Journal of Molecular Structure 1284 (2023) 135362

Contents lists available at ScienceDirect

Journal of Molecular Structure

journal homepage: www.elsevier.com/locate/molstr

# Comment on "Crystallographic and theoretical study of the atypical distorted octahedral geometry of the metal chromophore of zinc(II) bis((1*R*,2*R*)-1,2-diaminocyclohexane) dinitrate"☆

Martin Lutz

*Utrecht University, Faculty of Science, Bijvoet Centre for Biomolecular Research, Structural Biochemistry, Universiteitsweg 99, 3584 CG, Utrecht, The Netherlands*

ARTICLE INFO

*Article history:*
Received 15 December 2022
Revised 10 March 2023
Accepted 14 March 2023
Available online 29 March 2023

*Keywords:*
Symmetry
Chirality
Crystal structure validation

ABSTRACT

We comment on the crystal structure of an enanantipure chiral zinc complex which has been described by Ivanova & Spiteller (2022) erroneously in a centrosymmetric space group with the metal on an inversion center. Subsequent information about thermal motion, octahedral distortion and charge density in their article is highly flawed.



## 1. Introduction

The title compound in [1] has been synthesized with the enantiopure ligand (1*R*,2*R*)-1,2-diaminocyclohexane and the stereochemistry is highlighted in the title of the article. Surprisingly, the crystal structure was solved and refined in the centrosymmetric space group $P2_1/n$ with the zinc atom on an inversion center. The immediate consequences are extraordinarily high agreement factors (R-values) and physically unreasonable displacement parameters (Fig. 1). Six of the 14 non-hydrogen atoms have a non-positive definite displacement tensor. The Experimental Section of [1] mentions a thermal motion analysis with the THMA software [2]. The results are not provided but we assume that the program will fail, here.

Despite the wrong space group assignment, the unphysical atomic displacement parameters, the two missing hydrogen atoms (*i.e.* charged unit cell content), the low resolution of $\theta_{max} = 24.93^{\circ}$ ($d_{max} = 0.84$ Å), the low data completeness of 37.4% and the non-cryo measurement at $T = 300K$, the authors in [1] performed an extensive analysis based on the electron density from a multipole refinement. The experimental conditions for such a refinement have clearly not been met. Minimal experimental requirements can be found in textbooks and in the manual of the XD2016 software [4] used by the authors of [1].

The Supplementary Materials for [1] are very incomplete. The file 1-s2.0-S0022286021016161-mmc1.docx has a size of only 16 kByte and does not contain the tables and figures which are referenced in the main text. More importantly, the structure factors (X-ray reflection data) were not deposited. This is in contrast to the recommendations for current practice in crystallography [5]. Because of the missing data, the interested reader has no possibility to verify the presented results. We therefore had to re-synthesize the compound and to repeat the X-ray data collection ourselves. It turned out that all of our own crystals were twinned. It remains unclear whether the authors of [1] were able to find an untwinned specimen or whether they have overlooked the twinning.

## 2. Results

We solved and refined the crystal structure of $[C_{12}H_{32}N_4O_2Zn](NO_3)_2$ in the correct space group $P2_1$. This is a Sohncke space group and contains only symmetry operations of the first kind [6]. It is thus compatible with the enantiopure molecular structure. All atoms are located on general positions without symmetry. With the correct symmetry and appropriate treatment of the crystal twinning (*see* Experimental Section) low R-values are obtained and the displacement parameter behave reasonably (Fig. 2). No signs of disorder are detected and all hyrogen atoms can be located in difference Fourier maps. The enantiopurity of the crystal was confirmed by a determination of the Flack parameter using the quotient method [7] as implemented in the SHELXL-2018 refinement software [8].

