Bull. Chem. Soc. Ethiop. **2024**, 38(4), 1013-1025.
DOI: https://dx.doi.org/10.4314/bcse.v38i4.16

ISSN 1011-3924
Printed in Ethiopia
Online ISSN 1726-801X

SYNTHESIS, CHARACTERIZATION, AND ANTIBACTERIAL STUDIES OF SOME OF FIRST TRANSITION SERIES METALS AND ZINC COMPLEXES WITH MIXED LIGANDS OF TRIMETHOPRIM-ISATIN AND NITROGEN BASE

Amaal Y. Al-Assafe[1]* and Rana A.S. Al-Quaba[2]

[1]Chemistry Department, College of Education for Pure Science, University of Mosul, Iraq
[2]Chemistry Department, College of Science, University of Mosul, Iraq

(Received March 20, 2024; Revised April 13, 2024; Accepted April 19, 2024)

ABSTRACT. Complexes of mixed-ligand Schiff bases [trimetho-prim (TMP) with isatin] (L_1) and nitrogen bases [2,2′-bipyridine (bipy)] (L_2), [1,10-phenanthroline (phen) (L_3)] with metal chlorides: M = Cr^{3+}, Mn^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Zn^{2+} were prepared and characterized by metal content determination (%), FT-IR, electronic, nuclear magnetic resonance, mass spectroscopy, magnetic susceptibility, conductance measurements and elemental analysis (CHN). The bacterial activity of the ligands and their metal compounds was evaluated via various microorganisms. Infrared spectra of Schiff base showed an azomethine peak shifted in complexes that coincide synthesis and coordination of Schiff base through the nitrogen atom of azomethine C=N) and the oxygen atom of the carbonyl group of L_1 with metal ions. L_2, L_3 (bipy, phen) coordinated through the di imine nitrogen atoms. Conductance dimensions suggested the non-conductance nature of all the compounds except Cr(III) complexes, this outcome fits in with the molar conductance value estimated for 1:1 electrolyte in DMF. Magnetic susceptibility analysis and electronic spectra indicated an octahedral geometry for all complexes. Biological study for prepared compounds have been evaluated towards pathogenic microbes *Staphylococcus aureus* and *Bacillus subtilis*. Some compounds have stronger antibacterial action than Schiff base towards tested microbes.

KEY WORDS: Antimicrobial, Heterocyclic compounds, Schiff base, Trimethoprim drug, 2,2-Bipyridyl, 1,10-Phenanthroline

INTRODUCTION

Compounds with the azomethine groups (-C=N-) are identified as Schiff-bases combined when amines and ketones or aldehydes combine. They have been a great chemical development that has made major progress in inorganic chemistry. They act as donor ligands for the most transition metals, generating stable compounds [1, 2] have been used many applications, including tumors treatment, radio immunotherapy, cancer diagnosis and treatment, antimicrobial drugs, catalysts, etc. Schiff bases continue to have an important effect on the progress of industry and clinical chemistry [2, 3].

According to many organic compounds can act as ligands to form metallic drug compounds [4, 5], which may be more potent than the free drug. In order to produce more active pharmacological compounds, the special antibacterial properties of the sulfa drug may be coupled with the metal-drug compounds. Because of their bacterial activity, antineoplastic, cytotoxicity, anti-cancer effect, geno toxicity, thermal stability and uses [6-8], other bioinorganic [9, 10], mixed ligands compounds containing heterocyclic compounds for example (pyridine, bi-pyridine, 1,10-phenanthroline) which had been mentioned. On the mixed metal compounds of trimethoprim, there aren't many reports [11-13]. However, there was no information on the combined ligand of 2,2′-bipyridine, 1,10-phenanthroline, and Schiff base of trimethoprim and isatin. The purpose of the work is to combine and describe some new metal compounds of Schiff base (from trimethoprim and isatin) and nitrogen bases. In this article, we discuss the antibacterial activities of mixed-ligand compounds.

