



Original Article

Synthesis and Structural Characterization of Picolinoyl(4-ethylthiosemicarbazide) and its New Heteroleptic Cu(II) Complex

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Abstract: The ligand picolinoyl(4-ethylthiosemicarbazide) HL was synthesized by the reaction of picolinohydrazide and ethyl isothiocyanate in absolute ethanol. The structure of HL was characterized by spectroscopic methods such as IR, ^1H , and ^{13}C NMR spectroscopy. One-pot reaction of CuCl_2 and equimolar amounts of HL and *o*-phenanthroline in $\text{CH}_2\text{Cl}_2/\text{MeOH}$ mixture with the presence of a supporting base like pyridine gave rise to a new heteroleptic cationic Cu(II) complex with the composition of $[\text{Cu}(\text{L})(\text{o-phen})]^+$. Crystalline PF_6^- salt was obtained after workup with $(n\text{-Bu}_4\text{N})(\text{PF}_6)$ and single-crystal structure of the complex was determined. The spectroscopic data and X-ray crystallography demonstrated that the Cu(II) ion is five-coordinate with the coordination sphere consisted of (*S*, N^I , N_{pyridine}) and (*N*, *N*) donor sets belonging to the singly deprotonated ligand $\{\text{L}^-\}$ and *o*-phenanthroline, respectively.

Keywords: Acyl thiosemicarbazides, heteroleptic complexes, Cu(II) complexes.

1. Introduction

Acyl thiosemicarbazides (Figure 1 a) are the simplest representative of ligands possessing donor atoms with different basicity, namely hard *O*, border-line *N*, and soft *S* donors. Such an interesting feature and the weakly acidic $-\text{NH}-$ groups lead to various coordination fashions. In particular, the simple acyl thiosemicarbazides can serve as bidentate ligands with the donor sets of (*O*, N^2)

(Figure 1 b) [1, 2], or (*S*, N^I) (Figure 1 c) [3]. The presence of additional donor atom(s) in the acyl moiety not only expands the coordination capacity of the resulting ligands, but also causes the coordination between ligands and metal ions to be more selective [4, 5]. In such cases, the acyl thiosemicarbazides normally exhibit the coordination number of three with the donor sets of (*X*, N^I , *S*) (Figure 2 a). In this context, acyl thiosemicarbazides derived from picolinic acid are expected to be versatile (*N*, *N*, *S*)-tridentate ligands which can form stable complexes with various transition metal ions (Figure 2 b).

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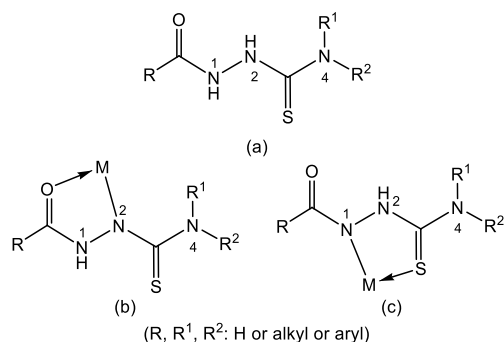


Figure 1. General formula of acyl thiosemicarbazides and their simple coordination modes.

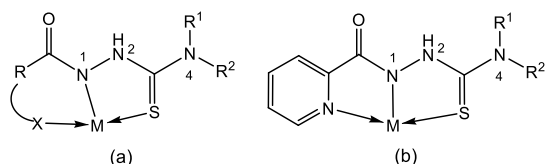


Figure 2. Tridentate coordination modes of (a) acyl and (b) picolinoyl thiosemicarbazides.

Surprisingly, a survey of literature reveals only a few reports on synthesis and characterization of some transition metal complexes with picolinoyl thiosemicarbazides [5-7]. As part of our ongoing effort to explore the coordination chemistry of acyl thiosemicarbazides, we report herein, the facile synthesis and structure determination of a new heteroleptic Cu(II) complex with picolinoyl (4-ethylthiosemicarbazide). The results would be useful for further studies on biological activities as well as catalytic applications of the obtained compounds.

