

Structure, luminescence and antimicrobial properties of mononuclear silver(I) complexes of pyridine 2-carboxamide

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Abstract. Two Ag(I) complexes, [Ag(HL)₂]ClO₄ (**1**) and [Ag(HL)₂]NO₃·H₂O (**2**), where HL is pyridine 2-carboxamide, have been synthesized and characterized by various spectroscopic techniques. The X-ray crystal structural analyses indicate that both the complexes consist of slightly distorted square planar silver(I) ions and ligand-supported weak Ag···Ag metallophilic interactions. Both the complexes show photoluminescence in solid state and acetonitrile solution at room temperature. Antimicrobial studies have been performed with these silver(I) complexes against various gram +ve, gram –ve bacterial and fungal species.

Keywords. Pyridine 2-carboxamide; silver(I) complexes; single crystal X-ray crystallography; photoluminescence; antimicrobial activity.

1. Introduction

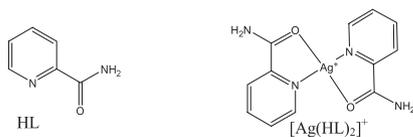
The coordination chemistry of silver(I) compounds that are biologically and pharmacologically active is currently a very active research area. Many silver complexes are known for their effective antibacterial, antifungal,^{1–9} antiseptic,¹⁰ anti-inflammatory¹¹ and antitumour^{12,13} activities. For example, silver sulfadiazine is a topical broad-spectrum antibiotic used clinically to stop bacterial infections in severe burns or chronic wounds.¹⁴ More recently, silver nanoparticles have been widely used in wound dressings and coatings for medical devices such as synthetic implants and urinary tract and venous catheters in order to prevent infections.¹⁵ Though silver complexes are widely used as antibiotics, the detailed mechanism behind the biological activity of silver complexes is not yet understood completely. The proposed modes of action include interaction of silver ions with the cell membrane, inactivation of enzymes by reaction with thiol groups, association with DNA, and interference with the electron transport chain.⁵ It is expected that the antimicrobial activities of silver complexes depend particularly on the nature of the atoms coordinated to the silver center and the ease of ligand replacement.

Silver(I) complexes with a greater likelihood of ligand replacement with biological ligands (sulfur-containing molecules) have a more pronounced antimicrobial effect. It is therefore reasonable that Ag(I)–N and Ag(I)–O bonded complexes, with weak metal–ligand bond strengths and showing a wider spectrum of antimicrobial activities are the potential target sites for the inhibition of bacterial and yeast growth.^{16,17} Ag(I)–S complexes¹⁸ possess a narrower spectrum of antibacterial activity than silver(I)–N^{2,4} and silver(I)–O complexes,^{3,5,17,19} whereas silver(I)–P²⁰ based coordination complexes have shown no activity against bacterial strains, yeast and moulds. The effective antimicrobial activities of Ag(I)–N and Ag(I)–O bonded complexes are due to the weak silver(I)–N and silver(I)–O bonds and can be easily replaced with biomolecules, especially with those of thiol groups.¹⁶ The antimicrobial activities of silver(I)–O complexes support the fact that the coordination geometry around the silver(I) influences the strength of antimicrobial activities and the ligand–exchangeability of the silver(I) complexes also plays a significant role in the magnitude of antimicrobial activities.

The present work describes the synthesis, crystal structures, photoluminescence properties and *in vitro* antimicrobial activity of two square planar Ag(I)

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complexes, $[\text{Ag}(\text{HL})_2]\text{ClO}_4$ (**1**) and $[\text{Ag}(\text{HL})_2]\text{NO}_3 \cdot \text{H}_2\text{O}$ (**2**), where HL is pyridine 2-carboxamide.



2. Experimental

2.1 Materials

All chemicals were of reagent grade and used without further purification. Solvents were purified and dried according to standard methods.²¹ The ligand pyridine-2-carboxamide (HL) was synthesized according to the method reported earlier.²² The complex **2** has been published earlier but we have reported²³ here a different method of synthesis.