---

*Corresponding authors. E-mail: amaalyounis62@uomosul.edu.iq

EXPERIMENTAL

Materials

Every compound employed was of analytical grade, no additional purification was necessary. Trimethoprim was acquired from Samarra, Iraq's state enterprise for the pharmaceutical industries and medical appliances (SDI). Metal salts [$CrCl_3$], [$MnCl_2.4H_2O$], [$CoCl_2.6H_2O$], [$NiCl_2.6H_2O$], [$CuCl_2.2H_2O$], [$ZnCl_2$], 2,2-bipyridine, 1,10-phenanthroline, isatin were supplied by Sigma Aldrich Company. Ethanol and dimethyl form amide (DMF) were provided by Fluka Company.

Instrumentation

FT-IR spectra were measured using a Shimadzu FT-IR84005 Spectrophotometer, Japan, at Education for Pure Sciences College, Tikrit University at wave number 400-4000 cm^{-1} (KBr disc). The ^{1}H-NMR and ^{13}C-NMR tests were carried out at Sciences College, Basra University using Bruker-DRX system at 400 MHz, (TMS) as standard in DMSO-d$_6$. Electronic spectra measurements for ligands and their compounds at a concentration of 10^{-3} M in DMF as a solvent at 25 °C were conducted using the Shimadzu UV-Vis spectrophotometer Ultra Violet-1800 Spectrophotometer at 190−1100 nm in Education for Pure Science College, Mosul University. The GCMSQp2010 Ultra Gas Mass Chromatography Spectroscopy, Shimadzu measurement device was used to determine their molecular weight at Samarra University's center laboratory. Element microanalyses were performed using a Leco 932 USA Elemental Analyzer (C.H.N). The molar conductance of the synthesized compounds was measured using the HANNA EC214 conductivity meter in dimethyl form amide at 25 °C in Education for Pure Science College, Mosul University. Metal ion analyses had been evaluated spectrophotometrically utilizing atomic absorption spectroscopy, Analytic Jena GmbH-novAA350 novAA350 at the College of Agriculture and Forestry, University of Mosul. Sherwood Scientific was used to assess the produced complexes' magnetic susceptibility at room temperature (MSB-MK) at Education for Pure Sciences College, Tikrit University.

Synthesis

Preparation of the Schiff base (L_1)

Trimethoprim (1.45 g, 5 mmol) and isatin (1.91 g, 5 mmol) in ethanol solution had been refluxed with stirring for about 3 h [14]. This was allowed to remain for about 24 h at room temperature to obtain the precipitation. The resulting particles were filtered, washed more than once in distilled water and diethyl ether and dried (Figure 1).

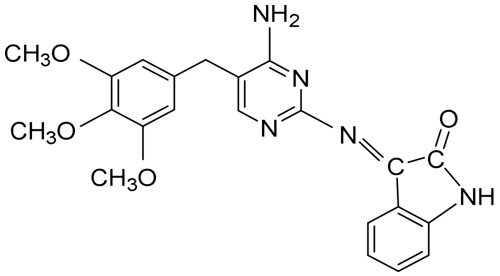

Figure 1. Schiff base L_1.

Preparation of metal ions complexes

(0.01 mol) of one of [$CrCl_3$], [$MnCl_2.4H_2O$], [$CoCl_2.6H_2O$], [$NiCl_2.6H_2O$], [$CuCl_2.2H_2O$], [$ZnCl_2$] and Schiff base (L_1) (0.01 mol) have been mixed in warm ethanol solution with (1.56 g, 10 mmol) of 2,2-bipyridine (L_2) or (1.98 g, 10 mmol) of 1,10-phenanthroline (L_3). Refluxing the reaction mixture for about 3–4 h, the resultant product filtered, washed with cold ethanol, ether and dried [15].

Reaction equation

$MCl_2 .xH_2O + L_1$ Schiff base + bipy or phen → [$M(L_1)$(bipy/phen)Cl_2].$nH_2O + yH_2O$ (1)

$CrCl_3 + L_1$ Schiff base + bipy/phen → [$Cr(L_1)$(bipy/phen)Cl_2] Cl (2)

M = Mn^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, x = 2 - 6.

For Mn^{2+}, Cu^{2+} compounds, n = 2, for Co^{2+}, Ni^{2+} compounds, n = 0. For ZnL_1(phen)Cl_2], n = 3.

