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Ferromagnetic interactions in new double End-On-azide-bridged dinuclear Ni(II) complex: Syntheses, crystal structures, magnetic and photoluminescence properties

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Abstract

A new double end-on azide-bridged dinuclear nickel(II) Schiff base complex, $[Ni_2(\mu_{1,1}-N_3)_2(HL)_2(MeOH)_2]$, [HL = 2-[(2-hydroxypropylimino)methyl)-3,5-chlorophenol] has been synthesized and characterized by elemental analysis, UV and IR spectroscopy, single crystal X-ray diffraction, magnetic and photoluminescence study. The asymmetric unit contains half of the dinuclear unit. The Ni(HL) units in each dinuclear molecule are connected to each other by two bridging end-on azide ligands. In the crystalline architecture of the Ni(II) complex, intermolecular O-H···N hydrogen bonds link the molecules which form one-dimensional structure. Additionally, low temperature magnetic measurements indicate a dominant intradimer ferromagnetic interactions in double end-on azide-bridged dinuclear Ni(II) complex. Room temperature solid state photoluminescence measurements of Ni(II) complex show strong green emission band at $\lambda_{max} = 508$ nm while its free ligand H₂L shows broad yellow emission band at $\lambda_{max} = 594$ nm. The luminescence materials.

Keywords: Single crystal X-ray analysis; Dinuclear nickel(II) complex; Photoluminescence, Magnetism

1. Introduction

Schiff base ligands have an important role as chelating ligands in the coordination of the main group and transition metals, which can be used in various applications and synthesis easily [1–12]. This research area is interesting with their special molecular structures and their specific functionalities by using Schiff base ligands in the synthesis of polynuclear complexes [13–16]. Metal complexes consisting of bridging groups have attracted considerable attention due to their various molecular structures and applications [17–21]. The nickel (II) complexes containing Schiff bases and varieties of bridging pseudo-halides can coordinate to the metal ions in different modes. In this context, among the pseudo-halides, the azido ligand shows two typical bridging modes: μ -1,1 (end-on, EO) and μ -1,3 (end-to-end, EE) (Scheme 1) that generate dimeric and polymeric compounds. The most important aspect of azido bridged complexes is the variety of their magnetic exchange

interactions. The EO coordination mode shows ferromagnetic interaction while the EE bridging mode shows antiferromagnetic interaction in the most cases [22–25].



Scheme 1. Possible coordination modes for azido ligands.

In addition, nickel (II) complexes have received considerable attention to have promising application for their luminescence [26,27]. Although, a sizeable number of nickel(II) schiff base complexes have been studied intensively due to their structural and magnetic properties [23,28], there is few report on their photoluminescence properties [29,30]. In recent communications, we and others have described the synthesis and characterization of monoand multinuclear Ni(II) Schiff base complexes [31–36]. In view of these findings and in an effort to enlarge the library of such complexes, we present here the synthesis, crystal structure, UV and IR spectroscopy, magnetic and photoluminescence study of a new double end-on azido-bridged dinuclear Schiff base nickel(II) complex, $[Ni_2(\mu_{1,1} N_3)_2(HL)_2(MeOH)_2]$, [HL = 2–[(2–hydroxypropylimino) methyl)–3,5–chlorophenol]. To the best of our knowledge, the solid-state photoluminescence properties of the azido-bridged Schiff base nickel(II) complex is described here for the first time.

2. Experimental

2.1. Materials and physical measurements

All chemicals and solvents used for the synthesis were of reagent grade and used without further purification. Elemental (C, H, N) analyses were carried out by standard methods with a LECO, CHNS–932 analyzer. Solid state UV-visible spectra were measured at room temperature with an Ocean Optics Maya 2000Pro Spectrophotometer. FT-IR spectra were measured with a Perkin-Elmer Spectrum 65 instrument in the range of 4000 – 600 cm⁻¹. Solid state photoluminescence spectra in the visible and NIR region were measured at room temperature with an ANDOR SR500i-BL Photoluminescence Spectrometer, equipped with