2.2 Preparation of the complexes

CAUTION! All the perchlorate salts reported in this study are potentially explosive and therefore should be handled with care.

2.2a $[\text{Ag}(\text{HL})_2]\text{ClO}_4$ (**1**): 10 mL of methanolic solution of AgClO_4 (1 mmol, 0.21 g) was added dropwise to a methanolic solution (20 mL) of pyridine 2-carboxamide (HL, 2 mmol, 0.23 g) with stirring at room temperature. The stirring was continued for 1 h, during which time a white compound separated out. Then the off-white compound was re-crystallized from methanol. Yield 0.35 g (82%). Anal. Calcd. for $\text{C}_{12}\text{H}_{12}\text{AgClN}_4\text{O}_6$: C, 31.92; H, 2.68; N, 12.41%. Found: C, 32.01; H, 2.65; N, 12.48%. FT-IR (KBr, ν/cm^{-1}): 3452(s), 3259(s, br), 3070(s, br), 1670(s), 1587(m), 1568(s), 1469(w), 1442(m), 1312(w), 1278(w), 1142(s), 1110(s), 1083(s), 783(m), 761(m), 657(m), 503(m). UV-Vis (in acetonitrile) [λ_{max} , nm (ϵ , $\text{M}^{-1} \text{cm}^{-1}$): 216 (23,850), 264 (7,470).

2.2b $[\text{Ag}(\text{HL})_2]\text{NO}_3 \cdot \text{H}_2\text{O}$ (**2**): Ligand HL (2 mmol, 0.23 g) was dissolved in 25 mL of methanol and a 10 mL solution of AgNO_3 (1 mmol, 0.17 g) in methanol was added to it. Solution was stirred for 1 h during which time an off-white compound appeared. This off-white compound was recrystallized from acetonitrile. Yield: 0.32 g (80%). Anal. Calcd. for $\text{C}_{12}\text{H}_{14}\text{AgN}_5\text{O}_6$: C, 33.35; H, 3.27; N, 16.21%. Found: C, 33.45; H, 3.33; N, 16.18%. FT-IR (KBr, ν/cm^{-1}): 3215(w, br), 3026(s, br), 1677(s), 1655(m), 1588(w), 1560(s), 1438(m), 1385(s), 1309(w), 1278(w), 1162(m), 1033(m), 783(m), 761(m),

657(m), 503(m). UV-Vis (in acetonitrile) [λ_{max} , nm (ϵ , $\text{M}^{-1} \text{cm}^{-1}$): 214 (26,510), 263 (7,530).

2.3 Antimicrobial activity

The antimicrobial activity of all the synthesized silver(I) complexes were investigated against bacterial strains gram-positive *Bacillus subtilis* (MTCC 441), *Staphylococcus aureus* (MTCC 96), gram-negative *Escherichia coli* (MTCC 2939), *Pseudomonas aeruginosa* (MTCC 2453), *Klebsiella pneumonia* (MTCC 618) and yeast *Aspergillus niger* (MTCC 1344), *Candida albicans* (MTCC 227) following reported method.²⁴ The stock solution (1 mg mL^{-1}) of the complexes were prepared by dissolving 10 mg of the test compound in 10 mL of 95:5 v/v water: dimethyl sulfoxide mixture. The stock solution was suitably diluted with sterilized 95:5 v/v water: dimethyl sulfoxide mixture to get dilution in between 400–1.6 $\mu\text{g mL}^{-1}$.

The bacteria were sub-cultured in Müller-Hinton agar. The Petri dishes were incubated for 24 h at 37°C. The fungi were sub-cultured in potato dextrose agar medium. The Petri dishes were incubated for 48 h at 37°C. Activity was determined by measuring the diameter of the zone (mm) showing complete inhibition of microbial growth that a clear zone surrounding the test sample (in sterile disc) where bacterial growth does not occur (or is inhibited). The growth of the bacteria and fungi were measured by observing the minimum inhibitory concentration.

