*Research Journal of Chemistry and Environment*______________________________________Vol. **27 (5)** May **(2023)**
Res. J. Chem. Environ.

A study of *in vitro* antimicrobial activities and antioxidant of lanthanide complexes with a tri dentate Schiff base ligand

Nagaraju N.*, Sreeramulu J., Anjaneyulu V., Malleswarareddy P. and Ramamohan G.
Department of Chemistry, Sri Krishnadevaraya University, Ananthapuramu- 515 003, INDIA
*nagachemsku9652@gmail.com

Abstract

The tridentate N3-type Schiff base 4-(anthracen-10-yl)-2,6-di(pyridin-2-yl)pyridine was synthesized from the condensation reaction of 2-acetyl pyridine and anthracene-10-carbaldehyde *with ammonia using one pot methodology. This hybrid ligand was used for synthesis of lanthanide complexes (La, Sm and Eu) as novel potential biological agent. The lanthanide complexes were characterized on the basis of elemental, FT-IR, UV-Visible, mass spectrometry as well as molar conductivity. The complexes were screened for in vitro antibacterial and antifungal activities against the multidrug resistant pathogens such as Escherichia coli, Staphylococcus aureus and Aspergillus niger.*

The antimicrobial results revealed that Sm^{+3} *complex has a good potency against different gram positive and gram negative bacteria in comparison with other complexes. All lanthanide complexes showed a moderate antioxidant activity with IC50. The DPPH· radical scavenging effects of the Schiff base ligand and its Ln (III) complexes were screened. The Ln (III) complexes were significantly more efficient in quenching DPPH· than the free Schiff base ligand.*

Keywords: Terpyridine, one pot method, lanthanides, antioxidant studies, anti-bacterial and anti-fungal activities.

Introduction

Terpyridine or tpy discovery in the early 1930s by Morgan and Burstall[25,26] terpyridine, or tpy, has piqued people's curiosity. Since this ground breaking study, various derivatives have been created by grafting various substituents onto the terpyridine core utilizing a variety of synthetic methods[13,18,35,38]. Terpyridine molecules have three nitrogen atoms, making them capable of chelating a wide spectrum of ions from the main group, transition metals and even lanthanides.

The thermodynamic chelate effect adds to the stability of coordination compounds containing transition metal centres and the s-donor/p-acceptor nature of the dative M—N pyridine bond also helps to the stability of the resultant coordination compounds. By altering the nature of the metal, the substitution pattern of the tpy moiety and lastly the character of the other ligands engaged in the coordination sphere, a variety of complexes were created.

The nature of the substitution pattern onto the tpy ligand allows these complexes to have fascinating redox and photophysical properties which can be fine-tuned. These molecules have found uses in a variety of sectors including photovoltaic materials[19,30], nano materials[21,33], biomarkers[20,31], medicinal chemistry[2,39,48] and catalysts[8]. Terpyridines and their derivative complexes are also commonly used in supramolecular chemistry.

Lanthanide coordination chemistry has been one of the most studied topics of chemistry in the last decade[32,46,47]. The fascinating structures[17,42,45] and prospective applications in a wide range of fields such as diagnostic tools in biology[5], catalysis[49], luminescence[22] and magnetism[10] have piqued chemists' interest in these areas of research. The acyclic ligand's flexibility and many coordination sites allow for a variety of structures with lanthanide ions[1,24]. This sort of ligand can be used to make a variety of coordination molecules. The literature contains several reports on its antibacterial[29], antifungal[41], anticancer[15] and depressive[11] properties. The goal of the study is to prepare, characterise and assess the biological activity of lanthanide complexes.

From the condensation reaction of 2-acetyl pyridine and anthracene-10-carbaldehyde with ammonia, we can make tridentate Schiff base 4-(anthracen-10-yl)-2,6-di(pyridin-2-yl)pyridine. Various approaches were used to establish the structure of the ligand and its lanthanide complexes (La, Sm and Eu) including elemental analysis, molar conductivity, UV–visible, NMR and infrared (IR) spectroscopies.

The biological activities of the free ligand and its lanthanide complexes were further studied utilising agar well diffusion and minimum inhibitory concentration (MIC) methods to assess their antibacterial activity against diverse harmful bacterial strains. In addition, using the 2,2 diphenyl1picrylhydrazyl (DPPH) test method, the antioxidant properties of the free ligand and its complexes were assessed in terms of their radical scavenging capability.

Material and Methods

Materials and reagents: $[Ln(NO_3)_3(H_2O)_6]$ (Ln = La, Sm,), $[Eu(NO_3)_3(H_2O)_5]$, anthracene-10-carbaldehyde , 2-acetyl pyridine and ammonia were purchased from Sigma Aldrich Chemical Company. All other solvents and reagents were of analytical grade and used without further purification.

https://doi.org/10.25303/2705rjce042051

Instruments: Elemental analysis was done using a Perkin-Elmer elemental analyser. Molar conductance of the complexes was measured in DMF (10^{-3} M) solutions using a Coronation Digital Conductivity Meter. The mass spectra were recorded on a JEOL JMS600H mass spectrometer. The 1H NMR spectra were recorded on a Bruker Advance 400 MHz spectrometer. IR (KBr) spectra were recorded on a JASCO FT/IR-410 spectrometer in the 4000–400 cm^{-1} region. The electronic spectra were recorded on a Double Beam UV-VIS Spectrophotometer (ELICO) SL 210 UV–VIS spectrometer.

Synthesis of Schiff base ligand L4: To a solution of 2-acetylpyridine (5 ml; 41 mmol) in ethanol (100 mL), anthracene-10-carbaldehyde (2.5 ml; 20 mmol), potassium hydroxide pellets (0.5 g; 67 mmol) and 25% aqueous ammonia (60 mL) are added using one-pot methodology. The reaction mixture was stirred at room temperature for 24 h. The solid was then filtered on a glass-sintered funnel and washed with ice-cold 50% ethanol until washings were colourless. The product was dried under vacuum. The ligand was obtained as a yellow solid. An analytical sample was obtained by recrystallization in ethanol. Molecular formulae of ligand is $C_{29}H_{19}N_3$. The synthesis of ligand L4 is shown in scheme 1.