a triple grating and an air-cooled CCD camera as a detector. The measurements were done using the excitation source (349 nm) of a Spectra-physics Nd:YLF laser with a 5 ns pulse width and 1.3 mJ of energy per pulse as the source. DC magnetic measurements were performed using a QD Squid magnetometer with applied field of 0.1 T, except when otherwise stated. To avoid possible orientation effects, microcrystalline powders were pressed in pellets. The data were corrected for sample holder contribution and diamagnetism of the sample using Pascal constants. Powder x-ray diffraction (PXRD) patterns were recorded on a Bruker-AXS D8-Advance diffractometer by using Cu-K α radiation (λ =1.5418 Å) in the range 5° < 20 < 50° in 0-0 mode with a step ns (5s < n < 10s) and step width of 0.03°. Comparison between experimental and calculated (from CIF's) PXRD patterns was performed with Mercury 3.9 [37].

X-ray single crystal data for Ni(II) complex was collected on an Xcalibur, Eos diffractometer at 293 K using MoK_{α} radiation ($\lambda = 0.71073$ Å) [38]. The data were collected for Lorentz, polarization and absorption effects using the analytical numeric absorption correction technique [39]. Using Olex2 [40], the structure was solved by direct methods using SHELXS [41] and refined by full-matrix least-squares based on $|F_{obs}|^2$ using SHELXL [42]. The crystallographic data and structure refinement detail for Ni(II) complex is given in Table 1. All non-hydrogen atoms were refined anisotropically. Hydrogen atom positions were calculated geometrically and refined using the riding model. The hydroxyl H atom was located in difference Fourier map and its position was allowed to refine with an O-H bondlength restraint of 0.84(2) Å. Details of the supramolecular π -interactions were calculated PLATON 1.17 program [43]. The crystal data and structure refinement details for the complex are listed in Table 1.

2.2. Synthesis of tridentate Schiff base ligand, H_2L

The tridentate Schiff base ligand, $[H_2L= 2-[(2-hydroxypropylimino)methyl)-3,5-$ chlorophenol], was prepared by mixing 3,5-dichlorosalicylaldehyde (1 mmol, 0.191 g) and 3-amino-1-propanol (1 mmol, 0.075 g) in hot methanol (50 ml). The solution obtained was stirred at 65 °C for 30 min. The yellow product of the ligand was precipitated from the solution on cooling. HL: Yellow compound, yield 78%. Anal. Calcd. for $Cl_2C_{10}H_{11}N_1O_2$ (%): C, 48.41; H, 4.47; N, 5.65. Found (%): C, 48.36; H, 4.49; N, 5.63.

2.3. Synthesis of Ni(II) Complex

Ni(II) complex was prepared by addition of nickel(II) acetate tetrahydrate (0.249 g, 1 mmol) in 30 ml of methanol and sodium azide (0.065g, 1 mmol) in 10 ml of methanol to the ligand (H₂L) (0.248 g, 1 mmol) in 30 ml of methanol. This solution was warmed to 65 °C and stirred for 1h. The resulting solution has been filtered rapidly and then allowed to stand at room temperature. After several weeks green crystals of Ni(II) complex suitable for X-ray analysis were obtained. Structure of the tridentate ONO-donor Schiff base ligand (H₂L) and relevant equations for the formation of the Ni(II) complex is presented in Scheme 2. Clear green crystals, yield 72%. Anal. Calcd. For $C_{22}H_{28}Ni_2N_8O_6$ (%): C, 42.76; H, 4.57; N, 18.13. Found (%): C, 42.75; H, 4.55; N, 18.14.