2.4 Physical measurements

Elemental (C, H and N) analyses were performed on a Perkin-Elmer 2400 II elemental analyzer. IR spectra were recorded using KBr disks on a Shimadzu FTIR 8400S spectrometer. The electronic spectra were recorded at room temperature using an Agilent 8453 diode array spectrophotometer. Steady-state emission spectra were recorded on a PerkinElmer LS-55 fluorescence spectrometer at room temperature.

Quantum yields of the complexes were determined by a relative method using 2-amino pyridine in the same solvent as the standard.²⁵ The quantum yields were calculated by using equation 1.²⁶

$$\phi = \phi_{\text{std}} (A_{\text{std}}/A) (I/I_{\text{std}}) (\eta^2/\eta_{\text{std}}^2) \quad (1)$$

where ϕ and ϕ_{std} are the quantum yields of unknown and standard samples [$\phi_{\text{std}} = 0.6$ (at 298 K) in 0.1 M H_2SO_4 at $\lambda_{\text{ex}} = 285 \text{ nm}$],²⁵ A and A_{std} (< 0.1) are the absorbances at the excitation wavelength (λ_{ex}), I and I_{std} are the integrated emission intensities, and η and η_{std}

are the refractive indices of the solvents. Experimental errors in the reported luminescence quantum yields were about 20%.

2.5 X-ray crystallography

Crystals suitable for structure determination of **1** and **2** were obtained by slow evaporation of their water-methanol solutions. The crystals were mounted on glass fibers using perfluoropolyether oil. Intensity data were collected on a Bruker-AXS SMART APEX diffractometer at 123(2) K using graphite-monochromated Mo-K α radiation ($\lambda = 0.71073$ Å). The data were processed with SAINT²⁷ and absorption corrections were made with SADABS softwares.²⁸ The structures were solved by direct and Fourier methods and refined by full-matrix least-squares methods based on F^2 using SHELX-97.²⁹ For the structure solutions and refinements the SHELX-TL software package³⁰ was used. The non-hydrogen atoms were refined anisotropically, while the hydrogen atoms were placed at geometrically calculated positions with fixed thermal parameters.

Table 1. Crystallographic data for [Ag(HL)₂](ClO₄) (**1**).

1	
Empirical formula	C ₁₂ H ₁₂ AgClN ₄ O ₆
<i>M</i>	451.58
<i>T</i> , K	150(2)
Crystal system	Triclinic
Space group	<i>P</i> -1
<i>a</i> /Å	7.374(5)
<i>b</i> /Å	8.124(5)
<i>c</i> /Å	13.301(5)
α /°	86.452(5)
β /°	79.095(5)
γ /°	68.721(5)
<i>U</i> /Å ³	729.1(7)
<i>Z</i>	2
<i>D</i> /g cm ⁻³	2.057
μ /mm ⁻¹	1.607
<i>F</i> (000)	448
Crystal size/mm	0.28×0.14×0.10
No. of measured reflections	6027
No. of observed reflections	2764
Parameter refined	261
No. of reflections [<i>I</i> >2 σ (<i>I</i>)]	2651
Goodness of fit, <i>S</i> ^a	1.122
Final <i>R</i> ₁ ^b , <i>wR</i> ₂ ^c [<i>I</i> >2 σ (<i>I</i>)]	0.0263, 0.0780
<i>R</i> ₁ ^b , <i>wR</i> ₂ ^c (all data)	0.0274, 0.0787

^a $S = [\sum w(F_o^2 - F_c^2)/(N - P)]^{1/2}$ where *N* is the number of data and *P* the total number of parameters refined.

^b $R_1(F) = \sum ||F_o| - |F_c|| / \sum |F_o|$.

^c $wR_2(F^2) = [\sum w(F_o^2 - F_c^2)^2 / \sum w(F_o^2)]^{1/2}$.

Crystal data and details of structure determination for complex **1** are summarized in table 1.