2. Materials and Methods

2.1. Materials

All chemicals used in this study were reagent-grade and used without further purification. Solvents were distilled before using. The preparation of $[\text{Cu}(\text{MeCN})_4](\text{PF}_6)$ was adopted from the literature [8].

2.2. Physical Measurements

IR spectra were measured from KBr pellets on an IRAffinity-1S spectrometer between

400 cm^{-1} and 4000 cm^{-1} at Department of Inorganic Chemistry, Faculty of Chemistry, VNU University of Science. ^1H and ^{13}C NMR spectra were recorded in DMSO-d_6 on an AscendTM-500MHz spectrometer at Faculty of Chemistry, VNU University of Science. ESI mass spectrum was measured with an Agilent LC/MSD Trap SL mass spectrometer at Vietnam Academy of Science and Technology. All MS results are given in the form: m/z , assignment.

The intensities for the X-ray determinations of the complex were collected on a Bruker D8 QUEST instrument at 293 K with Mo $K\alpha$ radiation ($\lambda = 0.71073 \text{ \AA}$) using a TRIUMPH monochromator. Standard procedures were applied for data reduction and absorption correction [9]. Structure solution and refinement were performed with the SHELXT and SHELXL 2014/7 programs included in the OLEX2-1.3 program package [10]. Hydrogen atoms were calculated for idealized positions and treated with the 'riding model' option of SHELXL.

2.3. Synthetic Procedures

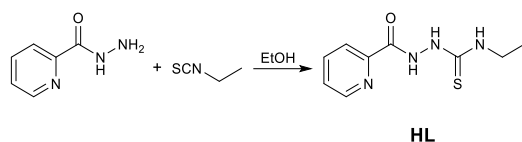
Synthesis of picolinoyl (4-ethylthiosemicarbazide) (HL): HL was prepared by the procedure published [7]. Ethyl isothiocyanate (2.2 mL, 0.025 mol) was added dropwise to an ethanolic solution (40 mL) of picolinohydrazide (3.43 g, 0.025 mol). The reaction mixture was refluxed for 1 hour. On cooling, a white precipitate appeared. The product was filtered off, washed with EtOH, and dried under vacuum. Yield: ~ 70% (3.96 g).

Synthesis of the complex: The synthesis of the complex was performed by the procedure previously reported with some modifications [7]. Equimolar amounts of HL (22.4 mg, 0.1 mmol) and *o*-phenanthroline (18.0 mg, 0.1 mmol) were dissolved in 2 mL mixture of $\text{CH}_2\text{Cl}_2/\text{MeOH}$ (1:1 v/v). A solution of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (17.0 mg, 0.1 mmol) in MeOH (0.5 mL) was added, followed by two drops of pyridine. After stirring at room temperature for 30 min, $(n\text{-Bu}_4\text{N})(\text{PF}_6)$ (40.0 mg, 0.1 mmol) was added and the temperature was increased to 40 °C and

kept for 1 h so that CH₂Cl₂ completely evaporated. During this process, the product deposited as dark green precipitate, which was then filtered off, washed with a small amount of MeOH, and dried under vacuum. Yield: ~ 64% (30 mg). Single crystals suitable for X-ray analysis were obtained by slow evaporation of a solution of the complex in CH₂Cl₂/MeOH mixture.

3. Results and Discussion

The ligand picolinoyl (4-ethylthiosemicarbazide) HL was synthesized in 70% yield by reaction of picolinohydrazide with ethyl isothiocyanate in absolute EtOH (Scheme 1).



Scheme 1. Synthesis of HL.