Scheme 2. The synthetic route of ligand H₂L and Ni(II) complex

3. **Results and discussion**

3.1. X-ray structure of Ni(II) Complex

The complex is double end-on azide-bridged dinuclear Schiff base nickel(II) complex and its asymmetric unit consists of half of the dinuclear $[Ni_2(\mu_{1,1}-N_3)_2(HL)_2(MeOH)_2]$ molecules (Fig.1). The Ni(HL) units in dinuclear molecule are connected to each other by two bridging end-on azide ligands. Each Ni(II) atom is six-coordinated by the ONO donor set of the Schiff base ligand and by one terminal N atom of one bridging azide ligand, defining the basal plane, and by one terminal N atom from the other bridging azide ligand and one donor O atom from the MeOH molecule occupying the axial positions. The three trans angles at each Ni atom lie in the range 171.46 (12)–178.71 (16)°. The other angles subtended at the Ni atom range from 85.00 (14) to 95.18 (13)°, indicating somewhat distorted octahedral configurations. Selected bond lengths and angles are listed in Table 2, which lie well within the range of reported values for corresponding bond lengths and angles of other dinuclear nickel(II) complexes [22,23,44–48]. The bridging azide groups are nearly linear and show bent coordination modes with the nickel atoms. The intramolecular distance of Ni1···Ni1ⁱ (symmetry code: (i) -x+1, -y+1, -z+1) is found to be 3.10 Å. X-ray single crystal determination shows that the Ni(II) complex forms a self-assembling continual 1D supramolecular chain-like structure by O3–H3…N4 intermolecular hydrogen bonding along b axis. (Fig.2b). C-H···Cl intermolecular hydrogen bonds link the molecules which form two-dimensional structure in the bc-plane (Fig. 3a). With the help of intermolecular hydrogen bonding C-H···N, O-H··· π and π ··· π interactions, a self-assembled 3D supramolecular structure is formed (Fig.2a, Table 3).

$C_{22}H_{28}Cl_4N_8Ni_2O_6$	
759.74	
Orthorhombic)
Pbca,	
a = 19.1422 (16) Å	
<i>b</i> = 7.7745 (9) Å	
c = 21.0882 (18)	
3138.4 (5)	
4	
1.608	
1.59	
294	
6216	
2962	
1.00	
$R_1 = 0.052, wR_2 = 0.109$	
	C ₂₂ H ₂₈ Cl ₄ N ₈ Ni ₂ O ₆ 759.74 Orthorhombic <i>Pbca</i> , a = 19.1422 (16) Å b = 7.7745 (9) Å c = 21.0882 (18) 3138.4 (5) 4 1.608 1.59 294 6216 2962 1.00 $R_1 = 0.052, wR_2 = 0.109$

 Table 1. Crystal data and structure refinement for Ni(II) complex.

Ni1—O1	1.978 (3)	Ni1—N2 ⁱ	2.106 (3)
Ni1—O2	2.104 (3)	Ni1—N2	2.100 (4)
Ni1—O3	2.077 (4)	N2—N3	1.181 (5)
Ni1—N1	2.001 (3)	N3—N4	1.158 (5)
		C	
01—Ni1—O2	171.46 (12)	N1—Ni1—O2	95.18 (13)
O3—Ni1—N2	175.04 (14)	N1—Ni1—O3	90.89 (15)
N1—Ni1—N2 ⁱ	178.71 (16)	N1—Ni1—N2	93.80 (14)
O1—Ni1—O3	92.11 (14)	N2—Ni1—O2	85.00 (14)
O1—Ni1—N2	89.38 (14)	N2—Ni1—N2 ⁱ	85.04 (15)
O1—Ni1—N2 ⁱ	87.83 (13)	O3—Ni1—N2 ⁱ	90.28 (15)
O1—Ni1—N1	91.60 (14)	O3—Ni1—O2	92.97 (14)
O2—Ni1—N2 ⁱ	85.29 (13)	N4—N3—N2	177.7 (5)
Symmetry code: (i) $-x+1$, -y+1, -z+1.		
()	V		
6			
V-			

Table 2. Some selected bond lengths [Å] and angles [°] for Ni(II) complex.

D-H····A*	D-H	Н…А	DA	D –H…A	Symmetry
O2–H2…O1	0.83	2.02	2.795	155	-x, 2-y, 1-z
O3-H3····N4	0.84	2.01	2.827	165	x,-1+y,z
C7–H7…N4	0.93	2.61	3.537	172	1/2-x,-1/2+y,z
C10–H10B…Cl2	0.97	2.83	3.538	131	1/2-x,2-y,1/2+z
O–H···Cg(I)				5	
O2-H2…Cg(1)	0.99	2.36	2.466	87	x, y, z
O2-H2···Cg(1)	0.99	2.36	2.466	87	-x, 2-y, 1-z
Cg(I)···Cg(J)	Cg(I)····Cg(J)	1	V		
$Cg(4)\cdots Cg(4)$	4.537				1/2-x,-1/2+y,z
$Cg(4)\cdots Cg(4)$	4.537	$\langle \rangle$			1/2-x,1/2+y,z

Table 3. Hydrogen bond geometry (Å, $^{\circ}$) and distance between ring centroids [Å] for Ni(II) complex.

