentate and N_p -bonded ($p = \text{piperazine}$) cipro^- ions to generate a coordination network containing *trans*- CdN_2O_4 octahedra. Conversely, $Cd(\text{Hcipro})_2Cl_2 \cdot 4\text{H}_2\text{O}$ is a mononuclear complex containing O,O-bidentate neutral, zwitterionic Hcipro molecules and two charge-balancing chloride ions to generate *trans*- $CdCl_2O_4$ octahedra [20].

References

1. Andersson, M.I.; MacGowan, A.P. Development of the quinolones. *J. Antimicrob. Chemother.* **2003**, *51*, 1–11.
2. Miyamoto, T.; Matsumoto, J.-I.; Chiba, K.; Egawa, H.; Shibamori, K.; Minamida, A.; Nishimura, Y.; Okada, H.; Kataoka, M.; Fujita, M.; Hirose, T.; Nakano, J. Pyridonecarboxylic acids as antibacterial agents. 14: Synthesis and structure-activity relationship of 5-substituted 6,8-difluoroquinolones, including sparfloxacin, a new quinoline antibacterial agent with improved potency. *J. Med. Chem.* **1990**, *33*, 1645–1656.
3. Qadri, S.M.; Ueno, Y.; Burns, J.J.; Almodovar, E.; Rabea, N. *In vitro* activity of sparfloxacin (CI-978), a new broad-spectrum fluoroquinolone. *Chemotherapy* **1992**, *38*, 99–106.
4. Tacconelli, E.; De Angelis, G.; Cataldo, M.A.; Pozzi, E.; Cauda, R. Does antibiotic exposure increase the risk of methicillin-resistant *Staphylococcus aureus* (MRSA) isolation? A systematic review and meta-analysis. *J. Antimicrob. Chemother.* **2007**, *61*, 26–38.
5. An, Z.; Gao, J.; Harrison, W.T.A. Two binuclear complexes containing the enrofloxacin anion: $\text{Cd}_2(\text{C}_{19}\text{H}_{21}\text{N}_3\text{O}_3\text{F})_4(\text{H}_2\text{O})_2 \cdot 4\text{H}_2\text{O}$ and $\text{Pb}_2(\text{C}_{19}\text{H}_{21}\text{N}_3\text{O}_3\text{F})_4 \cdot 4\text{H}_2\text{O}$. *J. Coord. Chem.* **2010**, *63*, 3871–3879.
6. Xiao, D.-R.; Wang, E.-B.; An, H.-Y.; Su, Z.-M.; Li, Y.-G.; Gao, L.; Sun, C.-Y.; Xu, L. Rationally designed, polymeric, extended metal-ciprofloxacin complexes. *Chem. Eur. J.* **2005**, *11*, 6673–6686.
7. An, Z.; Liu, L.-R.; Liu, Y.-Q. Poly[bis[μ -1-cyclopropyl-6-fluoro-4-oxido-7-(1-piperazinyl)-1,4-dihydroquinoline-3-carboxylato]nickel(II)]. *Acta Cryst.* **2008**, *E64*, m176.
8. Sivalakshmi, A.; Vyas, K.; Om Reddy, G. Sparfloxacin, an antibacterial drug. *Acta Cryst.* **2000**, *C56*, e115–e116.
9. Llinas, A.; Burley, J.C.; Prior, T.J.; Glen, R.C.; Goodman, J.M. Concomitant hydrate polymorphism in the precipitation of sparfloxacin from aqueous solution. *Cryst. Growth Des.* **2008**, *8*, 114–118.
10. Li, T.; Yang, L.; Wang, Y.C.; Lian, Q. Bis[(2*R*,6*S*)-4-(5-amino-3-carboxy-1-cyclopropyl-6,8-difluoro-4-oxo-1,4-dihydroquinolin-7-yl)-2,6-dimethylpiperazin-1-ium] sulfate pentahydrate. *Acta Cryst.* **2011**, *E67*, o3366.
11. Skyrianou, K.C.; Raptopoulou, C.P.; Psycharis, V.; Kessissoglou, D.P.; Psomas, G. Structure, cyclic voltammetry and DNA-binding properties of the bis(pyridine)bis(sparfloxacinato)nickel(II) complex. *Polyhedron* **2009**, *28*, 3265–3271.
12. Efthimiadou, E.K.; Sanakis, Y.; Raptopoulou, C.P.; Karaliota, K.; Katsaros, N.; Psomas, G. Crystal structure, spectroscopic, and biological study of the copper(II) complex with third-generation quinolone antibiotic sparfloxacin. *Bioorg. Med. Chem. Lett.* **2006**, *16*, 3864–3867.
13. Shingnapurkar, D.; Butcher, R.; Afrasiabi, Z.; Sinn, E.; Ahmed, F.; Sarkar, F.; Padhye, S. Neutral dimeric copper-sparfloxacin conjugate having butterfly motif with antiproliferative effects against hormone independent BT20 breast cancer cell line. *Inorg. Chem. Commun.* **2007**, *10*, 459–462.
14. Tarushi, A.; Polatoglou, E.; Kljun, J.; Turel, I.; Psomas, G.; Kessissoglou, D.P. Interaction of Zn(II) with quinolone drugs: Structure and biological evaluation. *Dalton Trans.* **2011**, *40*, 9461–9473.

15. Robinson, K.; Gibbs, G.V.; Ribbe, P.H. Quadratic elongation—quantitative measure of distortion in coordination polyhedra. *Science* **1971**, *172*, 567–570.
16. Brown, I.D.; Altermatt, D. Bond-Valence parameters obtained from a systematic analysis of the Inorganic Crystal Structure Database. *Acta Cryst.* **1985**, *B41*, 244–247.
17. *APEX2 and SAINT Diffractometer Control Software*; Bruker AXS Inc.: Madison, WI, USA, 2009.
18. Sheldrick, G.M. A short history of SHELX. *Acta Cryst.* **2008**, *A64*, 112–122.
19. Spek, A.L. Structure validation in chemical crystallography. *Acta Cryst.* **2009**, *D65*, 148–155.
20. Lopez-Gresa, M.P.; Ortiz, R.; Perello, L.; Latorre, J.; Liu-Gonzalez, M.; Garcia-Granda, S.; Perez-Priede, M.; Canton, E. Interactions of metal ions with two quinolone antimicrobial agents (cinoxacin and ciprofloxacin)—Spectroscopic and X-ray structural characterization. Antibacterial studies. *J. Inorg. Biochem.* **2002**, *92*, 65–74.

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