☆ B. Ivanova, M. Spiteller (2022) *J. Mol. Struct.*1248, 131488

*E-mail address:* m.lutz@uu.nl

https://doi.org/10.1016/j.molstruc.2023.135362

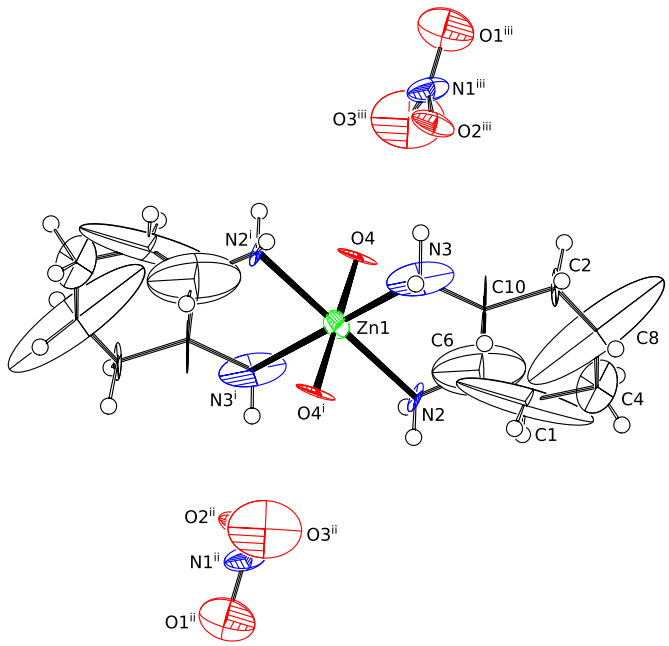


**Fig. 1.** Displacement ellipsoid plot (50% probability level) created from the data in [1] (deposition number 1576255 in the Cambridge Structural Database [3]). The structure is based on a wrong space group assignment $P2_1/n$, and the zinc atom is erroneously constrained on an inversion center. Hydrogen atoms of the coordinated water molecule are missing in the original data. Symmetry codes *i:* $-x, 1-y, -z$; *ii:* $1-x, -y, -z$; *iii:* $x-1, y+1, z$.

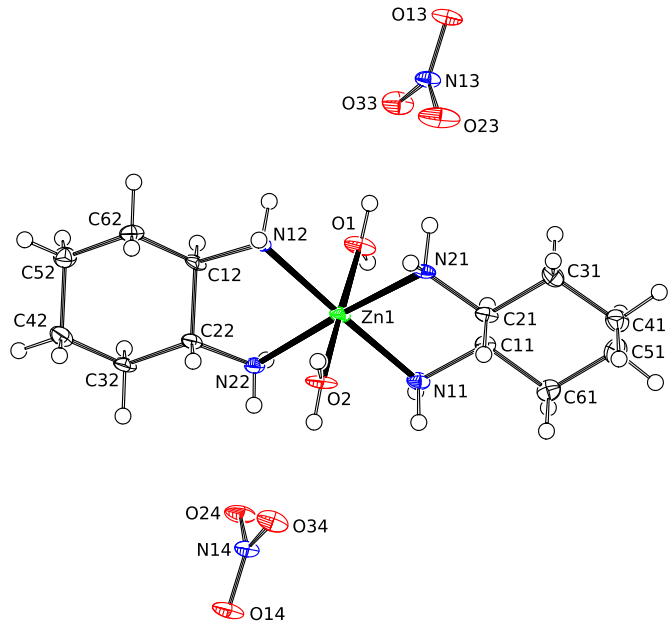


**Fig. 2.** Displacement ellipsoid plot (50% probability level) of the current study. The structure is based on the correct space group assignment $P2_1$, and all atoms are on general positions.

The title complex has a coordination number of six which is very common for zinc complexes [9,10]. It contains two symmetry independent diaminocyclohexane ligands. Both cyclohexane rings are in nearly perfect chair conformation. The metal complex only has the trivial $C_1$ symmetry but with the algorithm of [11] an approximate $C_2$ symmetry is found (r.m.s. deviation from perfect symmetry: 0.0665 Å). With a larger tolerance, the symmetry will be $D_2$ (r.m.s.d. 0.1222 Å). No approximate inversion center is present.