*D: Donor, A: Acceptor, Cg(I): Plane number I (= ring number in () above), Cg(I)-Cg(J) = Distance between ring Centroids, Cg(1): Ni1-N2-Ni1a-N2a, Cg(4): C1-C2-C3-C4-C5-C6.



Figure 1. ORTEP drawing of Ni(II) complex showing the atom labelling scheme (with 50% probability displacement ellipsoids).



Figure 2. (a) The crystal packing view of Ni(II) complex. (b) A perspective view of onedimensional chain structure along b axis, showing the intermolecular O–H…N hydrogen bonds (dashed lines).



Figure 3. (a) A perspective view of two-dimensional structure, showing the intermolecular $O-H\cdots N$ and $C-H\cdots Cl$ hydrogen bonds (dashed lines). (b) Space filling representation of Ni(II) complex as in Fig. 2a.

3.2. X-ray powder diffraction pattern of Ni(II) complex.

Before proceeding to the magnetic, spectroscopic and photoluminescence characterization, we note that experimental powder X-ray pattern for Ni(II) complex are well in position with those of simulated patterns on the basis of single crystal structure of Ni(II) complex (Fig. 4).



Figure 4. X-ray powder diffraction pattern of Ni(II) complex (Red simulated from CIFs, Black Experimental).

3.3. IR and Electronic Spectra

The IR spectra of Ni(II) complex is analyzed in comparison with that of its free ligand, H₂L in the range 4000–600 cm⁻¹ in Figure 5. The weak and broad absorption band at 3232 cm⁻¹ is assigned to v(O-H) stretching for the free ligand, H₂L. After complexation, v(O-H) absorption peak shifts to 3172 cm⁻¹ for Ni(II) complex [49,50]. Additionally, a new absorption peak appears at 3365 cm⁻¹ and it can be attributed to the v(O-H) stretching of the coordinated methanol molecule to the Ni(II) atom [51]. In the IR spectra of the free ligand, a high intensity v(C=N) band is observed at 1649 cm⁻¹. This band is shifted towards lower side and observed at about 1625 cm⁻¹ for Ni(II) complex. This downward shift shows the coordination of azomethine nitrogen to the Ni(II) ion. The strong band at 2078 cm⁻¹ for the

Ni(II) complex is attributed to the v(N=N) stretching of the bridging end-on azide groups [53,54]. The medium intensity bands are also observed in the broad region between 1100 and 700 cm⁻¹ which are assigned to (C–Cl) of the chlorobenzene ring [55, 56].



Figure 5. The IR spectrum of the H₂L (black line) and Ni(II) complex (red line).

The UV-Vis electronic spectra of the free ligand H₂L (black line) and its Ni(II) complex (red line) are indicated in Figure 6. The electronic spectrum of the free ligand (H₂L) shows a high broad absorption band at 373 nm. This arises process may be due the conjugated systems. On the contrary the UV-Vis spectrum of Ni(II) complex has been seen two different absorption bands at 308 nm and 442 nm. These absorption bands can be attributed to the $n\rightarrow\pi^*$ or $\pi\rightarrow\pi^*$ electronic transition for the lower one and can be attributed to the $d\rightarrow d$ transition for the higher one, respectively [44,54,57].



Figure 6. The solid state UV-Vis spectrum of the free ligand H₂L (black line) and Ni(II) complex (red line).