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.46-7.42(t,2H,J=7.29), 7.54 -7.49(m,2H,J=7.63),7.61-7.31(t,2H,J=7.87),7.79-7.67(t,2H, J=8.2),8.09-8.05(t,2H,J=8.2),8.32-8.18(dd,2H,J=7.16),8.55-8.45(t,2H,J=2.26). 8.67-8.62(m, 2H, J=1.19), 8.80-8.78(d, 2H, J=5.21). 9.01(m, 1H, J=2.26).

Synthesis of lanthanide complexes: Lanthanide complexes were prepared by refluxing and stirring 1:2 ratio of metal [$La(NO_3)_3(H_2O)_6$], (0.5 g, 0.1 mmol) and ligand (1g, 0.3 mmol) on a water bath for 8 h. After cooling to room temperature, the precipitate was collected, washed with methanol for several times and dried in vacuum at room temperature. All other Sm and Eu complexes were prepared in a similar manner.

***In vitro* antimicrobial activity:** The synthesised complexes were screened for *in vitro* antimicrobial activity against gram positive bacteria *Staphylococcus aureus* (MTCC 3160), gram negative bacteria *Escherichia coli* (MTCC 443) and fungal strains *Aspergillus niger* (MTCC 281) by tube dilution method[6,12,27] and results were compared with fluconazole (antifungal) and cefadroxil (antibacterial) as standard drugs. The stock solutions were prepared in DMSO having 100 µg/ml concentrations for standard and test drugs. Fresh pure cultures were used to prepare the bacterial and fungal inoculums.

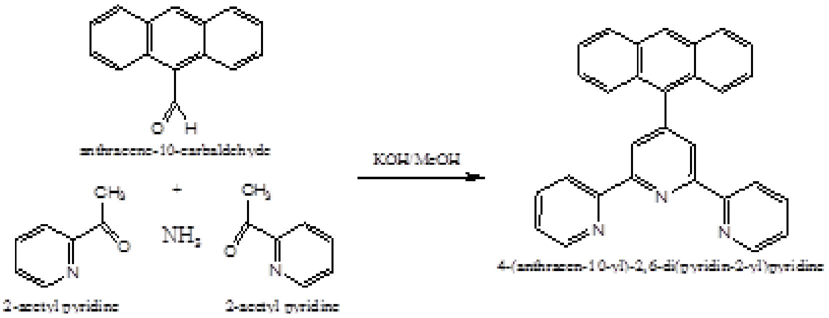
In the test-tubes containing serial dilutions (50, 25, 12.5, 6.25 and 3.12 µg/ml) of test and standard compounds in nutrient broth and Sabouraud dextrose broth, 100 µl of inoculum was added. After that it was incubated at 37 ± 1 °C for 24 h (bacteria), at 25 ± 1 °C for 7 days (*A. niger*). Antimicrobial screening results were recorded in terms of lowest concentration of test substances which inhibited the growth of microorganisms i.e. MIC.

DPPH free radical scavenging activity: Antioxidant activity was evaluated spectrophotometrically by using free radical scavenging method i.e. DPPH (1,1‑diphenyl‑2‑picrylhydrazyl) assay. The DPPH is a stable free radical and it reacts with hydrogen donors showing the reduction to its corresponding hydrazine with the maximum absorption at 517 nm. Colour of DPPH changes from violet to yellow indicating the reaction of DPPH with an antioxidant agent as it can donate hydrogen to get reduced with a considerable decrease in absorption at 517 nm. DPPH solution (3 µg/ml) was prepared in methanol. The solution of methanol and DPPH (1:1) was used for blank reference. Four dilutions of different concentrations (25 µg/ml, 50 µg/ml, 75 µg/ml, 100 µg/ml) of each synthesized compound and standard (ascorbic acid) were prepared in the methanol and 1 ml of each concentration was added to 1 ml of DPPH solution.

The solution mixture was placed in dark place for 30 min at room temperature after vigorous shaking and their absorbance was measured by Uv at 517 nm[37,40]. Percentage (%) inhibition of free radical DPPH was calculated as follows:

$$\%\ \text{inhibition} = \frac{\text{A Blank} - \text{A Sample}}{\text{A Blank}} \text{ X } 100$$

where A Blank = absorbance of the blank reaction, A Sample = absorbance of the test compounds.



Scheme 1: Synthesis of ligand L4

IC50 value was calculated from the graph plotted between % inhibition and synthesized derivatives. The antioxidant screening results indicated that few synthesized compound exhibited significant antioxidant activity while other showed good to moderate antioxidant activity.

Results and Discussion

Characterization of Schiff base ligand L4: The ligand L4 structure is identified by elemental analysis, IR and ^{1}H NMR spectral studies. The synthetic route for the ligand L4 is presented in scheme 1. The results of elemental analysis with molecular formula and the percentage yield of the ligand L4 are presented in table 1. Mass spectrum of ligand L4 is shown in figure 1. ^{1}HNMR spectrum of ligand both full and expanded are presented in figures 2 and 3.

Characterization of lanthanide complexes: The isolated solid complexes were characterized by elemental analysis, MASS, IR, molar conductance, UV–visible spectroscopy. All these complexes are stable in air at room temperature, non-hygroscopic, insoluble in water and most of organic solvents and soluble in DMF and DMSO solvents. Various attempts to obtain the single crystals of the complexes have so far been unsuccessful. The yields, molar conductivity values and elemental analysis of Ln(III) complexes and ligand L are summarized in table 1.

The stoichiometry of the complexes derived from elemental analysis corresponds to the general formula $[La(L4)(NO_3)_2H_2O],]$. These propositions are also in accord with molar conductivity measurements, IR and UV–Visible spectra. The mass spectrum of $[Sm(L4)(NO_3)_2H_2O]$ complex as shown in figure 4.