3. Results and Discussion

3.1 Synthesis and characterization

The synthesis of ligand pyridine 2-carboximidine was carried out following the method reported earlier.²² The mononuclear silver(I) complexes, [Ag(HL)₂](ClO₄) (**1**) and [Ag(HL)₂](NO₃)·H₂O (**2**) are obtained by reacting methanolic solution of ligand with AgClO₄ or AgNO₃, respectively.

The IR spectra of the complexes exhibit several diagnostic features. A weak band observed between 3080 and 3025 cm⁻¹ in **1** and **2** is due to the hydrogen bonded N-H stretching vibration of the amide -NH₂ group. The free ligand has characteristic IR band at 1680 due to amide I [(C=O)] vibration. The metal-coordinated C=O vibration in the compounds **1** and **2** are observed in between 1670–1665 cm⁻¹.

The compound **1** shows four characteristic ClO₄⁻ vibrations for anionic perchlorate at 1145, 1115, 1088 and 627 cm⁻¹. On the other hand, compound **2** exhibits a strong band at about 1385 due to the presence of nitrate group.

3.2 Description of crystal structure

The X-ray crystal structures of the complexes **1** and **2** have been determined. It should be mentioned that after determination of structure of the compound **2**, we found that the X-ray structure of this compound has been reported earlier.²³ The structure determination of **2** by us has been made at 120 K, the reported one was made at 296 K. Accordingly, the unit cell parameters found in the present case are relatively shorter as compared to the earlier reported values.²⁹ The influence of temperature can be appreciated by comparing the unit cell volume, which is 730.60(9) Å³ at 120 K as against 753.12(5) Å³ at 296 K. In terms of Ag–N(pyridine) and Ag–O(amide) distances, the difference observed in the two sets of studies are insignificant. The thermal ellipsoid plot of the compound **2** is shown in figure S1 (see Supplementary Information) and the crystal data and details of structure determination for complex **2** are summarized in table S1. The relevant bond distances and bond angles are given in table S2.

The thermal ellipsoid plot of the cation [Ag(HL)₂]⁺ in compound **1** is shown in figure 1 and the relevant metrical parameters involving the metal centers are given in table 2. The coordination environment around the

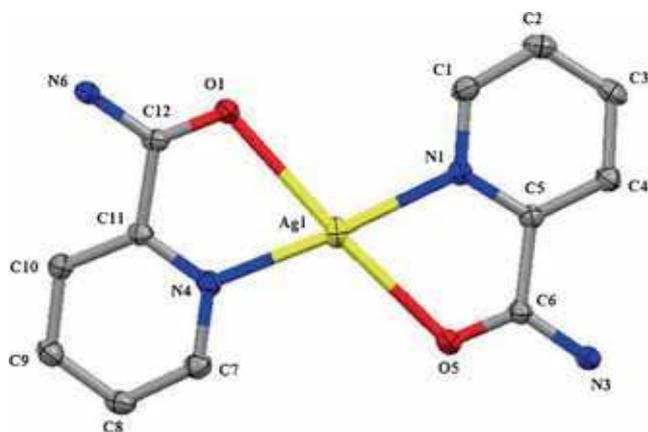


Figure 1. An ORTEP representation of the cation $[\text{Ag}(\text{HL})_2]^+$ showing 50% probability displacement ellipsoids in the compound **1**. Hydrogen atoms are removed for clarity.

Table 2. Selected bond lengths [Å] and angles [°] for $[\text{Ag}(\text{HL})_2]\text{ClO}_4(\mathbf{1})^a$.

1			
Ag1–O1	2.602(2)	O1–Ag1–O5	172.17(8)
Ag1–O5	2.535(3)	O1–Ag1–N1	106.12(9)
Ag1–N1	2.201(3)	O1–Ag1–N4	69.90(9)
Ag1–N4	2.176(3)	O5–Ag1–N1	69.76(8)
Ag1–Ag1A	3.273(2)	O5–Ag1–N4	113.76(8)
		N1–Ag1–N4	174.74(9)

^a‘A’ indicates atoms at : -x, -y, 1-z.

