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Redetermination of the crystal structure of (2*E*,4*Z*,13*E*,15*Z*)-3,5,14,16-tetramethyl-2,6,13,17-tetraazatricyclo[16.4.0.0^{7,12}]docosa-1(22),2,4,7,9,11,13,15,18,20-decaene, $C_{22}H_{24}N_4$

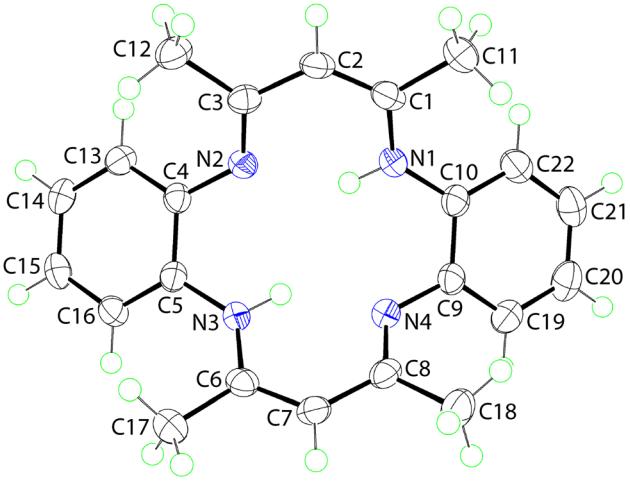

Table 1: Data collection and handling.

Crystal:	Yellow plate
Size:	0.20 × 0.20 × 0.10 mm
Wavelength:	Mo *K*α radiation (0.71073 Å)
μ:	0.08 mm^{-1}
Diffractometer, scan mode:	Rigaku Saturn724, ω
θ_{max}, completeness:	27.5°, 99%
$N(hkl)_{measured}$, $N(hkl)_{unique}$, R_{int}:	9263, 4078, 0.015
Criterion for I_{obs}, $N(hkl)_{gt}$:	$I_{obs} > 2\ \sigma(I_{obs})$, 3392
N(*param*)refined:	245
Programs:	REQAB [1], CrystalClear [2], SHELX [3, 4], WinGX/ORTEP [5], Diamond [6]

https://doi.org/10.1515/ncrs-2021-0244
Received June 15, 2021; accepted July 6, 2021;
published online July 21, 2021

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Abstract

$C_{22}H_{24}N_4$, triclinic, $P\bar{1}$ (no. 2), a = 9.217(4) Å, b = 9.774(4) Å, c = 10.843(4) Å, α = 96.770(2)°, β = 101.791(5)°, γ = 105.873(3)°, V = 903.9(6) Å^3, Z = 2, $R_{gt}(F)$ = 0.0391, $wR_{ref}(F^2)$ = 0.1069, T = 93(2) K.

CCDC no.: 1902271

The molecular structure is shown in the figure. Table 1 contains crystallographic data and Table 2 contains the list of the atoms including atomic coordinates and displacement parameters.

Source of material

The title macrocycle was isolated after a two-step procedure. Step 1: Preparation of the nickel(II) salt of the macrocycle. A solution of nickel(II) acetate tetrahydrate (2.00 g, 8.03 mmol) in butanol (10 mL) and 1,2-phenylenediamine (1.73 g, 16 mmol) in the same solvent (10 mL) were added to