Table 1
Analytical and Physical Characterization Data for Ligand and Its Metal Complexes

Compound	**Molecular Weight Found (Calculated)**	**Melting point (^0C)**	**Colour Yield (%)**	**Elemental analysis Found (calculated)**				**Molar conductivity Ω^{-1} cm^2 mol^{-1}**
				C(%)	**H(%)**	**N(%)**	**Ln(%)**	
Ligand L4	409 (408)	124-126	Yellow (67.26)	85.14 (85.35)	4.68 (4.69)	10.27 (10.29)	-	-
$[La(L4)(NO_3)_2H_2O]$	690 (689)	267-269	Yellow (88.94)	50.47 (50.54)	3.06 (3.07)	10.14 (10.16)	20.14 (20.17)	18.06
$[Sm(L4)(NO_3)_2H_2O]$	701 (700)	271-273	Red (87.55)	49.68 (49.75)	3.01 (3.02)	09.99 (10.00)	21.44 (21.47)	22.65
$[Eu(L4)(NO_3)_2H_2O]$	703 (702)	260-262	Orange (87.30)	49.53 (49.60)	3.01 (3.01)	09.96 (09.97)	21.62 (21.65)	25.31

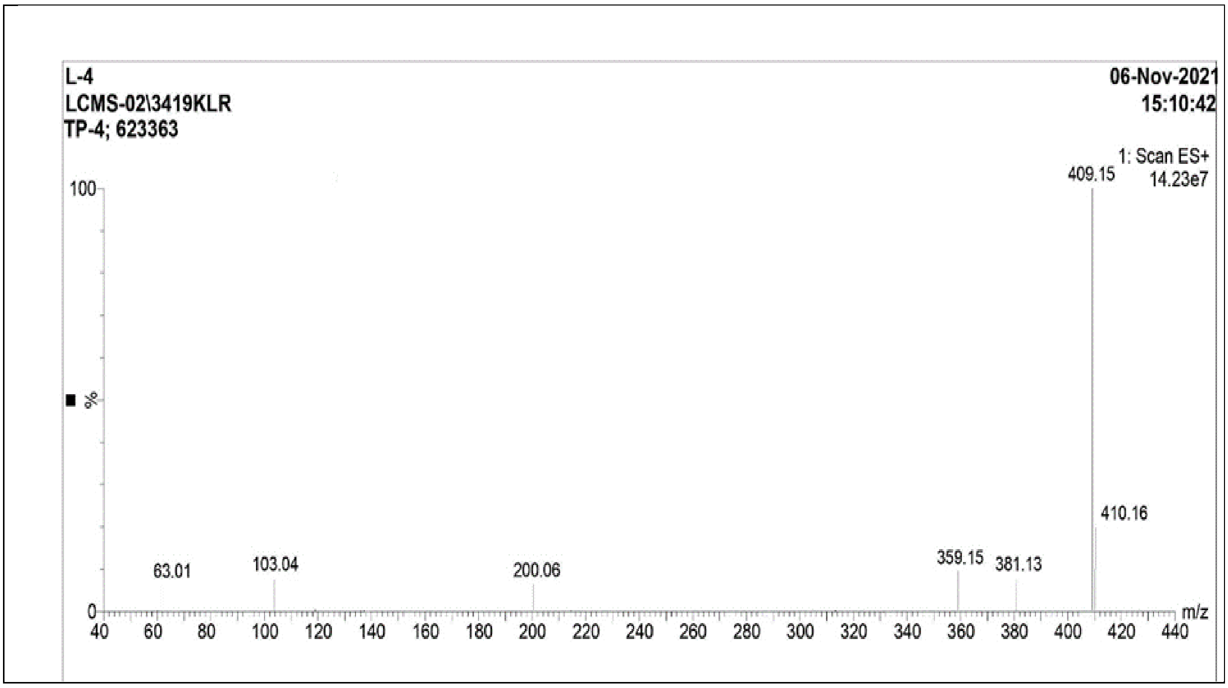


Figure 1: Mass spectrum of ligand L4

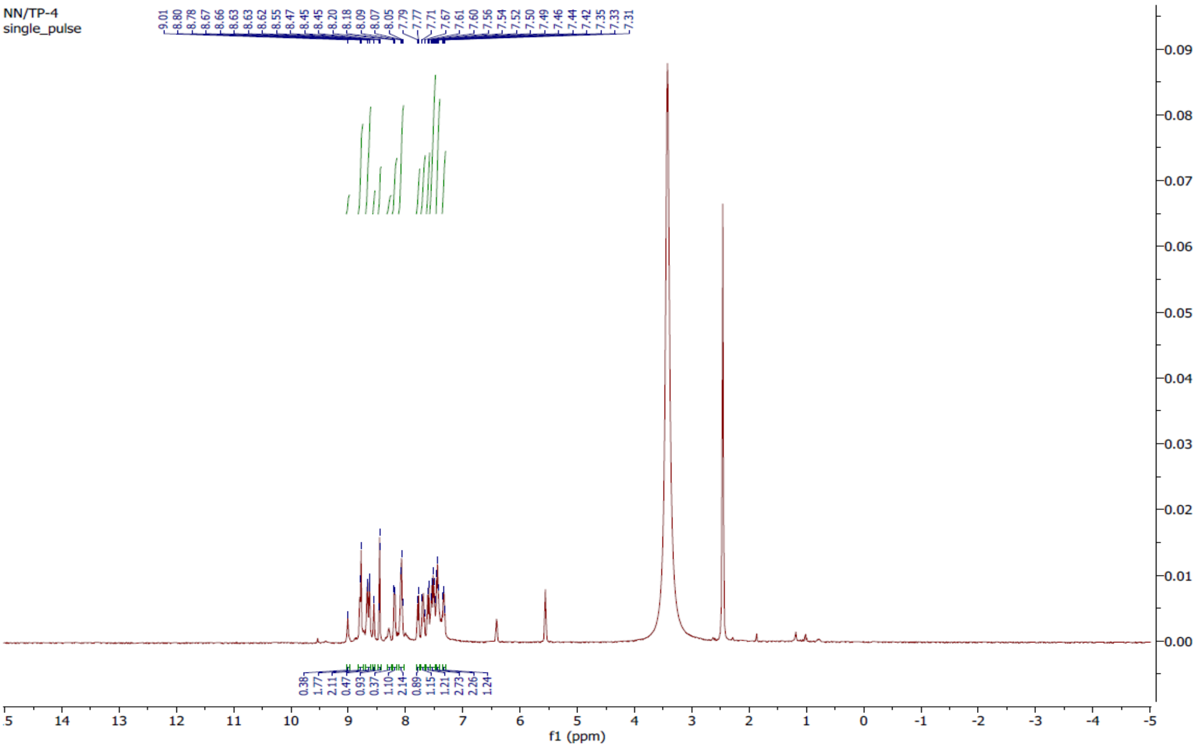


Figure 2: 1HNMR spectrum of ligand L4 (complete spectrum)