By hydrogen bonding the molecules are connected into layers extending in the $a, b$-plane. The water and the amino groups act as hydrogen bond donors and the nitrate anions as acceptors. The two-dimensional arrangement is consistent with the shape of the crystals. They are extremely thin plates where {001} has the short crystal dimension. Layer structures are prone to stacking faults [12]. The twin operation, a twofold rotation about [100] or equivalently about (001), is probably the consequence of such faults.

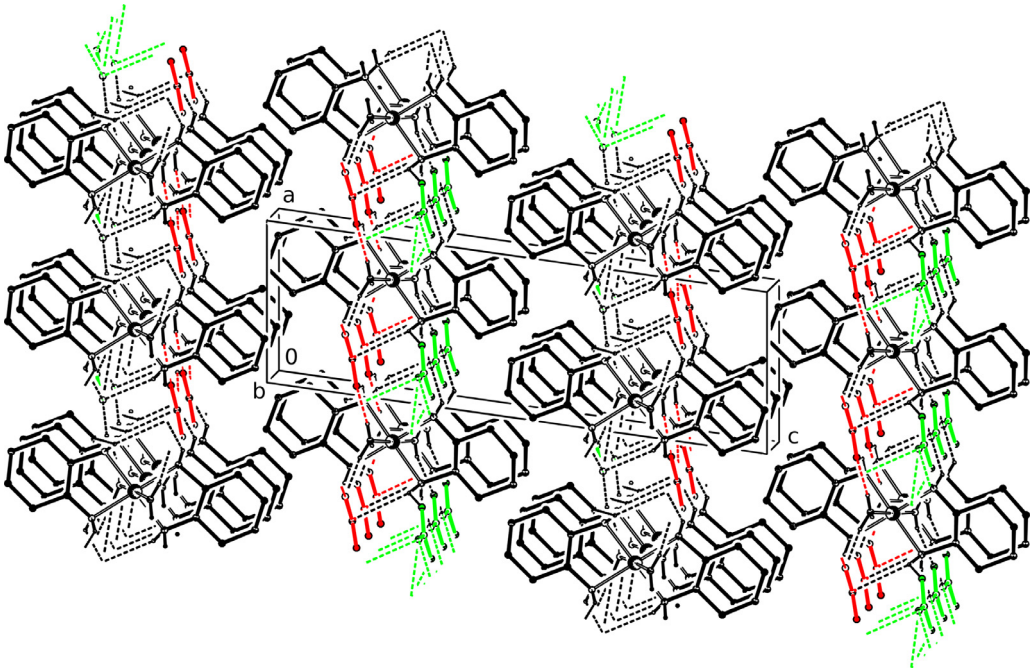


**Fig. 3.** Hydrogen-bonded layers in the crystallographic $a, b$-plane. C–H hydrogen atoms are omitted for clarity. The metal complex cations are drawn in black, the nitrate anions in red and green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