3.4 Photo-physical study

To be able to find out the emission process of the Ni(II) complex and its free ligand H₂L, the solid-state photoluminescence (PL) spectroscopy were carried out at room temperature in the visible regions upon excitation at λ_{ex} = 349 nm. In the Fig. 7, the PL spectrum of both samples have been shown and it can be easily seen that both spectra show broad emission bands. The free ligand H₂L shows broad yellow emission band at λ_{max} = 594 nm which may be assigned to the $\pi \rightarrow \pi^*$ electronic transition (ILCT) [58,59]. Ni(II) complex show stronger green emission band at λ_{max} = 508 nm. Effect of the bonding metal atom to the ligand may be responsible for the blue shift of this emission peak [60]. The enhancement of luminescence for Ni(II) complex may be attributed to the chelation of the ligand to the central metal atom. The chelation enhances the "rigidity" of the ligand and thus reduces the loss of energy through a radiationless pathway [61].



Figure 7. The emission spectra of the free ligand H_2L (yellow line) and Ni (II) complex (green line) in the solid samples at room temperature. (Upper-left photo is photoluminescent image of Ni(II) complex and upper-right photo is photoluminescent image of ligand H_2L , while excited at 349 nm.

3.5 Magnetic properties

The temperature dependence of the magnetic susceptibility of powdered polycrystalline samples of Ni(II) complex in the 1.9–40 K temperature range with an applied Dc field of 1 KOe and in the 40–300 K temperature range with an applied Dc field of 10 KOe is represented in the form χ_M and $\chi_M T vs$. T plots (χ_M is the susceptibility per dimeric unit) in Fig 8. The $\chi_M T$ value at room temperature, 2.72 cm³ K mol⁻¹, which is as expected for two magnetically spin triplets (g > 2.00), and agrees with the value found for similar compounds [23,44,62]. When the temperature is decreasing, the $\chi_M T$ value steadily increases reaching a maximum at 16 K (3.61 cm³ K mol⁻¹) then decreases to 2.02 cm³Kmol⁻¹ at 1.9 K. This feature confirms the presence of significant intramolecular ferromagnetic exchange interaction between the Ni^{II} ions leading to a S = 2 ground state. The decrease in $\chi_M T$ at low temperatures is more likely due to zero-field splitting effects of the ground state (D) and/or possible intermolecular antiferromagnetic interactions between the dimers (zJ') [53]. Ginsberg [63] pointed out that both D and zJ' are very strongly dependent on each other and show same results at low temperature. Thus it is difficult to calculate these values with

reasonable accuracy. That is why neglecting D as a fitting parameter, the data were fit using the theoretical $\chi_M vs. T$ expression for a dimer of two S=1 nickel (II) ions.

The experimental magnetic susceptibility data have been analyzed using the isotropic spin Hamiltonian $H = -2JS_1S_2$ for spin coupled dinuclear with $S_1 = S_2 = 1$ as shown in Eq. (1) [62], where x = J / kT. In addition, the inter-dimer exchange interaction was taken into account by using the mean field approximation Eq. (2) [62].

$$\chi_{\text{dimer}} = \frac{2Ng^2 \mu_B^2}{kT} \frac{e^{2J/kT} + 5e^{6J/kT}}{1 + 3e^{2J/kT} + 5e^{6J/kT}}$$
(1)
$$\chi_M = \frac{\chi_{\text{dimer}}}{1 - \chi_{\text{dimer}} (2zJ'/Ng^2 \beta^2)}$$
(2)

Where χ_M represents the magnetic susceptibility per dinickel(II), zJ' is the inter-dimer exchange parameter, z is the number of nearest neighbors of each dimer (z=2) and the other symbols have their usual meaning. The obtained best fit parameters for the experimental data are; $J = +9.26 \text{ cm}^{-1}$, $zJ' = -0.13 \text{ cm}^{-1}$, $g = 2.30 (R^2 = 0.9995)$. These values are comparable to those of related Ni(II)-azides complexes, [28,44,45,53,62] and confirm that the interactions mediated via the double EO azide bridges are ferromagnetic couplings.