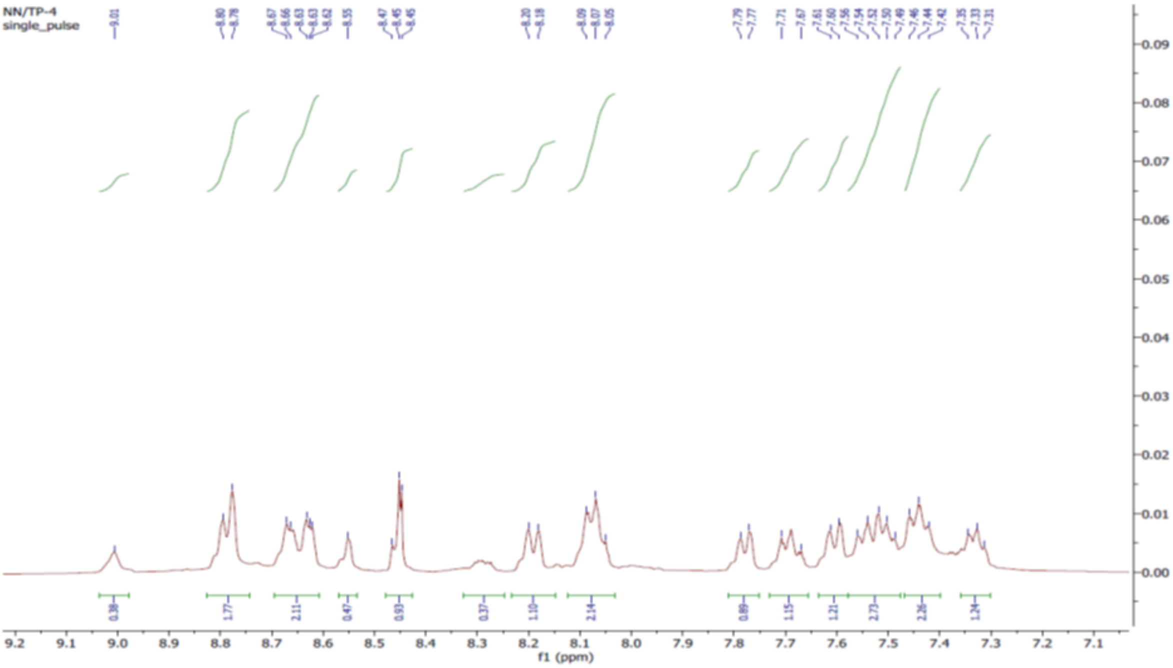


Figure 3: 1HNMR spectrum of ligand L4 (expanded form)

Table 2
Infra-Red Spectral Data for Ligand and Their Lanthanide Complexes

Compound	**υ(OH)**	**υ(C=N)**	**υ(NO_3^-)**					**υ(M-O)**	**υ(M-N)**
			$υ_1$	**$υ_2$**	**$υ_3$**	**$υ_4$**	**$υ_1$- $υ_4$**		
L4		1635	-	-	-	-	-	-	-
[La(L4)$(NO_3)_2H_2O$]	3425	1601	1469	1043	815	1275	194	475	445
[Sm(L4)$(NO_3)_2H_2O$]	3435	1592	1465	1039	829	1269	196	463	451
[Eu(L4)$(NO_3)_2H_2O$]	3443	1620	1472	1056	832	1279	193	469	449

Molar conductivity measurements: The molar conductivities of the Ln (III) complexes in DMF solutions at 25 ◦C are measured and tabulated in table 1. The molar conductivity values are in the range reported for 1:1 electrolytes revealing that the all complexes are non-electrolytes ($\Lambda m = 18.06–25.31\ \Omega^{-1}\ cm^2\ mol^{-1}$) [4, 16].

Infrared spectroscopy: The important infrared frequencies along with the tentative assignment of the ligand L and its respective Ln(III) complexes are presented in table 2. The IR spectra of the La complexes displayed the ligand characteristic bands with the appropriate shifts due to complex formation and the infrared of the other Ln(III) complexes displays the same manner. It was found that the C=N of the azomethine group occurs at 1635 cm^{-1} in the free Schiff base. After complexation, these bands are shifted to lower wave numbers by 15 to 43 cm^{-1} indicating a double bond character of the imine bonds and a coordination of the azomethine nitrogen atoms to the Ln(III) ion[28,34.] This coordination was further supported by the appearance of a medium intensity band around 445 to 451 cm^{-1} assigned to (Ln–N) vibration. This coordination was further supported by the appearance of a medium intensity band around 463 to 475 cm^{-1} assigned to (Ln–O) vibration.

In addition, the IR spectrum of the complex exhibits a broad band between 3443 to 3425 cm^{-1} which is attributed to the stretching frequency of (O–H), in the spectra of the Ln(III) complexes, with an increase in the intensity indicating that the hydroxyl oxygen is coordinated to the Ln(III) ion without proton displacement.

UV–visible spectroscopy of complexes: UV–Vis absorption spectra of the lanthanide complexes were carried out in DMF solvent at room temperature. The UV–Vis spectra values of the maximum absorption wavelength (λ max), frequency of Ln (III) complexes {Ln = La, Sm and Eu } and their assignment are listed in table 3.[3,7,36,43] The electronic spectrum of [Sm(L4)$(NO_3)_2H_2O$]complex is shown in the figure 5.

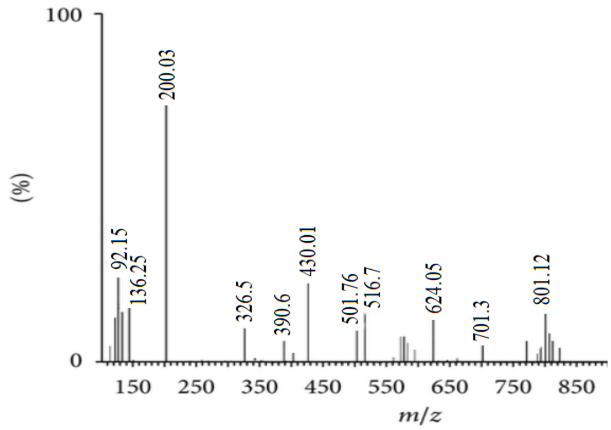


Figure 4: Mass spectrum of [Sm(L4)$(NO_3)_2H_2O$]complex.