In the IR spectrum of HL (Figure 3), broad medium absorptions in the region above 3000 cm⁻¹ are ascribed to stretching modes of NH groups. The characteristic absorption corresponding to the vibration of the carbonyl group $\nu_{C=O}$ is detected as a strong band around 1674 cm⁻¹. In addition, the absence of ν_{SH} absorption band in the region of 2650 - 2500 cm⁻¹ and the appearance of two bands assigned to $\nu_{C=S}$ and a combination of $\nu_{C=S}$ and ν_{CN} around 800 cm⁻¹ and 1240 cm⁻¹, respectively suggest the absence of any thiol tautomer and the existence of thione form of the organic compound in the solid state [11].

Although the synthesis and characterization of HL was previously reported [7], no information on NMR spectroscopic data has been provided. Such data obtained in this work validate the expected structure of the organic compound HL.

Indeed, the ¹H NMR spectrum of HL in DMSO-d₆ (Figure 4 a) exhibits three singlet signals in the low-field region, which are indicative of the presence of three weakly acidic NH groups.

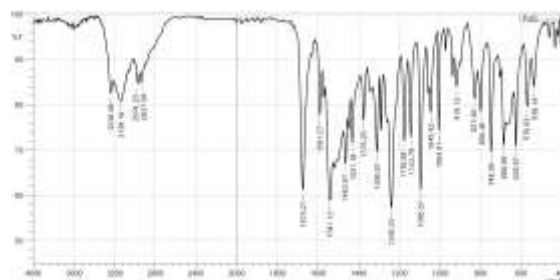


Figure 3. IR spectrum of HL.

The signals between 7.6 - 8.2 ppm are accompanied by protons of the pyridyl ring. The resonance of ethyl protons is observed as a doublet of doublet and a triplet at 3.45 ppm and 1.05 ppm, respectively. The ¹³C NMR spectrum of HL (Figure 4 b) exhibits 9 signals assigned to 9 carbon atoms. In particular, the signals corresponding to C=S and C=O carbon atoms appear at 181.0 ppm and 163.3 ppm, respectively, whereas those of carbon atoms of pyridyl ring are in the region of 120 - 150 ppm.

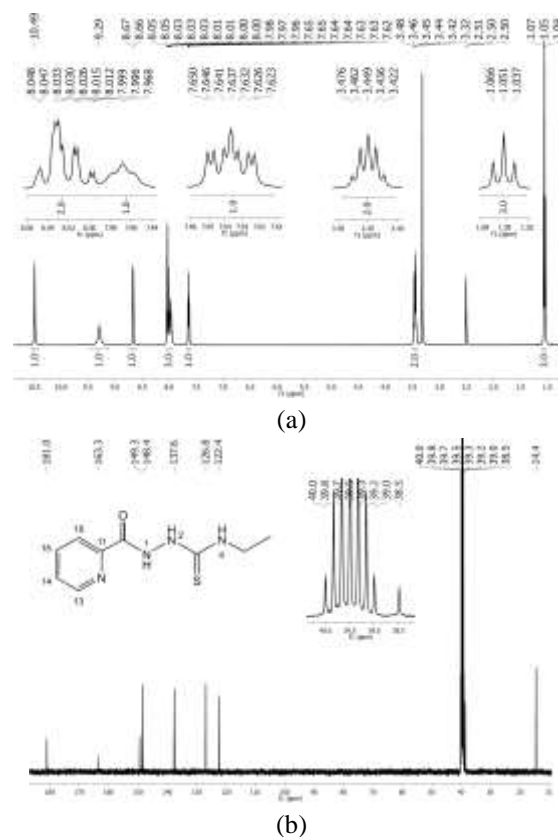


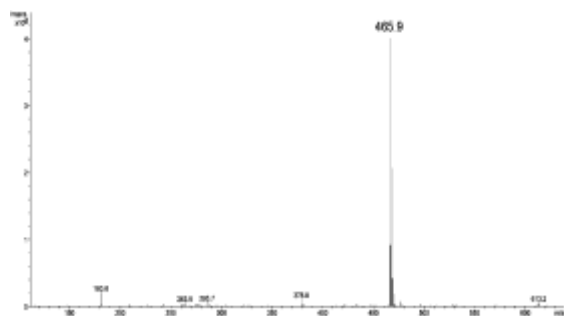
Figure 4. (a) ¹H and (b) ¹³C NMR spectra of HL.