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

Atom	*x*	*y*	*z*	U_{iso}*/U_{eq}
N1	0.27109 (12)	0.10660 (11)	0.66775 (10)	0.0213 (2)
H1N	0.3432 (14)	0.1715 (13)	0.6454 (13)	0.026*
N2	0.44043 (11)	0.20780 (10)	0.50519 (9)	0.0190 (2)
N3	0.68215 (12)	0.38152 (11)	0.69695 (9)	0.0209 (2)
H3N	0.5912 (12)	0.3434 (15)	0.7157 (13)	0.025*
N4	0.50957 (11)	0.28593 (11)	0.85799 (9)	0.0209 (2)
C1	0.21526 (13)	−0.01888 (12)	0.58099 (11)	0.0218 (3)
C2	0.26238 (14)	−0.02912 (12)	0.46907 (11)	0.0213 (2)
H2	0.217027	−0.118960	0.411109	0.026*
C3	0.37297 (13)	0.08140 (12)	0.42998 (11)	0.0199 (2)
C4	0.54675 (13)	0.32310 (12)	0.47286 (11)	0.0186 (2)
C5	0.67411 (13)	0.41255 (12)	0.57240 (11)	0.0191 (2)
C6	0.80638 (13)	0.38719 (12)	0.79100 (11)	0.0204 (2)
C7	0.78493 (14)	0.34181 (13)	0.90335 (11)	0.0214 (2)
H7	0.876047	0.349610	0.966936	0.026*
C8	0.63891 (14)	0.28408 (12)	0.93370 (11)	0.0208 (2)
C9	0.36310 (14)	0.23638 (13)	0.88525 (11)	0.0208 (2)
C10	0.23873 (14)	0.14242 (13)	0.78643 (11)	0.0207 (2)
C11	0.10744 (16)	−0.15005 (14)	0.61062 (13)	0.0301 (3)
H11A	0.138388	−0.152307	0.702184	0.045*
H11B	0.113235	−0.237675	0.560349	0.045*
H11C	0.000499	−0.145565	0.588628	0.045*
C12	0.40622 (15)	0.03588 (13)	0.30291 (12)	0.0252 (3)
H12A	0.328630	0.049814	0.233011	0.038*
H12B	0.401159	−0.066419	0.292176	0.038*
H12C	0.510374	0.094803	0.301296	0.038*
C13	0.52665 (14)	0.36269 (13)	0.35216 (11)	0.0216 (2)
H13	0.438940	0.306934	0.285291	0.026*
C14	0.63225 (15)	0.48175 (13)	0.32812 (12)	0.0235 (3)
H14	0.617882	0.505392	0.244889	0.028*
C15	0.75840 (14)	0.56599 (13)	0.42533 (12)	0.0235 (3)
H15	0.831755	0.646520	0.408565	0.028*
C16	0.77771 (14)	0.53283 (13)	0.54722 (12)	0.0223 (3)
H16	0.862641	0.592897	0.614367	0.027*
C17	0.96784 (14)	0.43626 (15)	0.77105 (13)	0.0276 (3)
H17A	0.966101	0.397355	0.683044	0.041*
H17B	1.037648	0.401207	0.831353	0.041*
H17C	1.005088	0.542242	0.785754	0.041*
C18	0.64604 (16)	0.21514 (15)	1.05196 (12)	0.0288 (3)
H18A	0.683633	0.290989	1.128847	0.043*
H18B	0.717228	0.156673	1.053412	0.043*
H18C	0.541854	0.153173	1.050106	0.043*
C19	0.33197 (15)	0.28716 (14)	0.99972 (12)	0.0265 (3)
H19	0.413262	0.355817	1.064366	0.032*
C20	0.18454 (16)	0.23921 (15)	1.02078 (13)	0.0304 (3)
H20	0.166081	0.272235	1.100382	0.036*
C21	0.06437 (15)	0.14299 (15)	0.92525 (13)	0.0286 (3)
H21	−0.036135	0.108072	0.940215	0.034*
C22	0.08997 (14)	0.09731 (14)	0.80777 (12)	0.0253 (3)
H22	0.005723	0.034890	0.741353	0.030*