RESULTS AND DISCUSSION

The prepared compounds were characterized using conductance measurements, (C.H.N.), magnetic susceptibility, elemental analysis (%), metal percentage (%), FT-IR, ^1H and ^{13}C-NMR, GC-Mass, and UV-Vis spectroscopies.

Elemental analysis and molar conductivity

Table 1 includes the analytical data as well as the physical characteristics of the compounds. Every compound exhibits constant temperature stability and is insensitive to airborne moisture and oxygen. All organic solvents, with the exception of dimethyl form amide (DMF) and dimethyl sulfoxide (DMSO) proved insoluble for them. The relatively low molar conductivities of the compounds, ranging from (11.5-33) ohm^{-1} cm^2 mol^{-1}, show their lack of electrolytic behaviour when dissolved. Conversely, the molar conductivity readings for Cr(III) compounds confirm their identity as 1:1 electrolytes [16-18].

Infrared spectra

Table 2 gives data on the ligands and compounds' infrared spectrum characteristics. In the spectrum of ligand [L_1] the form of a new band at 1622 cm^{-1} has been allocated to the ν(C=N), indicating the formation of a new compound (L_1), which has been truant in trimethoprim and isatin spectra (Figure 2a). In compounds the shift in azomethine peak from 1622 to 1677 cm^{-1} suggests interaction of azomethine nitrogen with metal ions. As well as the azomethine band, the Schiff base also showed a carbonyl group at 1731 cm^{-1}. This band has been shifted to 1731-1740 cm^{-1} in complex of Cr^{3+} (Figure 2b), Mn^{2+}, Co^{2+}, Ni^{2+}, and Zn^{2+} correspondingly, suggesting that coordination has been involved carbonyl oxygen atom. The stretching vibrations of the ν(M-N) and ν(M-O) groups were suggested as the reasons to the appearance of new peaks at (442-466) cm^{-1} and (500-525) cm^{-1}, respectively. As a result, the information suggested that the metal and the Schiff base were coordinated with the nitrogen atom of azomethine and oxygen atom of the carbonyl group. Once again, νM-Cl received bands at 346-393 cm^{-1}. Matched to co-ligand at 1570 cm^{-1}, in compounds (**1**, **2**, **3**, **4**, **6**) the distinguishing peaks of the νC= N bonds had been shifted to lower frequencies. This suggests that 2,2-bipy's two nitrogen are harmonized to the metal ion. The vibration νC= N at 1560 cm^{-1} in phen has shown similar behavior. In compounds **7**, **8**, **9**, **10**, **11**, and **12**, this band changes to lower frequencies, usually related to coordination with metal [19]. Broad bands have been shown at 3454-3620 cm^{-1} approving the existence of lattice/coordinated water molecules [20].

Table 1. Physical properties of L_1, L_2, L_3 and prepared compounds.