The magnetic susceptibilities conform well to Curie-Weiss law ($\chi_m = C / (T - \theta)$) in the range of 1.9–300 K for complex (1) with a positive Weiss constant ($\theta = +4.99$ K and C = 2.64 cm³ K mol⁻¹). The positive θ confirms the ferromagnetic interactions between the Ni^{II} ions. As a complementary characterization, the field-dependent magnetization for Ni(II) complex has been measured at 2.0 K (Fig. 9). The field dependence of the magnetization matches well with the Brillouin function for an S_{total} = 2 spin state, indicating the ferromagnetic interactions in Ni(II) complex. The fact that the magnetization is not fully saturated at high field may be due to the presence of a significant magnetic anisotropy.



Figure 8. Temperature dependence of $\chi_M T$ vs T and χ_M^{-1} vs T for Ni(II) complex. The solid red line represents the best-fit obtained using Eq. 2. The solid green line represents the best fit using Curie-Weiss law. (Inset-the magnetic exchange coupling pathway for Ni(II) complex).



Figure 9. Field dependence of magnetization (black-squares); the solid red line was plotted according to the Brillouin function for an S = 2 spin system.

4. Conclusions

We have presented the preparation, and structural, spectroscopic and magnetic characterizations of a new double EO azido-bridged dinuclear nickel(II) complex. Analysis of its variable-temperature magnetic study revealed a ferromagnetic behavior with J = +9.26 cm⁻¹. Furthermore, photoluminescence studies show the blue shift and the stronger of the emission compared with its free ligand as a result of the influence of the coordination of metal atom to the ligand. The luminescent properties showed that the photoluminescence arose from the intraligand emission, and that it is novel potential candidates for applications in optoelectronic devices.

Supplementary data

Crystallographic data for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre (The Director, CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK; e-mail: deposit@ccdc.cam.uk; www: http://www.ccdc.cam.ac.uk; fax: +44 1223 336033) and are available free of charge on request, quoting the Deposition No. CCDC 1547546.

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References

- Shawish, H. B., Maah, M., Nadiah, S., Halim, A. & Shaker, S. A. (2016). *Arab. J. Chem.*, 9, 1935–1942.
- [2] Bang, S., Kim, J., Jang, B. W., Kang, S.-G. & Kwak, C. H. (2016). *Inorg. Chim. Acta*, 444, 176–180.
- [3] Jee, J. E. & Kwak, C. H. (2013). Inorg. Chem. Commun., 33, 95–98.
- [4] Hajikhanmirzaei, L., Safaei, E., Wojtczak, A. & Jagličić, Z. (2015). *Inorg. Chim.* Acta, 430, 125–131.
- [5] Vyas, K. M., Jadeja, R. N., Gupta, V. K. & Surati, K. R. (2011). J. Mol. Struct., 990, 110–120.
- [6] Yahsi, Y. (2016). Acta Cryst, C72, 585–592.
- Sow, M. M., Diouf, O., Gaye, M., Sall, A. S., Pérez-Lourido, P., Valencia-Matarranz, L., Castro, G., Caneschi, A. & Sorace, L. (2013). *Inorg. Chim. Acta*, 406, 171–175.
- [8] Abdallah, S. M., Mohamed, G. G., Zayed, M. A. & El-ela, M. S. A. (2009). Spectrochim. Acta - Part A., 73, 833–840.
- [9] Surati, K. R., Thaker, B. T., Shah, G. R., Surati, K. R., Thaker, B. T. & Shah, G. R. (2008). Synth. React. Inorganic, Met. Nano-Metal Chem., 38, 272–279.
- [10] Rawat, K. A., Surati, K. R. & Kailasa, S. K. (2014). Anal. Methods, 6, 5972–5980.
- [11] Vamja, A. C. & Surati, K. R. (2017). Luminescence, DOI: 10.1002/bio.3311.
- [12] Thaker, B. T., Surati, K. R., Patel, P. & Parmar, S. D. (2006). J. Iran. Chem. Soc., 3, 371–372.
- [13] Yahsi, Y., Gungor, E., Coban, M. B. & Kara, H. (2016). *Mol. Cryst. Liq. Cryst.*, 637, 67–75.
- [14] Elmehdawi, R. M., Nasir El-Kaheli, M., Abuhmaiera, R. G., Treish, F. A., Mabruk,
 M. El, Younes, B., Bazzicalupi, C., Guerri, A., Caneschi, A. & Amjad, A. (2017).
 Materials (Basel)., 10, 1–12.
- [15] Safak, B., Yahsi, Y., Gungor, E. & Kara, H. (2015). J. Struct. Chem. Orig. Russ. Text, 56, 1527–1532.
- [16] Otgonbaatar, E., Chung, M.-C., Umakoshi, K. & Kwak, C.-H. (2015). J. Nanosci. Nanotechnol., 15, 1389–1395.
- [17] Erkarslan, U., Oylumluoglu, G., Coban, M. B., Öztürk, E. & Kara, H. (2016). Inorg.