a solution of 2,4-pentanedione (1.7 mL, 16.6 mmol) in butanol (10 mL) in a 100 mL round bottom flask. The mixture was refluxed on a magnetic stirrer for 2–3 h. At this stage, the colour of the mixture was dark-green. After removing the flask from the heat source, the mixture was allowed to cool until just warm to the touch. Then, methanol (30 mL) was added, and the mixture was cooled in an ice-salt bath for at least 15 min to precipitate the purple crystalline product. After that, the mixture was filtered under vacuum and washed with methanol until the washings were colourless to pale-green. The obtained product (1.0 g) was suspended in absolute ethanol (30 mL) in a 100 mL round-bottom flask. A moderate stream of HCl gas was bubbled through the suspension with swirling occasionally. Caution was maintained as the mixture gets quite warm. Once a large quantity of bright-purple precipitate $[H_4(C_{22}H_{22}N_4)][NiCl_4]$, was formed, the mixture was filtered and washed with ethanol followed by diethyl ether. The yield was 95%.

Step 2: Isolation of the free macrocycle $[H_2(C_{22}H_{22}N_4)]$. The $[H_4(C_{22}H_{22}N_4)][NiCl_4]$ salt was dissolved in water (10 mL). Some water-insoluble white impurities were present at this stage which were removed by filtration. Solid NH_4PF_6 (1.0 g) was added to the filtrate which was swirled until a large amount of white precipitate formed. Then, the $[H_4(C_{22}H_{22}N_4)][PF_6]_2$ that had formed was filtered and washed with water until the product was pale-green. In this step, the by-product $[NH_4]_2[NiCl_4]$ was washed away to prevent nickel from re-inserting into the macrocycle upon basification; the large volume of water used resulted in some loss of the desired product. The sticky product $[H_4(C_{22}H_{22}N_4)][PF_6]_2$ that formed was transferred into a 50 mL beaker, rinsing with methanol to maximize the mass of product transferred. Triethylamine was added dropwise to this methanolic suspension with swirling. The bright-yellow free macrocycle $[H_2(C_{22}H_{22}N_4)]$, crystallised immediately, filtered on a Büchner funnel, washed with methanol and dried in air. The yield was 57%. **M. pt.** (Microprocessor Melting Point Apparatus, SYSTONIC): 346 K. **Elemental analysis** (Leco CHNS-932 elemental analyzer) for $C_{22}H_{24}N_4$: C, 76.70; H, 6.97; N, 16.30. Found: C, 76.62; H, 6.99; N, 16.41. **IR** (Shimadzu IR 20 spectrophotometer, KBr; cm^{-1}): 3255 (w) ν(N–H), 1383 (s) $\nu(CH_3)$, 1618 (s) and 1551 (s) ν(Ar C=C), 1364 (m) and 1187 (s) ν(Ar CN), 1027 (m) 743 (s) ν(Ar C–H). ^{1}**H NMR** (Bruker AVANCE 400 NMR spectrometer, DMSO, ppm): δ 2.16 (s, $C(CH_3)$, 12H), 4.91 (s, CH, 2H), 7.02 (m, Aromatic-H, 8H), 12.61 (br, N–H,

2H). ^{13}**C**{^{1}**H**} **NMR** (as for ^{1}H NMR) δ: 8.64, 20.911 [C(CH_3)], 97.98 [CH], 123.00 [N–C–CH_3], 138.54 [Aromatic-C], 158.97 [N–C(Aromatic)]

Experimental details

The C-bound H atoms were geometrically placed (C–H = 0.95–1.00 Å) and refined as riding with U_{iso}(H) = 1.2–1.5U_{eq}(C). The N-bound atoms were located from a Fourier difference map and refined with N–H = 0.88 ± 0.01 Å, and with U_{iso}(H) = 1.2U_{eq}(N). Owing to poor agreement, one reflection, i.e. (2 1 1), was omitted from the final cycles of refinement.