No.	Compounds	Color	mp °C	Yield %	M.Wt g.mol^{-1}	Elemental analysis% Exp./(Calc.)			Metal% found/ (calc)	Conductivity ohm^{-1} cm^2 mol^{-1}
						C	H	N		
L_1	Schiff base($C_{22}H_{21}N_5O_4$)	Orange	162-164	85	419	62.8(63.00)	4.90 (5.01)	16.35 (16.70)	-	-
L_2	2,2-Bipyridine(bipy)($C_{10}H_8N_2$)	White	72-74	-	156.19	76.67 (76.82)	4.85 (5.12)	17.47 (17.92)	-	-
L_3	1,10-Phenanthrolene (phen)($C_{12}H_8N_2$). H_2O	White	98-100	-	198	72.53 (72.72)	3.75 (4.04)	13.87 (14.14)	-	-
1	$[CrL_1(bipy)Cl_2]$ Cl	Reddish orange	139-141	84.9	734.686	51.98 (52.26)	3.66 (3.94)	13.05 (13.33)	6.73 (7.07)	65
2	$[MnL_1(bipy)Cl_2].2H_2O$	Brown	170-172	84.9	738.128	51.87 (52.02)	3.79 (3.92)	12.84 (13.27)	7.21 (7.44)	31
3	$[CoL_1(bipy)Cl_2]$	Dark green	140-142	85	706.123	54.11 (54.38)	3.98 (4.10)	13.59 (13.87)	8.12 (8.34)	30
4	$[NiL_1(bipy)Cl_2]$	Orange	165-167	84	705.88	54.22 (54.40)	3.74 (4.10)	13.69 (13.88)	8.15 (8.31)	11.5
5	$CuL_1(bipy)Cl_2].2\ H_2O$	Green	169-171	90	710.733	53.69 (54.02)	3.59 (4.08)	13.57 (13.78)	8.65 (8.94)	25
6	$ZnL_1(bipy)Cl_2]$	Orange	150-152	85.9	712.57	53.66 (53.88)	3.89 (4.06)	13.53 (13.75)	9.00 (9.17)	21
7	$[CrL_1(phen)Cl_2]$ Cl	Dark orange	145-147	85	758.496	53.38 (53.79)	3.55 (3.82)	12.68 (12.92)	6.48 (6.85)	71
8	$[MnL_1(phen)Cl_2].2H_2O$	Brown	194-196	86	761.938	53.33 (53.54)	3.72 (3.80)	12.32 (12.86)	7.10 (7.21)	29
9	$[CoL_1(phen)Cl_2]$	Green	148-150	94.4	729.933	55.47 (55.89)	3.67 (3.97)	13.02 (13.42)	7.83 (8.07)	33
10	$NiL_1(phen)Cl_2]$	Light orange	170-172	86.4	729.693	55.68 (55.91)	3.74 (3.97)	13.18 (13.43)	7.73 (8.04)	13
11	$CuL_1(phen)Cl_2].2H_2O$	Olive green	166-168	91.7	734.546	55.17 (55.54)	3.66 (3.94)	13.19 (13.34)	8.39 (8.65)	20
12	$ZnL_1(phen)Cl_2].3H_2O$	Orange	154-156	86	736.38	55.25 (55.40)	3.53 (3.93)	13.08 (13.30)	8.63 (8.87)	18

Table 2. FTIR bands of the mixed ligands (L_1, L_2, L_3) and their compounds in cm^{-1}.

No.	Compound	νNH$_2$	νC=O	νC=N	νC=N diimine	νM-O	νM-**N**	νM-Cl	νH$_2$O
L_1	Schiff base	3467	1731	1622					
L_2	2,2-Bipyridine(bipy)				1570				
L_3	1,10-Penanthrolene(phen)				1560				
1	$[CrL_1(bipy)Cl_2]$ Cl	3406	1732	1677	1533	503	456	393	
2	$[MnL_1(bipy)Cl_2].2H_2O$	3407	1733	1676	1530	516	449	364	3550
3	$[CoL_1(bipy)Cl_2]$	3453	1735	1627	1557	516	458	368	
4	$[NiL_1(bipy)Cl_2]$	3422	1738	1666	1551	512	453	346	
5	$CuL_1(bipy)Cl_2].2\ H_2O$	3406	1734	1675	1522	511	447	379	3559
6	$ZnL_1(bipy)Cl_2].3H_2O$	3407	1733	1670	1614	524	449	391	3454
7	$[CrL_1(phen)Cl_2]$ Cl	3404	1730	1675	1531	500	445	389	
8	$[MnL_1(phen)Cl_2].2H_2O$	3409	1735	1670	1529	514	442	359	3460
9	$[CoL_1(phen)Cl_2]$	3458	1733	1625	1550	518	466	372	
10	$NiL_1(phen)Cl_2]$	3400	1740	1670	1550	513	459	364	
11	$CuL_1(phen)Cl_2].2\ H_2O$	3407	1731	1676	1508	514	450	381	3620
12	$ZnL_1(phen)Cl_2].3H_2O$	3407	1735	1670	1540	525	449	352	3454