four-coordinated metal centre $[\text{AgN}_2\text{O}_2]$ may be considered distorted square planar.³¹ The donor atoms O1, O5, N1 and N4 around silver(I) form an exact plane from which the metal atom is displaced by 0.111(3) Å. The average Ag–O(amide) and Ag–N(pyridine), distances are 2.189(3) and 2.568(3) Å, respectively. In the basal plane, two of the opposing angles, O1–Ag–N1 [106.12(9)°] and O5–Ag–N4 [113.76(9)°], differ considerably, whereas the other two opposing angles, O1–Ag–N4 [69.90(9)°] and O5–Ag–N1 [69.76(9)°], are nearly equal. Again, the transverse angles O1–Ag–O5 and N1–Ag–N4 are almost identical [172.17(8)° and 174.80(10)°]. Complex **2** also features a square planar cation, being similar to that found for **1**. Two Ag–O distances are 2.587(3) and 2.587(3) Å, whereas two Ag–N distances are 2.190(3) and 2.181(4) Å. In addition, the *cisoid* angles vary from 69.20(10)° to 111.39(11)°, while the *transoid* angles of the silver(I) centre are almost equal [173.8(1) and 173.31(12)] but deviate significantly from the ideal value leading to the formation of distorted square planar geometry. The indicator of a four-coordinated

geometry τ_4 is ~ 0.09 ($\tau_4 = 0$ for square planar and $\tau_4 = 1$ for tetrahedral) for both the compounds.³² The distance between the metal centres $[\text{Ag}(1) \cdots \text{Ag}(1a)$, 3.273(2) Å] is longer than in metallic silver (2.888 Å) but less than twice the van der Waals radius for silver (3.44 Å), thus indicating a certain degree of d^{10} – d^{10} ligand supported intermetallic interaction.³³ In compound **2**, Ag \cdots Ag distance is found to be 3.3776(4) Å which is still smaller than the sum of the van der Waals radii of two silver atoms, and a weak interaction cannot be discarded.

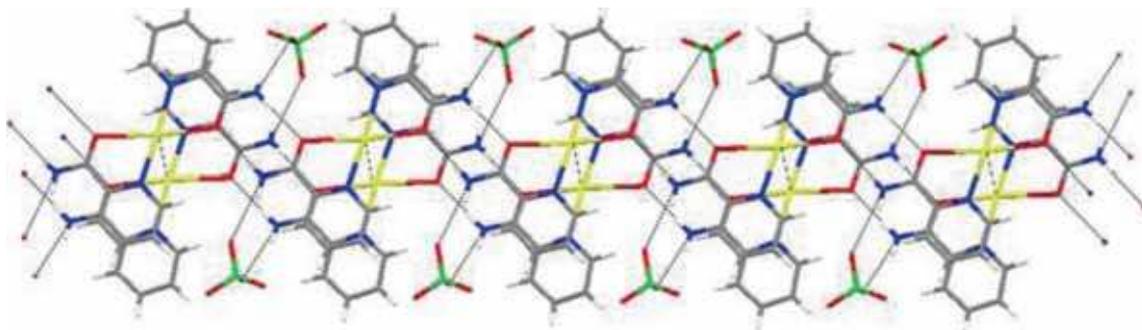
A noteworthy feature of the molecular structure of **1** is the occurrence of four intermolecular N–H \cdots O bonds involving amide nitrogen, amide oxygen and oxygen atoms of perchlorate anion, as listed in table 3. The oxygen atoms of the amide group and perchlorate anion act as acceptor whereas amide nitrogens act as donor. The donor–acceptor D \cdots A distances lie between 2.866(4) and 3.037(4) Å and the D–H \cdots A angles range from 161(5)° to 174(4)° (table 3), indicating that the hydrogen bonds are very strong. The packing diagram of compound **1** shows two $[\text{Ag}(\text{HL})_2]^+$ cationic unit are linked through amide–amide hydrogen bonds of ‘head-to-head’ $R_2^2(8)$ motif, leading to infinite chains. The perchlorate anions act only as a cross-link between two such symmetry related cationic chains via hydrogen bonds forming 1D supramolecular double sheets (figure 2). In compound **2**, along with amide–amide hydrogen bonds, two H_2O molecules and two NO_3^- anions form centro-symmetrical hydrogen bonded $R_4^2(8)$ rings that are further linked with four remaining amide hydrogen atoms thus generating the 2-D double sheet structure (figure S2). The packing diagram of compound **1** also reveals the presence of intermolecular π – π interaction between the pyridine ring C1, C2, C3, C4, C5 and N1 with the pyridine ring C7, C8, C9, C10, C11 and N4 [the distance between the two centroids is 3.789 Å].