Comment

Macrocyclic chemistry has sustained great fascination to scientists owing to its specific roles in different sectors of contemporary science. Thus, macrocyclic compounds are prominent in coordination chemistry [7], pharmacology [8, 9] as well as in crystal engineering [10]. These compounds also play a remarkable role in medicinal chemistry: as anti-cancer agents [11, 12], radioimmunotherapeutics [13] and as MRI contrast agents [14]. In this connection, researchers continue to report different types of macrocycles and their metal complexes [15–19], prepared by both the template and non-template methods. In continuation of these studies, herein the synthesis of a nickel(II) complex with a macrocyclic molecule of composition [H_2($C_{22}H_{22}N_4$)] (I), by the template method and the subsequent isolation of the free macrocycle is described. It is noted that the crystal and molecular structures of (I) have been described previously [20]. However, disorder in the positions of the acidic hydrogen atoms precluded a definitive assignment of the putative tautomeric structure. As the authors noted in the Abstract to the paper: "A detailed structural interpretation of the free ligand is complicated by disorder involving degenerate tautomeric structures in the crystal lattice" [20]. The present, low-temperature structure determination of (I) allows a definitive assignment of the tautomeric structure as well as a detailed analysis of the molecular packing. The molecular structure of (I) is shown in figure (70% probably displacement ellipsoids). The molecule lacks symmetry and adopts a saddle-like conformation whereby the phenyl rings lie to one side of the N_4-plane, forming a dihedral angle of 47.82(6)°, and with the remaining atoms lying to the other side of the N_4 plane; the dihedral angle between the best planes through N1,N2,C1–C3 and N3,N4,C6–C8 atoms = 67.55(4)°. The molecular connectivity and conformation is as reported for the earlier determination [20]. However, the new analysis enables an unambiguous assignment of the tautomeric form of the molecule; no disorder was evident in the positions of the N-bound hydrogen atoms which are located on the N1 and N3 atoms. The imine bonds correspond to C3–N2 [1.3088(15) Å] and C8–N4 [1.3079(16) Å] with the bond lengths significantly shorter than the adjacent C4–N2 [1.4081(15) Å] and C9–N4 [1.4085(16) Å] bonds. The ethylene bonds correspond to C1–C2 [1.3718(18) Å] and C6–C7 [1.3776(17) Å] which are significantly shorter than the C2–C3 [1.4380(17) Å] and C7–C8 [1.4309(18) Å] single bonds. Intramolecular amine N–H···N(imine) hydrogen bonds stabilise the observed conformation [N1–H1n···N2: H1n···N2 = 1.937(14) Å, N1···N2 = 2.6856(19) Å with angle at H1n = 142.1(12)° and N3–H3n···N4: H3n···N4 = 1.926(13) Å, N3···N4 = 2.6756(19) Å with angle at H3n = 140.3(12)°]. In the molecular packing, following the distance criteria assumed in PLATON [21], the only directional interactions between molecules of (I) are π–π interactions occurring between centrosymmetrically related (C4,C5,C13–C16) rings [Cg(C4,C5,C13–C16)···Cg(C4,C5,C13–C16)^{i} = 3.5776(17) Å, with a slippage value = 1.171 Å for symmetry operation i: 1–x, 1–y, 1–z] to form a dimeric aggregate.

The lack of directional interactions in the crystal is supported by the analysis of the calculated Hirshfeld surfaces and of the full and delineated two-dimensional fingerprint plots. These were calculated with the program Crystal Explorer 17 [22] following literature methods [23]. The surface contacts are dominated by H···H contacts, contributing 67.3% of all contacts with significant contributions from C···H/H···C [22.6%] and N···H/H···N [6.3%]. The next most significant contributions to the surface contacts are from C···C [2.7%] and N···C/C···N [1.1%].

Author contributions: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Research funding: This study was supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS) in collaboration with the Japan Science and Technology Agency (JST) and the Japan

International Cooperation Agency (JICA) (Grant No. JPMJSA1603), the Environmental Radioactivity Research Network Center at Fukushima University, Japan (Grant Nos I-19-08, I-20-09 and I-21-09), Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (JSPS) (Grant No. 21K12287) and Sunway University Sdn Bhd (Grant No. GRTIN-IRG-01–2021).

Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

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