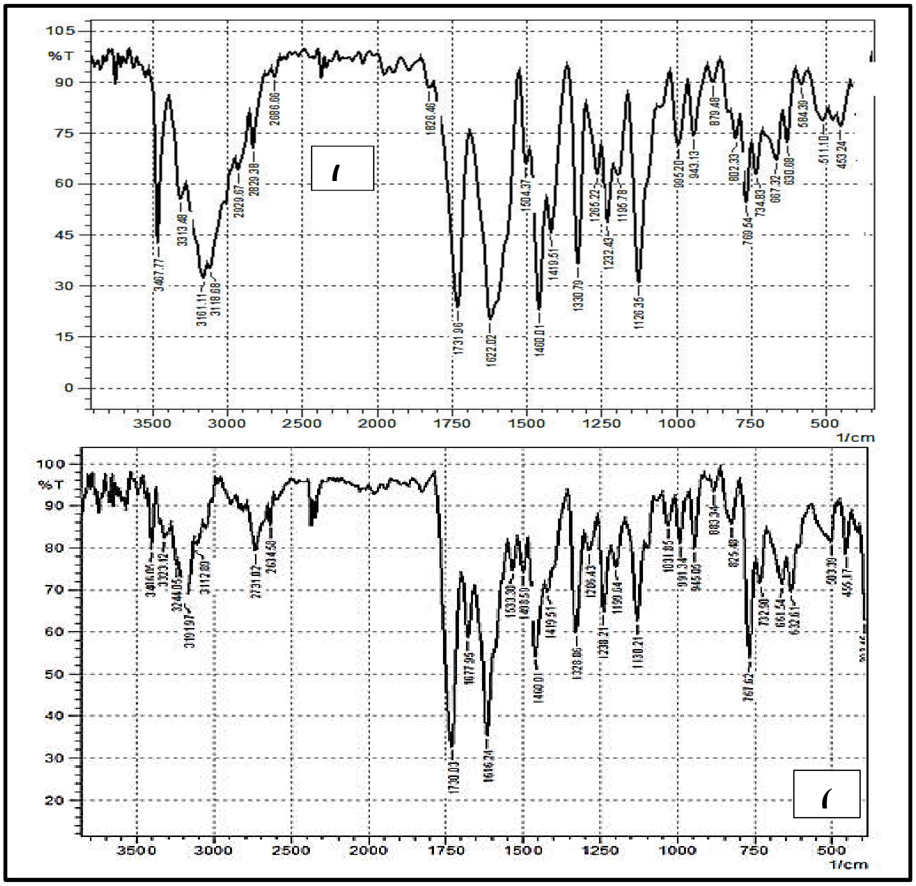

Figure 2. **(a)** FT-IR spectrum of L_1, and **(b)** FT-IR spectrum of $[CrL_1(bipy)Cl_2]Cl$ complex.

Magnetic measurements

For Cr(III) compounds, the results of the magnetic measurements (Table 1) show magnetic moment values of 3.01, 3.10 B.M. These data suggest that the metal ions are paramagnetic and contain three unpaired electrons [21].

A high spin octahedral configuration has been indicated by the magnetic moment values of manganese(II) compounds observed at 5.34 and 5.45 B.M. [22]. Three unpaired electrons in the Co(II) ion are indicated by the magnetic measurements (4.53, 4.63 B.M.) for Co(II) compounds, which is suitable for their octahedral geometry [23, 24]. The magnetic moment values of nickel(II) compounds (2.98, 2.99 B.M.) are in agreement with the magnetic susceptibility value (2.9-3.3 B.M.) for Ni(II) octahedral compounds reported in the literatures [25]. The copper(II) complex's monomeric structure was confirmed by a magnetic moment of copper(II) of 1.74 BM, 1.76 B.M. The values of magnetic moment found for the metal(II) compounds were in agreement with the octahedral geometry proposed for each compound synthesized in this work. It was discovered that two chlorine atoms from the metal salts coordinated to the metal center to balance the coordination number. This was verified gravimetrically, and the results of the elemental analysis confirmed it [26].