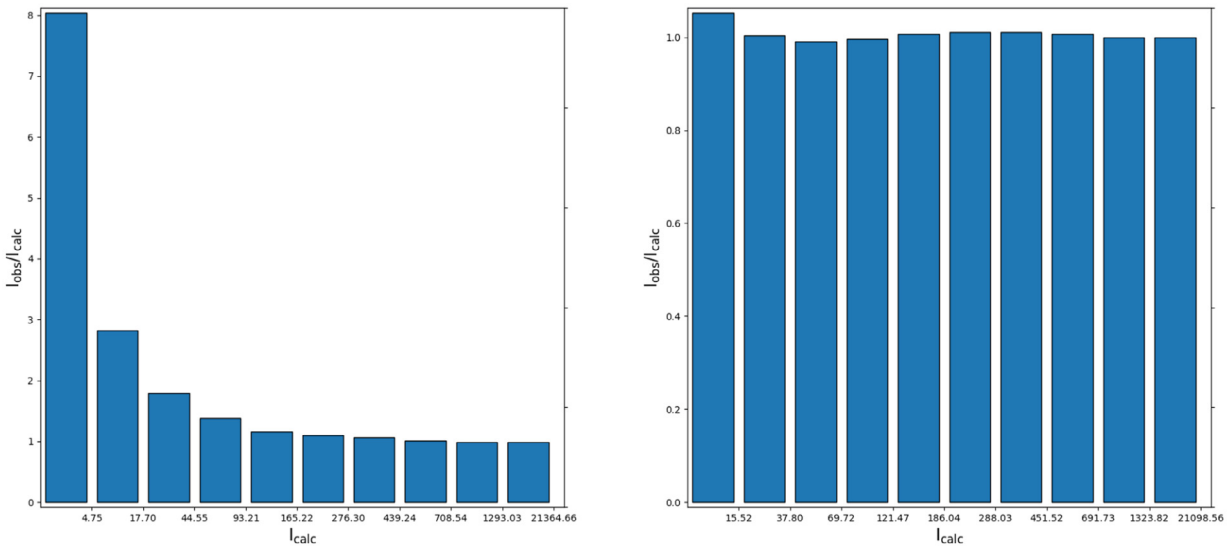


**Fig. 4.** Histogram of the scale factor $k = mean(F^2_{obs})/mean(F^2_{calc})$ versus $F^2_{calc}$. The $F^2_{obs}$ data are de-twinned (*LIST 8* instruction in SHELXL-2018). Plots were prepared with the anafcf software [16]. The left histogram is from space group $P2_1/n$, the right from space group $P2_1$.

The routine ADDSYM in the PLATON software [13] detects an 85% fit for the transformation of the current structure into the centrosymmetric space group $P2_1/n$. As expected, the deviating atoms are the asymmetric carbons C1x and C2x (x=1,2). Additionaly, the ring carbons C4x and C5x also do not fit. The maximum deviation between an atom and its potentially symmetry equivalent is 0.43 Å, which is more than anisotropic displacement parameters can model. Ignoring our knowledge about the enantiopurity we refined the structural model of [1] against our reflection data. Taking the twinning into account, the R-values improve slightly from $R1 = 0.1235$ in [1] to $R1 = 0.0936$ with the current X-ray data. Still, the displacement parameters are unacceptable and one atom remains non-positive definite.

With the refinement in the incorrect space group $P2_1/n$ it was possible to compare the variance of scale factors with the correct refinement in $P2_1$. In the histogram, the scale factor $k = I_{obs}/I_{calc}$ should be constant and close to 1 for all intensity bins. A large deviation for the weak/weakest reflections is a strong indication for a wrong symmetry [14,15]. Only the data from space group $P2_1$ show a flat histogram (Fig. 4) while the incorrect $P2_1/n$ shows large variations, expecially for the weak reflections. The histograms thus support the choice for $P2_1$.

Space group determination from systematic absences is difficult in the current case because of the non-merohedral twinning and the presence of *pseudo*-symmetries. The de-twinned reflection data indeed show significantly lower intensities for $h + \ell = odd$ (*n*-glide plane) but these reflections are not really absent. 81 of these reflections have an intensity of $I > 3\sigma(I)$ and are thus violating the *n*-glide condition. It should also be noted that reflections with $h + k + \ell = odd$ are weak and indicate a *pseudo*-I centered Bravais lattice. In the peak search for the unit cell determination it is thus important to include the weaker reflections.

## 3. Experimental section

### 3.1. Synthesis

0.19 g (1.66 mmol) (1*R*,2*R*)-(-)-Diaminocyclohexane (Aldrich) are dissolved in 10 mL technical ethanol. 0.25 g (0.84 mmol) Zinc nitrate hexahydrate (Sigma-Aldrich) in 5 mL water are slowly added under stirring at room temperature. After slow evaporation at room temperature, crystals appeared after 4 days.