Chim. Acta, 445, 57-61.

- [18] Amjad, A., Clemente-Juan, J. M., Coronado, E., Luis, F., Evangelisti, M.,
 Espallargas, G. M. & Del Barco, E. (2016). *Phys. Rev. B Condens. Matter Mater. Phys.*, 93, 224418-1-224418–9.
- [19] Cucos, P., Tuna, F., Sorace, L., Matei, I., Maxim, C., Shova, S., Gheorghe, R., Caneschi, A., Hillebrand, M. & Andruh, M. (2014). *Inorg. Chem.*, 53, 7738–7747.
- [20] Abu-Dief, A. M. & Mohamed, I. M. A. (2015). *Beni-Suef Univ. J. Basic Appl. Sci.*, 4, 119–133.
- [21] Brodowska, K. & Łodyga-Chruścińska, E. (2014). Chemik, 68, 129–134.
- [22] Manca, G., Cano, J. & Ruiz, E. (2009). Inorg. Chem., 48, 3139–3144.
- [23] Pratim Chakrabarty, P., Giri, S., Schollmeyer, D., Sakiyama, H., Mikuriya, M., Sarkar, A. & Saha, S. (2015). *Polyhedron*, 89, 49–54.
- [24] Mahendrasinh, Z., Kumar, S. B., Suresh, E. & Ribas, J. (2010). Transit. Met. Chem., 35, 757–763.
- [25] Bai, S.-Q., Fang, C.-J., He, Z., Gao, E.-Q., Yan, C.-H. & Hor, T. S. A. (2012). Dalt. Trans., 41, 13379.
- [26] Schmitz, C., Pösch, P., Thelakkat, M., Schmidt, H. W., Montali, A., Feldman, K., Smith, P. & Weder, C. (2001). Adv. Funct. Mater., 11, 41–46.
- [27] Yam, V. W.-W., Lo, K. K.-W. & Wong, K. M.-C. (1999). Chem. Soc. Rev., 28, 323–334.
- [28] Mukherjee, P. S., Dalai, S., Zangrando, E., Lioret, F. & Chaudhuri, N. R. (2001). *Chem. Commun.*, 1444–1445.
- [29] More, M. S., Pawal, S. B., Lolage, S. R. & Chavan, S. S. (2017). J. Mol. Struct., 1128, 419–427.
- [30] More, M. S., Devkule, S. S. & Chavan, S. S. (2017). J. Fluoresc., 27, 841–851.
- [31] Elerman, Y., Kara, H. & Prout, K. (2001). Acta Crystallogr. Sect. C, 149–150.
- [32] Kara, H., Elerman, Y., Elmali, A., Structure, C. & Properties, S. (2003). Z. *Naturforsch*, 58b, 955–958.
- [33] Yardan, A., Hopa, C., Yahsi, Y., Karahan, A., Kara, H. & Kurtaran, R. (2015). Spectrochim. Acta - Part A., 137, 351–356.
- [34] Ünver, H., Elmali, A., Karakaş, A., Kara, H. & Donmez, E. (2006). J. Mol. Struct., 800, 18–22.
- [35] Celen, S., Gungor, E., Kara, H. & Azaz, A. D. (2013). J. Coord. Chem., 66, 3170–3181.