Electronic spectra

The UV-Vis spectra of metal ion complexes at 10^{-3} M solutions in DMSO were recorded at 200–1000 cm^{-1} (25 °C). Table 3.summarizes ligands and compounds' electronic spectrum absorptions. The aromatic (C=C) group's intra-ligand $\pi \rightarrow \pi^*$ transition formed the first of two major bands in electronic spectra of Schiff-base, which appeared at 47847 cm^{-1} (209 nm). The imine (-C=N-) group induced $n \rightarrow \pi^*$ transition, which led directly to the other band at 34246 cm^{-1} (272 nm) [27] (Table 3). The ligands (bipy, phen) showed peaks at 42553 cm^{-1} which were allocated to the $n \rightarrow \pi^*$ transitions as a consequence of the C=C group and 35587 cm^{-1} which were due to $\pi \rightarrow \pi^*$ transition [28-31]. The ligand-metal ion coordination was clearly shown by the shifting transition caused by the metal-ligand interaction [32]. Three absorption bands were observed, with the main band containing secondary peaks at 25252 and roughly 34013 cm^{-1}, respectively. The distortion of the octahedral geometry in Cr compounds is propped by these bands [33]. The octahedral geometry of $^6A_1g \rightarrow ^4 E_2g$ is propped by the electronic spectra of Mn compounds, which reveal 5.34, 5.45 B.M. configuration. The electronic spectrum of [CoL_1(bipy)Cl_2] and [CoL_1(phen)Cl_2] compounds shows three bands: (14529-14925) ,(19 342-19423) and (22703-22 730) cm^{-1} owing to transitions ^4T_1g (F) → ^4T_2g (F) (ν_1), ^4T_1g (F) → ^4A_2g (F) (ν_2) and ^4T_1g (F) → ^4T_1g (P) (ν_3) suggesting an octahedral geometry. Regarding d-d transitions, the electronic spectrum of [NiL_1(bipy)Cl_2] and [NiL_1(phen)Cl_2] complexes revealed peaks at 16286, 16393 cm^{-1} and 22670, 22760 cm^{-1} due to [^3A_2g (F) → ^3T_1g (F) and ^3A_2g (F) → ^3T_1g (P)] transitions respectively, suitable for the octahedral geometric structure.

In compounds of Cu(II) electronic absorption spectra showed two peaks at 17100, 18050 and 28571, 28517 cm^{-1} that were connected with the transition $^2B_1g \rightarrow ^2A_1g$. Below 10,000 cm^{-1}, no spectral groups were observed, indicating octahedral structures [34-36]. There was no d-d transition and only one band at 35211, 33350 cm^{-1} in Zn(II) compound spectra, because of ligand-metal charge transfer (C.T.). Since the ligand's Zn(II) compounds were determined to be diamagnetic as estimated [22]. These compounds are assigned an octahedral geometry with six coordinates.

Table 3. Electronic spectral values of L_1 (Schiff-base), L_2, L_3 and their compounds.

No.	Compound	μeff (B.M.)	Electronic transitions (cm^{-1})	
			d-d	Charge transfer
L_1	Schiff base	-	-	34246 47847
L_2	Bipy	-	-	42553
L_3	Phen	-	-	35587
1	[CrL_1(bipy)Cl_2] Cl	3.01	25252	34013
2	[MnL_1(bipy)Cl_2].2H_2O	5.34	-	35211
3	[CoL_1(bipy)Cl_2]	4.63	14925,19342,22730	37037
4	[NiL_1(bipy)Cl_2]	2.99	16393,22670	37370
5	[CuL_1(bipy)Cl_2].2 H_2O	1.76	18050,28571	31159
6	[ZnL_1(bipy)Cl_2].3H_2O	Dia.	-	33350
7	[CrL_1(phen)Cl_2] Cl	3.10	25524	35144
8	[MnL_1(phen)Cl_2].2H_2O	5.45	-	34356
9	[CoL_1(phen)Cl_2]	4.53	14947,18796,21928	38167
10	[NiL_1(phen)Cl_2]	2.98	16286,23260	38615
11	[CuL_1(phen)Cl_2].2 H_2O	1.74	17995	32610
12	[ZnL_1(phen)Cl_2].3H_2O	Dia.	-	35211