Table 3
Electronic Spectral Data for Lanthanide Complexes

Compound	**Wavelength λ max (nm)**	**Frequency (cm^{-1})**	**Band assignments**
[La(L4)$(NO_3)_2H_2O$]	272	36.764	π→π* transition
	298	33.557	π→π* transition
	325	30,769	π→π* transition
	375	26,666	π→π* transition
	404	24,752	n→π* transition
[Sm(L4)$(NO_3)_2H_2O$]	265	37.735	π→π* transition
	275	36.363	π→π* transition
	325	30,769	π→π* transition
	380	26,315	π→π* transition
	425	23,529	n→π* transition
[Eu(L4)$(NO_3)_2H_2O$]	268	37.313	π→π* transition
	279	35,842	π→π* transition
	315	31,746	π→π* transition
	350	28,571	π→π* transition

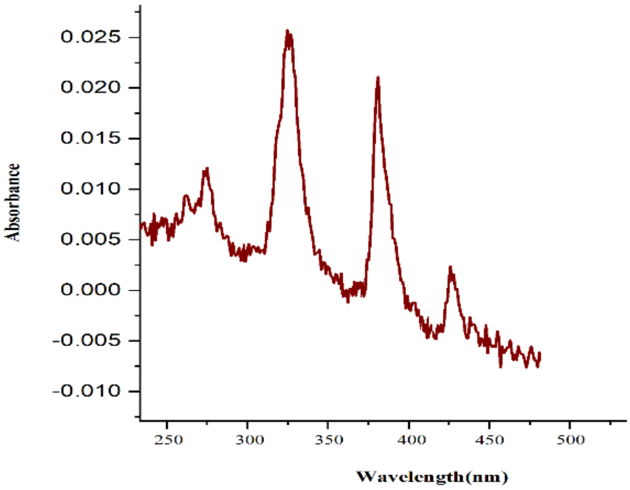


Figure 5: Electronic spectrum of [Sm(L4)$(NO_3)_2H_2O$]complex.

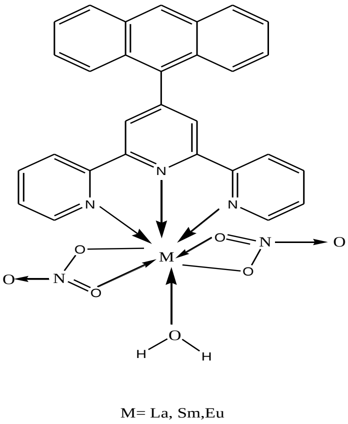


Figure 6: Schematic representation of lanthanide metal [M (L4) $(NO_3)_2H_2O$] complex.

Tentative general structure for [Ln(L4)$(NO_3)_2H_2O$] complexes is shown in the figure 6.

Antimicrobial activity: The MIC of the ligand L and its Ln(III) complexes against different types of gram-negative, gram-positive bacteria and fugal activities was determined and tabulated in table 4. DMSO was used as a negative control and Cefadroxil was used as positive standards for antibacterial. Fluconazole was used as a reference for antifungal studies. These compounds exhibit moderate to strong antimicrobial activity. Comparatively a better activity is found for the bacteria rather than the fungi. The Sm(III) complex exhibits a higher activity than the other metal complexes towards fungal species. The Sm(III) complex shows a good activity, especially against the gram-negative and gram positive bacteria such as *E. coli* and *S.aureus*. The La(III) complex shows equal activity compared to Sm(III) complex in gram-negative bacteria and fungal species. The antimicrobial activity of the complexes is greater than those of the free ligand, this indicates that the complexation to metal enhances the activity of the ligand. This is explained on the basis of overtone's concept and chelation theory. Chelation tends to make the ligand a more powerful and potent bacterial agent. A possible explanation for this increase in the activity upon chelation is that, in a chelated complex, the positive charge of the metal is partially shared with donor atoms present in the ligands and there is an electron delocalization over the whole chelated ring. This, in turn, increases the lipoid layers of the bacterial membranes.

Generally, it is suggested that the chelated complexes deactivate various cellular enzymes which play a vital role in various metabolic pathways of these microorganisms. Other factors such as solubility, conductivity and dipole moment that are affected by the presence of metal ions, may also be the possible reasons for increasing the biological activity of the metal complexes as compared to the ligand from which they are derived[9,14].

Table 4
The MIC of the ligand L and its Ln(III) complexes against different types of gram-negative, gram-positive bacteria and fugal activities

Tested compounds	**Gram(-) bacteria**	**Gram(+) bacteria**	**Fungal species**
	E.coli	*S.aureus*	*A.niger*
Ligand L4	-	-	-
[La(L4)(NO_3)$_2$$H_2O$]	++	+	++
[Sm(L4)(NO_3)$_2$$H_2O$]	++	++	++
[Eu(L4)(NO_3)$_2$$H_2O$]	+	++	+
DMSO (- ve control)	-	-	-
Fluconazole (+ ve control)			++
Cefadroxil (+ ve control)	++	++	

Note: Inhibition zone :0 mm(-)inactive; 1-5 nm(+)= less active; 6-10 mm(++) moderately active; 10-15 mm(+++) highly active;

Table 5
Scavenging Effect of Schiff Base Ligand (L) and Its Lanthanide Complexes on Dpph Free Radical at various concentrations

Compound	**DPPH scavenging activity (%)**				**IC$_{50}$**
	25µM	50µM	75µM	100µM	
ligand	25.64	31.42	52.43	67.28	-
[La(L4)(NO_3)$_2$$H_2O$]	28.15	42.18	61.53	72.14	49.71
[Sm(L4)(NO_3)$_2$$H_2O$]	31.58	47.43	64.17	77.13	64.05
[Eu(L4)(NO_3)$_2$$H_2O$]	34.62	55.43	68.72	82.14	74.52
Ascorbic acid	36.42	56.13	67.42	85.63	41.12