3.3 Photoluminescence properties

It is well-known that the presence of direct metal–metal interaction is one of the important factors contributing to the photoluminescent properties of d^{10} metal compounds.³⁴ Nevertheless, until now, only a few silver(I) complexes have been reported to emit at room temperature,³⁵ because most of them exhibit emission only at low temperature.³⁶ Interestingly, the ligand HL and its silver(I) complexes **1** and **2** are luminescent at room temperature, in solid state (figure S3) and in acetonitrile solution (figure 3). When excited at room temperature at 300 nm, complexes **1** and **2** exhibit some

Table 3. Metrical parameters for H-bonding and $\pi \cdots \pi$ interactions in compound **1**.

	D–H \cdots A	D–H distance (Å)	H \cdots A distance (Å)	D \cdots A distance (Å)	D–H \cdots A angle (deg)
H-bonding	N(3)–H(3B) \cdots O(1)	0.92(4)	2.01(4)	2.924(4)	174(4)
	N(6)–H(6A) \cdots O(5)	0.89(4)	2.00(4)	2.866(4)	164(4)
	N(3)–H(3A) \cdots O(4)	0.79(4)	2.14(4)	2.890(4)	159(4)
	N(6)–H(6B) \cdots O(3)	0.82(5)	2.25(5)	3.037(4)	161(5)
$\pi \cdots \pi$	$\pi \cdots \pi^a$ atoms π C(2) \cdots C(7) \cdots π C(23) \cdots C(28)			$\pi \cdots \pi$, distance (Å)	3.53
	D–H \cdots A	D–H distance (Å)	H \cdots A distance (Å)	D \cdots A distance (Å)	D–H \cdots A angle (deg)
H-bonding	N(3)–H(3B) \cdots O(1)	0.92(4)	2.01(4)	2.924(4)	174(4)
	N(6)–H(6A) \cdots O(5)	0.89(4)	2.00(4)	2.866(4)	164(4)
	N(3)–H(3A) \cdots O(4)	0.79(4)	2.14(4)	2.890(4)	159(4)
	N(6)–H(6B) \cdots O(3)	0.82(5)	2.25(5)	3.037(4)	161(5)
	N(3)–H(3B) \cdots O(1)	0.92(4)	2.01(4)	2.924(4)	174(4)
$\pi \cdots \pi$	$\pi \cdots \pi^a$ atoms π C(2) \cdots C(7) \cdots π C(23) \cdots C(28)			$\pi \cdots \pi$, distance (Å)	3.53
	D–H \cdots A	D–H distance (Å)	H \cdots A distance (Å)	D \cdots A distance (Å)	D–H \cdots A angle (deg)
H-bonding	N(3)–H(3B) \cdots O(1)	0.92(4)	2.01(4)	2.924(4)	174(4)
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$\pi \cdots \pi$	$\pi \cdots \pi^a$ atoms π C(2) \cdots C(7) \cdots π C(23) \cdots C(28)			$\pi \cdots \pi$, distance (Å)	3.53

**Figure 2.** A capped stick projection of the one dimensional supramolecular double sheets structure of $[\text{Ag}(\text{HL})_2]\text{ClO}_4$ (**1**).

low-energy emission bands, which have shapes and positions similar to the free ligands HL (figure S4). The emissions are neither metal-to-ligand charge transfer (MLCT) nor ligand-to-metal charge transfer (LMCT) in nature and probably can be assigned to the intraligand $\pi \rightarrow \pi^*$ transition fluorescent emission because very similar emissions are also observed for the free ligands. The quantum yields (ϕ) of ligand HL, complexes **1** and **2** in acetonitrile at room temperature are 7.76×10^{-3} , 9.51×10^{-4} and 1.12×10^{-3} , respectively, indicating them to be weak emitters.