NMR spectra

The ligand [L_1] and complex (**6**) ^{1}H-NMR and ^{13}C-NMR spectra were obtained in DMSO-d_6 (Table 4). Proton-NMR spectra data of Schiff–base (L_1) shows the band at δ 11.06 ppm related to the proton of (NH) group as single. At chemical shift δ 6.56 ppm due to protons of the (NH_2)group as single .The singlet proton of (-HC=N) pyrimidine ring at δ 7.05 ppm. The aromatic protons at δ (7.43-7.52) ppm as multiple. The related methyl protons in the (OCH_3) group can be seen as a single peak at 3.72, 3.61 ppm integrated for three protons. At 2.5 ppm, the DMSO signal appeared [23] (Figure 3a). The spectrum of the complex Zn(II) (Figure 3b) displayed multiple signals. Integration revealed that these signals are equivalent to twenty nine protons, which are assigned to Schiff base and bipy protons. These signals overlap because the protons' frequencies are within convergent shifts.

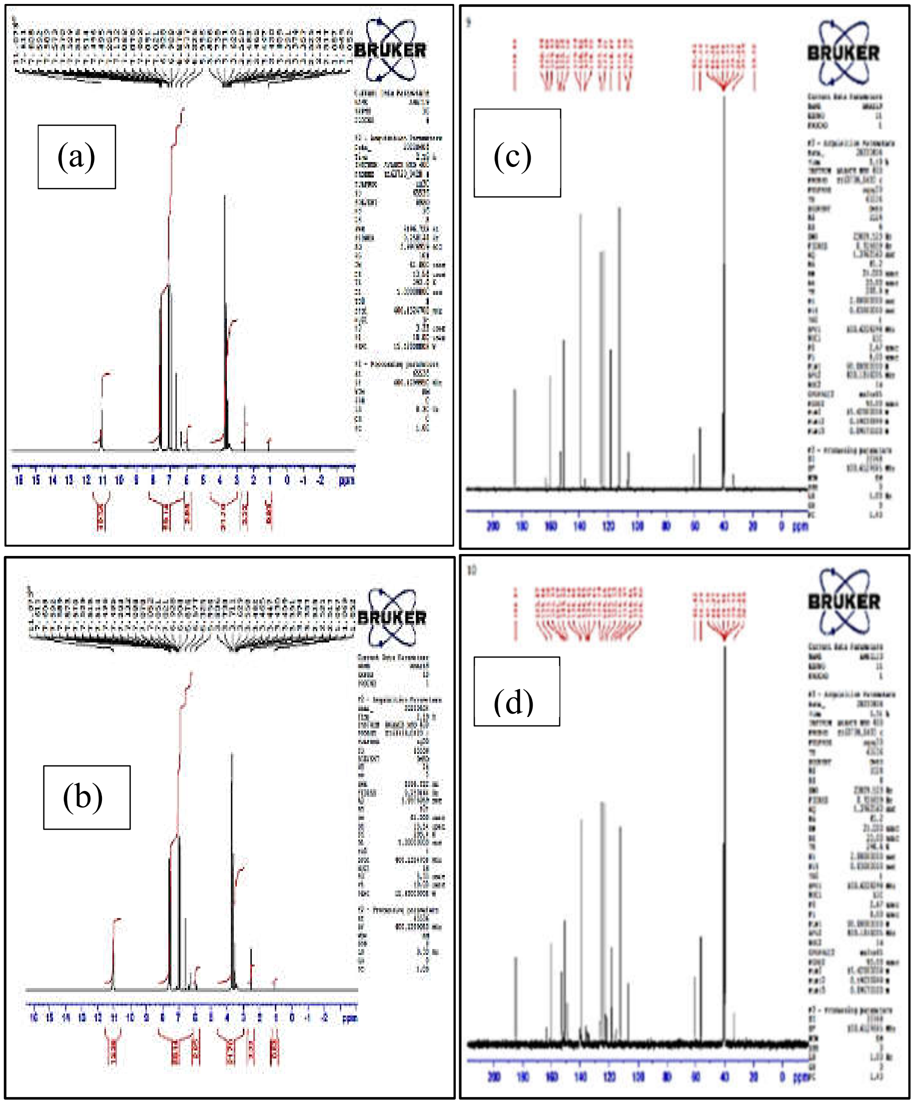

Figure 3. **(a)** ^{1}H-NMR for L_1 (Schiff base), **(b)** ^{1}H-NMR for $[ZnL_1(bipy)Cl_2].3H_2O$, **(c)** ^{13}C-NMR for L_1 (Schiff base), and **(d)** ^{13}C-NMR of $[ZnL1(bipy)Cl_2].3H_2O$.