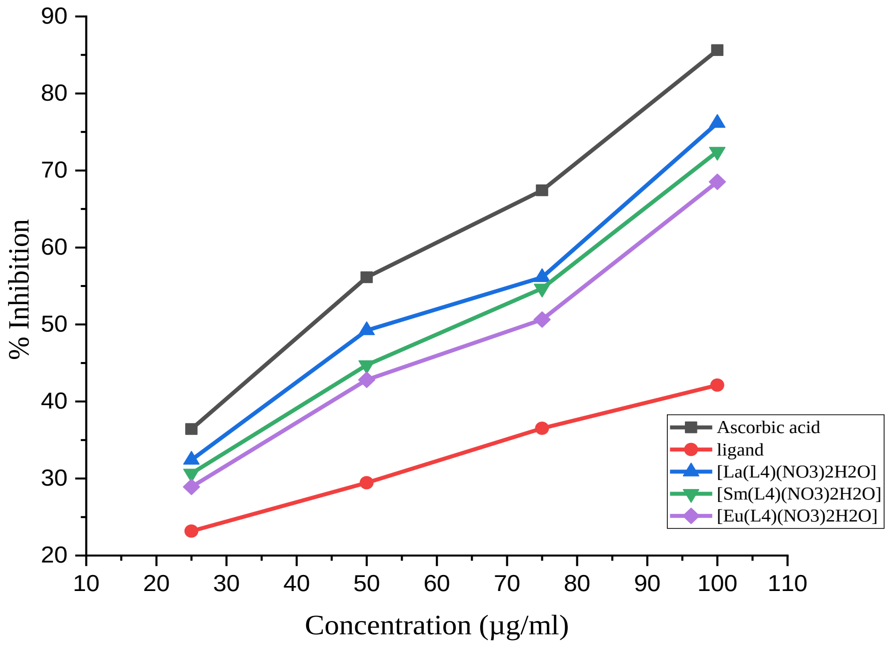


Figure 7: Antioxidant activity of the ligand and the lanthanide complexes.

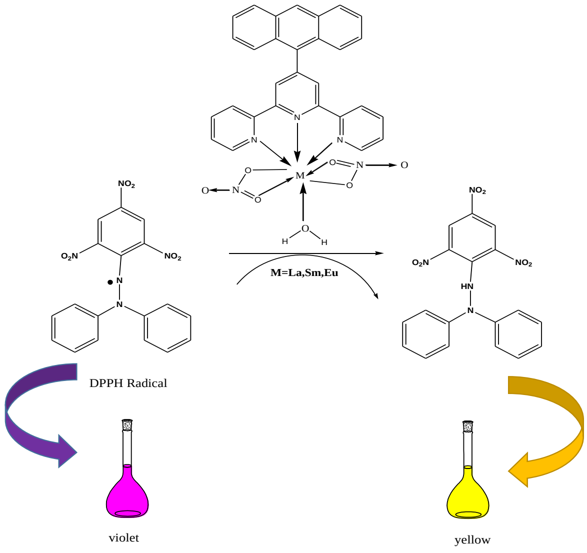


Figure 8: Addition of Ln complex to $DPPH^{\cdot}$ Radical.

Antioxidant activity: The antioxidant activity of the ligand L and its Ln(III) complexes has attracted increasing interests and has been substantially investigated [23,44]. Figure 6 shows the plots of DPPH• free radical scavenging activity % for the ligand L4 and its Ln(III) complexes. It is obvious that the scavenging activity increases with increasing sample concentration in the range tested. As shown in table 5, The free radical scavenging activity of ligand L and its lanthanide complexes was determined by their ability to bleach DPPH radical, which has been previously reported. This assay provides information on the reactivity of a compound with a stable free radical. Ln (III) complexes are significantly more efficient in quenching DPPH radical than free ligand L. The antioxidant activity of the Schiff base is due to hydrogen- or electron-donating tendency to DPPH• so as to produce a stable diamagnetic molecule.

Molecules with greater ability to donate electrons or hydrogen to DPPH• have a higher antioxidant activity. The interaction of ligand L with the positively charged Ln (III) increases the electron density drawn from the nitrogen and oxygen atoms which make the N─ H or O─ H bonds more polarized. Among the examined lanthanide complexes, the La (III) complex has the highest activity. It can quench the DPPH radical more efficiently than the other lanthanide ions. In them, complex La (III) exhibited excellent antioxidant activity compared to Eu (III) and Sm (III) complexes found to have IC50 value and (%) inhibition[48,49]. Addition of Ln complex to $DPPH^{\cdot}$ radical is shown in the figure 8.

Conclusion

In this work, the tridentate Schiff base ligand L and its Ln(III) complexes are synthesized and characterized. Analytical and spectral data reveal that the ligand L coordinates to the central Ln(III) ion [La(III), Sm(III) and Eu(III)] with coordination number 8. The antimicrobial activity results show that the synthesized Ln(III) complexes possessed good antibacterial activity higher than that of the corresponding ligand L.

The antioxidant activity of the Ln(III) complexes on DPPH• is concentration dependent and higher than that of the free ligand L. The $[Sm(L4)(NO_3)_2H_2O]$complex show good anti-microbial and $[La(L4)(NO_3)_2H_2O]$ shows good anti-oxidant compared with $[Eu(L4)(NO_3)_2H_2O]$.

Acknowledgement

The author would like to thank to RIPER ananthapuramu for providing microbial strains and to Bangalore university for anti-oxidant studies and to the SAIF centres in Dharwad, IIT Madras and IIT Bombay for providing instrumentation for IR, NMR and mass analysis. The author (NN) is thankful to CSIR-HRDG, New Delhi for providing financial support.