3.4 Antimicrobial activity

The amide ligand and its silver(I) complexes (**1** and **2**) were evaluated for *in vitro* antibacterial activity against gram-positive *Bacillus subtilis*, *Staphylococcus aureus*, gram-negative *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumonia* and *in vitro* antifungal activity against *Saccharomyces cerevisiae* and *Candida albicans*. Muller Hinton, potato dextrose broth and agar were employed for bacterial and fungal growth, respectively. Minimum Inhibitory Concentrations (MIC) were

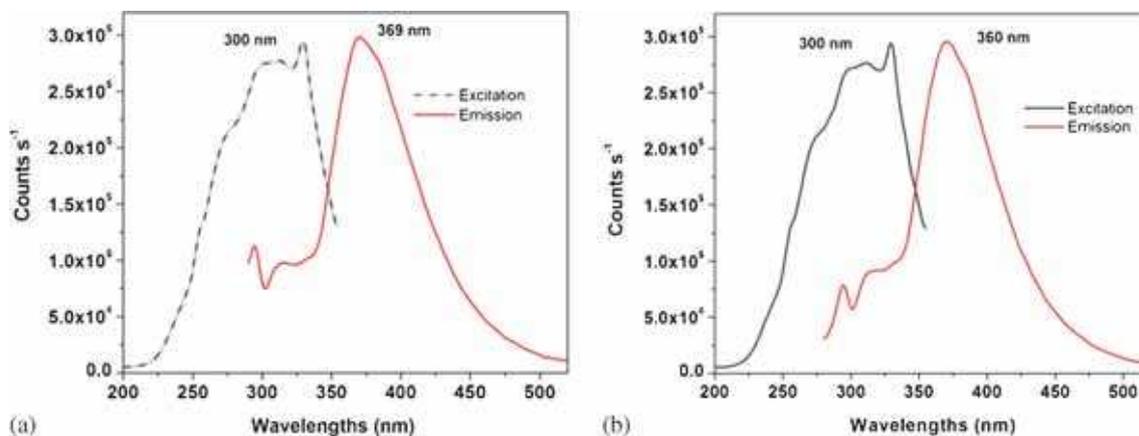


Figure 3. Emission ($\lambda_{\text{ex}} = 300 \text{ nm}$) and excitation ($\lambda_{\text{em}} = 360 \text{ nm}$) spectra in acetonitrile ($5 \times 10^{-5} \text{ M}$) at room temperature for complexes (a) **1** and (b) **2**.

Table 4. Minimum inhibitory concentrations (MIC) for the complexes **1** and **4** ($\mu\text{g mL}^{-1}$).

Compound	Antibacterial activity					Antifungal activity	
	<i>S. aureus</i>	<i>B. subtilis</i>	<i>E. coli</i>	<i>P. aeruginosa</i>	<i>K. pneumonia</i>	<i>C. albicans</i>	<i>S. cerevisiae</i>
1	12.5	3.1	6.2	3.1	6.2	3.1	6.2
2	3.1	3.1	1.6	3.1	12.5	3.1	6.2
AgNO ₃	25.0	6.2	6.2	12.5	25.0	6.2	25