### 3.2. X-ray crystal structure determination

$[C_{12}H_{32}N_4O_2Zn](NO_3)_2$ Fw = 453.80, colourless plate, 0.37 × 0.27 × 0.06 mm, monoclinic, $P2_1$ (no. 4), a = 6.6990(5), b = 7.1567(7), c = 20.9053(12) Å, $\beta = 97.846(4)^\circ$, V = 992.87(14) Å$^3$, Z = 2, $D_x = 1.518$g/cm$^3$, $\mu = 1.29$mm$^{-1}$. The diffraction experiment was performed on a Bruker Kappa ApexII diffractometer with sealed tube and Triumph monochromator ($\lambda$ = 0.71073 Å) at a temperature of 125(2) K up to a resolution of $(\sin\theta/\lambda)_{\max} = 0.65$ Å$^{-1}$. The crystal appeared to be non-merohedrally twinned with a twofold rotation about $uvw = [1, 0, 0]$ as twin operation. Consequently, two orientation matrices were used for the intensity integration with the Eval15 software [17]. A large isotropic mosaicity of 1.5° was used for the prediction of the reflection profiles. The integration results were written in HKLF5 format [18]. A multi-scan absorption correction and scaling was performed with TWINABS [19] (correction range 0.55-0.75). A total of 34,148 reflections was measured, 4654 reflections were unique ($R_{int}$ = 0.061), 4240 reflections were observed [$I > 2\sigma(I)$]. The structure was solved with Patterson superposition methods using SHELXT [20]. Structure refinement was performed with SHELXL-2018 [8] on $F^2$ of all reflections. Non-hydrogen atoms were refined freely with anisotropic displacement parameters. All hydrogen atoms were located in difference Fourier maps. C–H hydrogen atoms were refined with a riding model. O–H and N–H hydrogen atoms were kept fixed at their located positions. 245 Parameters were refined with one restraint (floating origin). R1/wR2 [$I > 2\sigma(I)$]: 0.0316 / 0.0728. R1/wR2 [all refl.]: 0.0369 / 0.0744. S = 1.044. Twin fraction BASF=0.3601(12). Flack parameter [7] x = 0.023(10). Residual electron density between –0.51 and 0.36 e/Å$^3$. Geometry calculations and checking for higher symmetry was performed with the PLATON program [13].

## 4. Conclusions

The crystal structure in [1] is based on the assumption of a wrong space group. This is very obvious from the chemical synthesis and should have been noted earlier by the authors and the reviewers. Because of the missing structure factors in [1] we had to re-synthesize the compound and re-analyze the crystal structure. We could prove that the true space group is the non-centrosymmetric $P2_1$. All information derived from the crystal

structure in [1] is useless and should be disregarded by potential readers.

## Credit Author Statement

The current manuscript has been prepared by a single author.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

CCDC 2226587 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

## Acknowledgements

Loes Kroon-Batenburg is acknowledged for helpful discussions.

## Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.molstruc.2023.135362

## References

[1] B. Ivanova, M. Spiteller, Crystallographic and theoretical study of the atypical distorted octahedral geometry of the metal chromophore of zinc(ii) bis((1r,2r)-1,2-diaminocyclohexane) dinitrate, J Mol Struct 1248 (2022) 131488, doi:10.1016/j.molstruc.2021.131488. https://www.sciencedirect.com/science/article/pii/S0022286021016161

[2] V. Schomaker, K.N. Trueblood, Correlation of internal torsional motion with overall molecular motion in crystals, Acta Crystallographica Section B 54 (5) (1998) 507–514, doi:10.1107/S0108768198003243.

[3] C.R. Groom, I.J. Bruno, M.P. Lightfoot, S.C. Ward, The Cambridge Structural Database, Acta Crystallographica Section B 72 (2) (2016) 171–179, doi:10.1107/S2052520616003954.

[4] A. Volkov, P. Macchi, L.J. Farrugia, C. Gatti, P.R. Mallinson, T. Richter, T. Koritsanszky, XD2016 - a computer program for multipole refinement, topological analysis of charge densities and evalution of intermolecular interaction energies from experimental or theoretical structure factors, Technical Report, 2016.