References

1. Angelusiu M.V., Barbuceanu S.F., Draghici C. and Almajan G.L., New Cu(II), Co(II), Ni(II) complexes with aroyl-hydrazone based ligand. Synthesis, spectroscopic characterization and in vitro antibacterial evaluation, *Eur. J. Med. Chem.*, **45**, 2055–2062 **(2010)**

2. Anthonysamy A., Balasubramanian S., Shanmugaiah V. and Mathivanan N., Synthesis, characterization and electrochemistry of 4′-functionalized 2,2′:6′,2″-terpyridine ruthenium(ii) complexes and their biological activity, *Dalton Trans.*, **16**, 2136-2143 **(2008)**

3. Ayad M., Schollhammer P., Mest Y.L., Wojcik L., Petillon F.Y., Poul N.L. and Mandon D., Mononuclear copper(II) complexes containing a macrocyclic ditopic ligand: Synthesis, structures and properties, *Inorg. Chim. Acta*, **497**, 119081 **(2019)**

4. Bayoumi H.A. et al, Cu(II), Ni(II), Co(II) and Cr(III) Complexes with N_2O_2-Chelating Schiff's Base Ligand Incorporating Azo and Sulfonamide Moieties: Spectroscopic, Electrochemical Behavior and Thermal Decomposition Studies, *Int. J. Electrochem. Sci*., **8**, 9399-9413 **(2013)**

5. Caki N., Gündüz S., Rengarasu R. and Angelovski G., Synthetic strategies for preparation of cyclen-based MRI contrast agents, *Tetra Hedron Lett*., **56**, 759–765 **(2015)**

6. Cappuccino J. and Sherman N., Microbiology: a laboratory manual, 5th ed., Benjamin/Cummings, California **(1999)**

7. Carnall W.T., Gschnlder K.A. and Eyring L.R., eds., Handbook on the physics and chemistry of rare earths, North Holland, Amsterdam, **3**, 171 **(1979)**

8. Chelucci G., Saba A., Vignola D. and Solinas C., New chiral 2,2′:6′,2″-terpyridines as ligands for asymmetric catalysis: cyclopropanation and hydrosilylation reactions, *Tetrahedron*, **57**, 1099-1104 **(2001)**

9. Coskun D. et al, Synthesis, characterization and antimicrobial activity of novel benzofuran- and thiophene-containing diketoxime derivatives, *J. Serb. Chem. Soc.*, **82**, 367-377 **(2017)**

10. Cristovao B. and Hnatejko Z., Lanthanide(III) compounds with the N2O4-donor Schiff base – Synthesis, spectral, thermal, magnetic and luminescence properties, *J. Mol. Struct*., **1088**, 50-55 **(2015)**

11. Demir D., Eken C., Çelik E. and Alkan N., Effect of Rhizoctonia spp. on Polyphenol Oxidase Enzyme Activity in Alfalfa Seedling, *Res. J. Biotech.*, **16(11)**, 47-50 **(2021)**

12. Dharmaraj N., Viswanathamurthi P. and Natarajan K., Ruthenium(II) complexes containing bidentate Schiff bases and their antifungal activity, *Transit. Met. Chem*., **26**, 105-109 **(2001)**

13. Fallahpour R.A., Synthesis of 4′-Substituted-2,2′:6′,2″-Terpyridines, *Synthesis*, **2**,155-184 **(2003)**

14. Fouad R., Synthesis and characterization of lanthanide complexes as potential therapeutic agents, *J. Coor Chem.*, **73**, 2015-2028 **(2020)**

15. Gaikwad S.D., Ph. D. Thesis, University of Pune (India) **(1997)**

16. Geray W.J., The use of conductivity measurements in organic solvents for the characterisation of coordination compounds, *Coord. Chem. Rev*., **7**, 81-122 **(1971)**

17. Han S.D., Miao X.H., Liu S.J. and Bu X.H., Magnetocaloric effect and slow magnetic relaxation in two dense (3,12)-connected lanthanide complexes, *Inorg. Chem. Front.*, **1**, 549–552 **(2014)**

18. Heller M. and Schubert U.S., Syntheses of Functionalized 2,2′:6′,2″-Terpyridines, *Eur J Org Chem*., **2003**, 947-961 **(2003)**

19. Kalyanasundaram K. and Grätzel M., Applications of functionalized transition metal complexes in photonic and optoelectronic devices, *Coord Chem Rev.*, **77**, 347-414 **(1998)**

20. Khatyr A. and Ziessel R., *Synthesis*, **11**, 1676 **(2001)**

21. Kurth D.G., Severin N. and Rabe J.P., Perfectly Straight Nanostructures of Metallosupramolecular Coordination-Polyelectrolyte Amphiphile Complexes on Graphite, *Angew Chem Int Ed*., **41**, 3681 **(2002)**

22. Lahoud M.G., Frem R.C.G., Gálico D.A., Bannach G., Nolasco M.M., Ferreira R.A.S. and Carlos L.D., Intriguing light-emission features of ketoprofen-based Eu(III) adduct due to a strong electron–phonon coupling, *J. Lumin.*, **170**, 357–363 **(2016)**

23. Li T.R., Yang Z.Y., Wang B.D. and Qin D.D., Synthesis, characterization, antioxidant activity and DNA-binding studies of two rare earth(III) complexes with naringenin-2-hydroxy benzoyl hydrazone ligand, *Eur. J. Med. Chem.*, **43**, 1688–1695 **(2008)**

24. Mohanan K., Kumari B.S. and Rijulal G., Microwave assisted synthesis, spectroscopic, thermal and antifungal studies of some lanthanide(III) complexes with a heterocyclic bishydrazone, *J. Rare Earths*, **26**, 16–21 **(2008)**

25. Morgan S.G. and Burstall F.H., Dehydrogenation of pyridine by anhydrous ferric chloride, *J. Chem Soc*., **0**, 20-30 **(1932)**

26. Morgan S.G. and Burstall F.H., Researches on residual affinity and co-ordination. Part XXXVII. Complex metallic salts containing 2: 6-di-2′-pyridylpyridine (2 : 2′ : 2″-tripyridyl), *J Chem Soc.*, **0**, 1649-1655 **(1937)**

27. Mukherjee D.P.K., Evaluating Natural Products and Traditional Medicine, Quality Control of Herbal Drugs, 564 **(2012)**

28. Nakamoto K., Infrared and Raman Spectra of Inorganic and Coordination Compounds, 3rd ed., Wiley-Interscience, New York **(1978)**