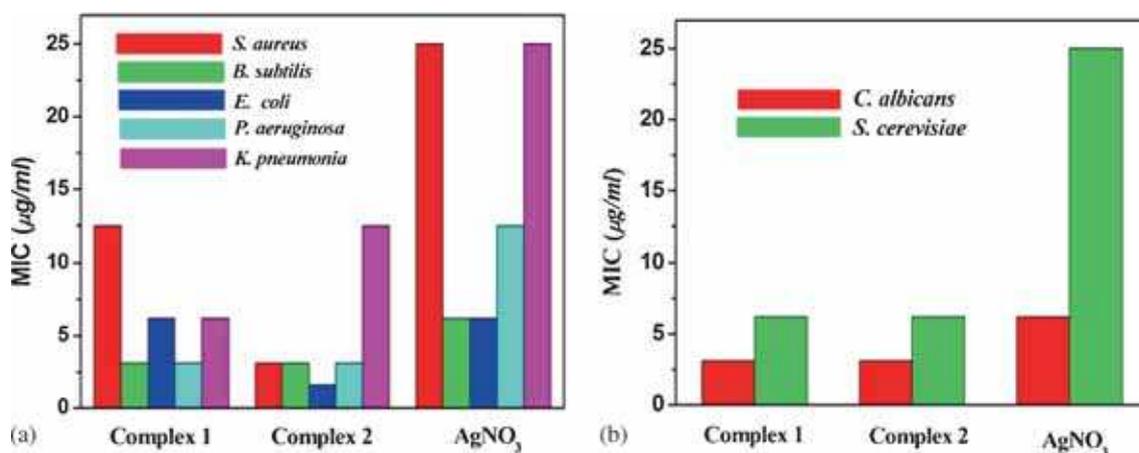


Figure 4. (a) Antimicrobial; and (b) antifungal activities of the complexes **1** and **2**, and AgNO₃ with the minimum inhibitory concentrations (MIC) in ($\mu\text{g mL}^{-1}$).

determined by disc diffusion method.²⁴ The MIC values for both the compounds as well as for control compound (AgNO₃) are given in $\mu\text{g mL}^{-1}$. The results are summarized in table 4. It can be noted that both the compounds inhibited growth of both bacterial and fungal strains. The free ligand did not inhibit the growth of the tested organisms at concentrations below $500 \mu\text{g mL}^{-1}$.

For compound **1**, the most promising results were obtained for *B. subtilis*, *P. aeruginosa* and *C. albicans*. Compound **2** revealed the most promising results for *S. aureus*, *B. subtilis*, *E. coli*, *P. aeruginosa* and *C. albicans*. A comparative study of the ligands, metal salt (AgNO₃) and its complexes indicates that the latter exhibits more antimicrobial activity than the metal salt and ligands against all of the aforementioned bacterial

and fungal strains, except compound **1** against *E.coli*. Silver(I) complexes, **1** and **2** have been found to be very effective antibacterial and antifungal (table 4, figure 4) agents, but are relatively better antibacterial than antifungal agents.

4. Conclusions

The synthesis, crystal structures, photoluminescence and antimicrobial studies of complexes [Ag(HL)₂]ClO₄ (**1**) and [Ag(HL)₂]NO₃·H₂O(**2**) have been reported. Both the complexes have adopted a square planar geometry with coordination number four. The structures reveal Ag···Ag interactions and face-to-face $\pi - \pi$ stacking interactions between the pyridyl groups. Extensive hydrogen bonding interactions have been found in both the complexes. The presence of the two different anions, ClO₄⁻ and NO₃⁻ do not change the skeleton of the monomeric [Ag(HL)₂]⁺ unit, but modulate the hydrogen bonding interactions to form 1-D double sheet and 2-D double sheet structure in compounds **1** and **2**, respectively. The emission studies reveal that the complexes show luminescence in solid and in solution states at room temperature, and this is believed to be due to the existence of intermetallic interactions. The synthesized silver(I) complexes can be used as antimicrobial agents and potential drugs. The chelation of ligands with metal ions has increased the biological activity of the title complexes against some of the selected bacterial strains and fungal species.

Supplementary Information

Characterization data for ligand HL, table S1, table S2, ORTEP representation of compound **2** (figure S1), H-bonding pattern of compound **2** (figure S2), figure S3 and figure S4 are available in Supplementary Information at www.ias.ac.in/chemsci. CCDC-1058772 (**1**) and 1058773 (**2**) contain 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.

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