[5] J.R. Helliwell, B. McMahon, J.M. Guss, L.M.J. Kroon-Batenburg, The science is in the data, IUCrJ 4 (6) (2017) 714–722, doi:10.1107/S2052252517013690.

[6] H. Flack, Chiral and achiral crystal structures, Helv. Chim. Acta 86 (4) (2003) 905–921, doi:10.1002/hlca.200390109.

[7] S. Parsons, H.D. Flack, T. Wagner, Use of intensity quotients and differences in absolute structure refinement, Acta Crystallographica Section B 69 (3) (2013) 249–259, doi:10.1107/S2052519213010014.

[8] G.M. Sheldrick, Crystal structure refinement with *SHELXL*, Acta Crystallographica Section C 71 (1) (2015) 3–8, doi:10.1107/S2053229614024218.

[9] M.M. Harding, The geometry of metal–ligand interactions relevant to proteins, Acta Crystallographica Section D 55 (8) (1999) 1432–1443, doi:10.1107/S0907444999007374.

[10] M. Dudev, J. Wang, T. Dudev, C. Lim, Factors governing the metal coordination number in metal complexes from cambridge structural database analyses, The Journal of Physical Chemistry B 110 (4) (2006) 1889–1895, doi:10.1021/jp054975n. PMID: 16471760

[11] T. Pilati, A. Forni, *SYMMOL*: a program to find the maximum symmetry group in an atom cluster, given a prefixed tolerance, J Appl Crystallogr 31 (3) (1998) 503–504, doi:10.1107/S0021889898002180.

[12] M. Lutz, L. Kroon-Batenburg, Accurate intensity integration in the twinned $\gamma$-form of *o*-nitroaniline, IUCrData 7 (11) (2022) x221059, doi:10.1107/S2414314622010598.

[13] A.L. Spek, Structure validation in chemical crystallography, Acta Crystallographica Section D 65 (2) (2009) 148–155, doi:10.1107/S090744490804362X.

[14] M. Walker, E. Pohl, R. Herbst-Irmer, M. Gerlitz, J. Rohr, G.M. Sheldrick, Absolute configurations of Emycin D, E and F; mimicry of centrosymmetric space groups by mixtures of chiral stereoisomers, Acta Crystallographica Section B 55 (4) (1999) 607–616, doi:10.1107/S0108768199003948.

[15] Y. Huang, M.-E. Moret, R.J.M. Klein Gebbink, M. Lutz, Crystallographic space group choice and its chemical consequences: revised crystal structure of [fe(phen)2cl2]no3, Eur J Inorg Chem 2013 (13) (2013) 2467–2469, doi:10.1002/ejic.201201452. https://chemistry-europe.onlinelibrary.wiley.com/doi/abs/10.1002/ejic.201201452

[16] A.M.M. Schreurs, M. Lutz., anafcf (Utrecht University, The Netherlands), 2022, http://www.crystal.chem.uu.nl/distr.

[17] A.M.M. Schreurs, X. Xian, L.M.J. Kroon-Batenburg, *EVAL15*: a diffraction data integration method based on *ab initio* predicted profiles, J Appl Crystallogr 43 (1) (2010) 70–82, doi:10.1107/S0021889809043234.

[18] R. Herbst-Irmer, G.M. Sheldrick, Refinement of twinned structures with *SHELXL*97, Acta Crystallographica Section B 54 (4) (1998) 443–449, doi:10.1107/S0108768197018454.

[19] M. Sevvana, M. Ruf, I. Usón, G.M. Sheldrick, R. Herbst-Irmer, Non-merohedral twinning: from minerals to proteins, Acta Crystallographica Section D 75 (12) (2019) 1040–1050, doi:10.1107/S2059798319010179.

[20] G.M. Sheldrick, *SHELXT* – Integrated space-group and crystal-structure determination, Acta Crystallographica Section A 71 (1) (2015) 3–8, doi:10.1107/S2053273314026370.