The resonance at 38.5 ppm partly hidden by signals due to DMSO-d₆ solvent is attributed to methylene carbon atom. Finally, the most high-field signal at 114.4 ppm is ascribed to the methyl carbon atom. More detailed assignment of signals in ¹H and ¹³C NMR spectra of HL is found in Table 1.

Table 1. ¹H and ¹³C NMR spectral data of HL

	¹ H NMR (δ , ppm)	¹³ C NMR (δ , ppm)
N ² H	10.49 (s, 1H)	-
N ¹ H	9.29 (s, br, 1H)	-
N ⁴ H	8.67 (s, 1H)	-
C ¹¹	-	149.3
C ¹³ H, C ¹⁶ H	8.00 – 8.05 (m, 2H)	148.4, 126.8
C ¹⁵ H	7.97 (dd, 1H, $J = 5.0$, 5.0 Hz)	137.6
C ¹⁴ H	7.64 (ddd, 1H, $J = 7.0$, 5.0, 2.0 Hz)	122.4
CH ₂	3.45 (dq, 2H, $J = 7.5$, 7.5 Hz)	38.5
CH ₃	1.05 (t, 3H, $J = 7.5$ Hz)	14.4
CO	-	163.3
CS	-	181.0

One-pot reaction of equimolar amounts of HL, *o*-phenanthroline and CuCl₂ in CH₂Cl₂/MeOH mixture with the presence of a supporting base like pyridine resulted in a dark green cationic complex with the expected composition of [Cu(L)(*o*-phen)]⁺, which was separated in the solid state as PF₆⁻ salt after workup with (*n*-Bu₄N)(PF₆). The formation of the cationic complex is strongly supported by the base peak in the ESI⁺ mass spectrum (Figure 5) with $m/z = 465.9$ matching up with the cation [Cu(L)(*o*-phen)]⁺ (calcd. 466.1).

Figure 5. ESI⁺ mass spectrum of the complex.

The presence of the counter ion PF₆⁻ in the component of the isolated complex is verified by a strong band in the IR spectrum at about 840 cm⁻¹ (Figure 6), which is characteristic of the ν_{PF} vibrations [12]. The disappearance of some broad absorption bands above 3100 cm⁻¹ reveals the partial deprotonation of the NH groups of HL.



Figure 6. IR spectrum of the complex.

Table 2. IR spectral data of the ligand and the complex

	IR bands (cm ⁻¹)				
	ν_{NH}	$\nu_{\text{C=O}}$	$\nu_{\text{C=S}} + \nu_{\text{CN}}$	$\nu_{\text{C=S}}$	ν_{PF}
HL	3239 – 3138 (br, m)	1674 (s)	1240 (s)	800 (m)	-
Cu(II) complex	3277(m), 3111(br, m)	1641 (s)	1230 (w)	808 (w)	840 (s)

Furthermore, the marked reduction in intensity of the absorption bands relating to $\nu_{\text{C=S}}$ and the bathochromic shift (about 30 cm⁻¹) of the C=O band could be the result of extended π -electron delocalization in the formation of (*S*, *N*) and (*O*, *N*) chelates (Table 2).

The structural elucidation using spectroscopic studies is confirmed by X-ray diffraction analyses. Crystal data and structure calculation parameters are given in Table 3.