29. Picón-Ferrer, Hueso-Ureña F., Illán-Cabeza N.A., Jiménez Pulido S.B., Martínez-Martos J.M., Ramírez-Expósito M.J. and Moreno-Carretero M.N., Chloro-fac-tricarbonylrhenium(I) complexes of asymmetric azines derived from 6-acetyl-1,3,7-trimethylpteridine-2,4(1H,3H)-dione with hydrazine and aromatic aldehydes: Preparation, structural characterization and biological activity against several human tumor cell lines, *J. Inorg. Biochem.*,**103**, 94–100 **(2009)**

30. Polo A.S., Itokazu M.K. and Murakami Iha N.Y., Metal complex sensitizers in dye-sensitized solar cells, *Coord Chem Rev.*, **248**, 1343-1361 **(2004)**

31. Poupart S., Boudou C., Peixoto P., Marsonneau M., Renard P.Y. and Romieu A., *Org Biomol Chem.*, **4**, 4167 **(2006)**

32. Procházkova S., Hraní ek J., Kubí ek V. and Hermann P., Formation kinetics of europium(III) complexes of DOTA and its bis(phosphonate) bearing analogs, *Polyhedron*, **111**, 143–149 **(2016)**

33. Rotas G., Sandanayaka A.S.D., Tagmatarchis N., Ichihashi T., Yudasaka M., Lijima S. and Ito O.J., (Terpyridine)copper(II) −Carbon Nanohorns: Metallo-nanocomplexes for Photoinduced Charge Separation, *Am Chem Soc.*, **130**, 4725-4731 **(2008)**

34. Sakamoto M., Synthesis and characterization of lanthanoid(III) complexes with a pentadentate ligand derived from 2,6-diacetylpyridine and benzoylhydrazide, *Inorg. Chim. Acta*, **131**, 139-142 **(1987)**

35. Schubert U.S., Hofmeier H. and Newkome G.R., Modern Terpyridine Chemistry, Wiley VCH, Weinheim **(2006)**

36. Shebl M., Mononuclear, homo- and hetero-binuclear complexes of 1-(5-(1-(2-aminophenylimino)ethyl)-2,4-dihydroxyphenyl)ethanone: synthesis, magnetic, spectral, antimicrobial, antioxidant and antitumor studies, *J. Coord. Chem*., **69**, 199-214 **(2016)**

37. Sheikhshoaie I., Ebrahimipour S.Y., Lotfi N., Mague J.T. and Khaleghi M., Synthesis, spectral characterization, X-ray crystal structure and antimicrobial activities of two cis dioxido-vanadium(V) complexes incorporating unsymmetrical dimalonitrile-based (NNO) Schiff base ligands, *Inorg. Chim. Acta*, **442**, 151-157 **(2016)**

38. Sichun Y., Huichuan W. and Haibo C., Progress in Catalyst Systems for the Fried länder Reaction, *Chinese J Org Chem*, **29**, 1-12 **(2009)**

39. Son J.K., Zhao L.X., Basnet L.X.A., Thapa P., Karki R., Na Y., Jahng Y., Jeong T.C., Jeong B.S., Lee C.S. and Lee E.S., Synthesis of 2,6-diaryl-substituted pyridines and their antitumor activities, *Eur J Med Chem.*, **43**, 675 **(2008)**

40. Takao T., Watanabe N., Yagi I. and Sakata K., *Biosci. Biotechem.*, **58**, 1781 **(1994)**

41. Thomas A.B., Nanda R.K., Kothapalli L.P. and Hamane S.C., Synthesis and biological evaluation of Schiff's bases and 2-azetidinones of isonocotinyl hydrazone as potential antidepressant and nootropic agents, *Arabian J. Chem.*, **9**, S79–S90 **(2016)**

42. Tian D., Li Y., Chen R.Y., Chang Z., Wang G.Y. and Bu X.H., A luminescent metal–organic framework demonstrating ideal detection ability for nitroaromatic explosives, *J. Mater. Chem. A*, **2**, 1465–1470 **(2014)**

43. Tossidis I.A., Bolos C.A., Aslanidis P.N. and Katsoulos G.A., Monohalogenobenzoylhydrazones III, Synthesis and structural studies of Pt(II), Pd(II) and Rh(III) complexes of Di-(2-pyridyl)ketonechlorobenzoyl hydrazones, *Inorg. Chim. Acta*, **133**, 275-280 **(1987)**

44. Udilova N., Kozlov A.V., Bieberschulte W., Frei K., Ehrenberger K. and Nohl H., The antioxidant activity of caroverine, *Biochem. Pharmacol.*, **65**, 59–65 **(2003)**

45. Wen R.W., Han S.D., Ren G.J., Chang Z., Li Y.W. and Bu X.H., A flexible zwitterion ligand based lanthanide metal–organic framework for luminescence sensing of metal ions and small molecules, *Dalton Trans.*, **44**, 10914–10917 **(2015)**

46. Xu Z.Q., Mao X.J., Jia L., Xu J., Zhu T.F., Cai H.X., Bie H.Y., Chen R.H. and Ma T.L., Synthesis, characterization and anticancer activities of two lanthanide(III) complexes with a nicotinohydrazone ligand, *J. Mol. Struct.*, **102**, 86–90 **(2015)**

47. Yang X., Jones R.A. and Huang S., Luminescent 4f and d-4f polynuclear complexes and coordination polymers with flexible salen-type ligands, *Coord. Chem. Rev.*, **273–274**, 63–75 **(2014)**

48. Zhao L.X., Kim T.S., Ahn S.H., Kim T.H., Kim E.K., Cho W.J., Choi H., Lee C.S., Kim J.A., Jeong T.C., Chang C.J. and Lee E.S., Synthesis, topoisomerase I inhibition and antitumor cytotoxicity of 2,2':6',2"-, 2,2':6',3"- and 2,2':6',4"-terpyridine derivatives, *Bioorg Med Chem Lett*., **11**, 2659-2662 **(2001)**

49. Zhou H., Jiang Y., Chen M., Wang Y., Yao Y., Wu B. and Cui D., Synthesis and characterization of lanthanide amides bearing phenoxy(quinolinyl)amide ligand and their application in the ring-opening polymerization of 1,4-dioxan-2-one, *J. Organomet. Chem.*, **763–764**, 52–59 **(2014)**.

(Received 05th May 2022, accepted 07th July 2022)