- [36] Celen, S., Gungor, E., Kara, H. & Azaz, A. D. (2016). Mol. Cryst. Liq. Cryst., 631, 164–175.
- [37] Mercury, version 3.9 (2016). Cambridge Crystallographic Data Centre: Cambridge, U.
- [38] Agilent. (2014). Technol. UK Ltd, Yarnton, Oxford, UK,.
- [39] Clark, R. C., Reid, J. S. (1995). Acta Cryst. ., A51, 887-897.
- [40] Dolomanov, O. V., Bourhis, L. J., Gildea, R. J., Howard, J. A. K. & Puschmann, H. (2009). J. Appl. Cryst., 42, 339–341.
- [41] Sheldrick, G. M. (2008). Acta Cryst., A64, 112–122.
- [42] Sheldrick, G. M. (2015). Acta Cryst., C71, 3-8.
- [43] Spek, A. L. (2009). Acta Cryst., D65, 148–155.
- [44] Solanki, A., Monfort, M. & Kumar, S. B. (2013). J. Mol. Struct., 1050, 197–203.
- [45] Bhattacharyya, A., Bhaumik, P. K., Das, M., Bauza, A., Jana, P. P., Harms, K., Frontera, A. & Chattopadhyay, S. (2015). *Polyhedron*, 101, 257–269.
- [46] Bhattacharyya, A., Kumar, P., Pratim, P. & Chattopadhyay, S. (2014). *Polyhedron*, 78, 40–45.
- [47] Li, H. (2009). Synth. React. Inorganic, Met. Nano-Metal Chem., 39, 516–519.
- [48] Liang, S., Liu, Z., Liu, N., Liu, C., Di, X. & Zhang, J. (2010). J. Coord. Chem., 63, 3441–3452.
- [49] You, Z. & Zhu, H. (2006). Z. Anorg. Allg. Chem., 1, 140–146.
- [50] Ray, A., Rosair, G. M., Kadam, R. & Mitra, S. (2009). Polyhedron, 28, 796–806.
- [51] Mukherjee, P., Drew, M. G. B., Gómez-García, C. J. & Ghosh, A. (2009). *Inorg. Chem.*, 48, 5848–5860.
- [52] Hopa, C. and & Cokay, I. (2016). Acta Cryst. , C 72, 149–154.
- [53] Deoghoria, S., Sain, S., Soler, M., Wong, W. T., Christou, G., Bera, S. K. & Chandra, S. K. (2003). *Polyhedron*, 22, 257–262.
- [54] Dhara, P. K., Pramanik, S., Lu, T.-H., Drew, M. G. B. & Chattopadhyay, P. (2004). *Polyhedron*, 23, 2457–2464.
- [55] Alaşalvar, C., Demircan, A., Koşar, B., Pekacar, A. I. & Büyükgüngör, O. (2016). J. Mol. Struct., 1123, 213–224.
- [56] Udayakumar, V., Periandy, S. & Ramalingam, S. (2011). Spectrochim. Acta Part A., 79, 920–927.
- [57] Leovac, V. M., Jovanović, L. S., Jevtović, V. S., Pelosi, G. & Bisceglie, F. (2007). *Polyhedron*, 26, 2971–2978.

- [58] Hopa, C. & Cokay, I. (2016). Acta Cryst, C72, 601-606.
- [59] Bibi, S., Mohammad, S., Manan, N. S. A., Ahmad, J., Kamboh, M. A., Khor, S. M., Yamin, B. M. & Abdul Halim, S. N. (2017). *J. Mol. Struct.*, 1141, 31–38.
- [60] Yahsi, Y., Ozbek, H., Aygun, M. & Kara, H. (2016). Acta Cryst, C72, 426-431.
- [61] Gungor, E. (2017). Acta Cryst., C73, 393–398.
- [62] Biswas, R., Mukherjee, S., Ghosh, S., Diaz, C. & Ghosh, A. (2015). *Inorg. Chem. Commun.*, 56, 108–111.
- [63] Ginsberg, A. P.; Martin, R. L. & Brookes, R. W. and Sherwood, R. C. (1972). *Inorg. Chem.*, 11, 2884–2889.

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ACCEPTED MANUSCRIPT

Highlights

- Synthesis of a double end-on azide-bridged dinuclear nickel(II) complex.
- Characterization of the Ni(II) complex by UV-Vis, IR and X-ray diffraction.
- Magnetic and photoluminescence properties of Ni(II) complex have been investigated.