Table 3. Crystal data and structure refinement for the solvated complex [Cu(L)(*o*-phen)](PF₆) · CH₂Cl₂

Formula	C ₂₂ H ₂₁ ON ₆ SCl ₂ PF ₆ Cu
Mw	696.92
Crystal system	Triclinic
$a/\text{\AA}$	9.248(8)
$b/\text{\AA}$	12.570(11)
$c/\text{\AA}$	13.625(12)
$\alpha/^\circ$	112.668(16)

$\beta/^\circ$	91.704(16)
$\gamma/^\circ$	103.178(17)
$V/\text{\AA}^3$	1411(2)
Space group	$P\bar{1}$
Z	2
$D_{\text{calc}}/\text{g}\cdot\text{cm}^{-3}$	1.641
μ/mm^{-1}	1.163
No. reflect.	3918
No. indep.	1317
R_{int}	0.0630
No. param.	367
R_1/wR_2	0.0809/0.2101
GOF	1.076

The structure of the complex is presented in Figure 7, while selected bond lengths are introduced in Table 4. The structure analyses demonstrate a heteroleptic cationic Cu(II) complex with the expected composition of $[\text{Cu}(\text{L})(o\text{-phen})](\text{PF}_6)$. The central Cu(II) ion is five coordinate with the coordination sphere consisted of (N, N) donor sets from bidentate o -phenanthroline and $(S, N^1, N_{\text{pyridine}})$ donor sets of the singly deprotonated tridentate ligand $\{\text{L}^-\}$. The Cu–N and Cu–S bond lengths are in a good agreement with those found in a few Cu(II) trinuclear complexes reported [6, 13-15].

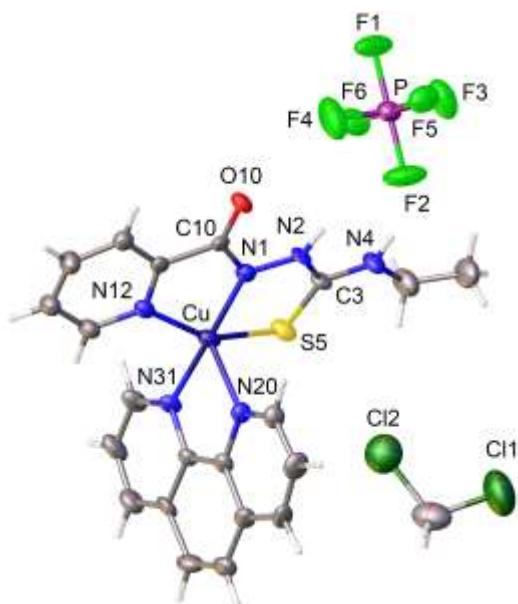


Figure 7. Molecular structure of the solvated complex $[\text{Cu}(\text{L})(o\text{-phen})](\text{PF}_6) \cdot \text{CH}_2\text{Cl}_2$.

Table 4. Selected bond lengths (\AA) in the complex

Cu–S5	2.308(8)	C10–O10	1.23(2)
Cu–N1	1.908(19)	N1–C10	1.28(3)
Cu–N12	2.009(19)	N1–N2	1.39(2)
Cu–N20	1.982(17)	N2–C3	1.31(2)
Cu–N31	2.202(18)	C3–N4	1.33(3)
		C3–S5	1.68(2)

The double-bond character of the C3–S5 bond and the less double-bond character of C3–N2 and C3–N4 bonds compared to that of C10–N1 bond (Table 4) demonstrate that by the complexation, the deprotonation of N^2H and N^4H groups through the thiol tautomerization is less favorable than the deprotonation of N^1H group. Moreover, the formation of extended π -electron delocalization in the amide group $\text{C}(\text{O})\text{--N}$ by coordination with metal ion accounts for the bathochromic shift of the $\text{C}=\text{O}$ absorption band in the IR spectrum of the complex despite the absence of (N, O) chelate.

4. Conclusion

An acyl thiosemicarbazide derived from picolinic acid HL and its new heteroleptic Cu(II) complex have been synthesized and characterized by spectroscopic methods as well as X-ray crystallography. The studies reveal a heteroleptic complex with the composition of $[\text{Cu}(\text{L})(o\text{-phen})](\text{PF}_6)$, in which Cu(II) ion is five coordinate with (N, N) -bidentate o -phenanthroline and singly deprotonated $(S, N^1, N_{\text{pyridine}})$ -tridentate ligand $\{\text{L}^-\}$.

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