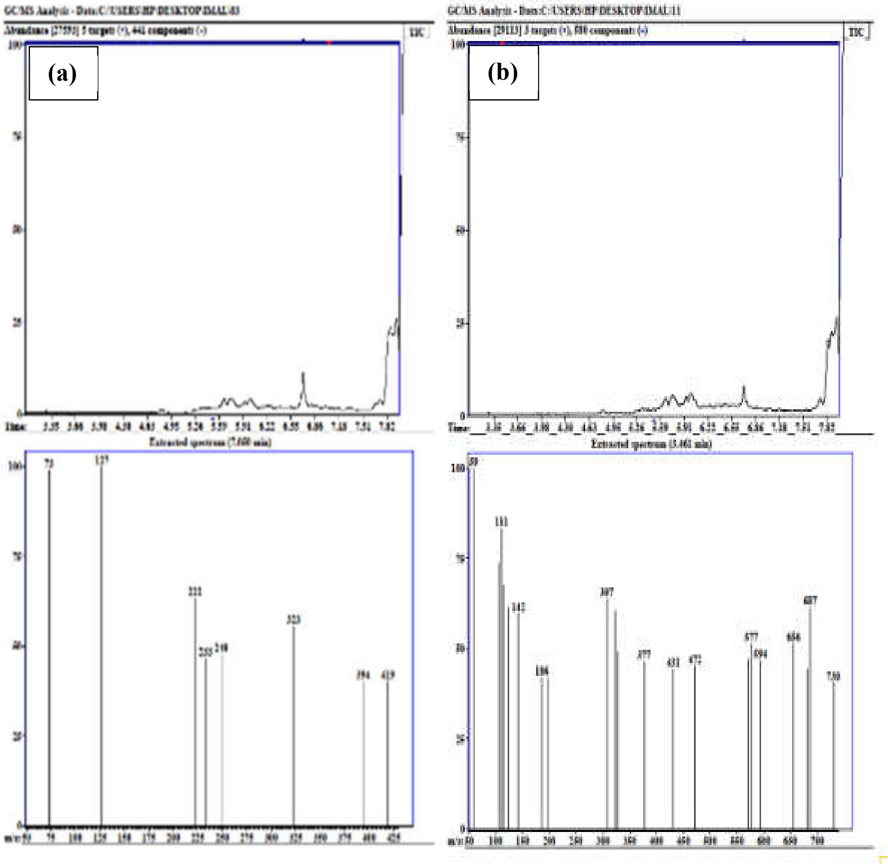

Figure 4. **(a)** Mass spectra of (L_1) and **(b)** mass spectra of complex [$CoL_1(phen)Cl_2$].

Table 4. ^1H, ^{13}C-NMR spectral data (δ) of (L_1) and some compounds.

Compounds	^1H-NMR spectra	^{13}C-NMR spectra
L_1 (Schiff base)	δ_H (400 MHz, DMSO-d_6) 11.06 (1H, s), 7.57 (2H, td, J 7.8, 1.2 Hz), 7.52 – 7.43 (2H, m), 7.05 (1H, dd, J 11.0, 3.9 Hz), 6.90 (2H, d, J 7.9 Hz), 6.56 (2H, s), 3.72 (6H, s), 3.61 (3H, s), 3.53 (2H, s).	δ_C (101 MHz, DMSO-d_6) 184.4, 159.4, 152.7, 150.7, 138.4, 124.7, 122.8, 117.8, 112.2, 105.8, 6.0, 55.8, 32.9.
[$ZnL_1(bipy)Cl_2$].$3H_2O$	δ_H (400 MHz, DMSO-d_6) 11.05 (1H, s), 8.74 – 8.51 (4H, m), 8.17 (1H, s), 7.67 – 7.55 (4H, m), 7.49 (2H, d, J 7.4Hz), 7.06 (2H, t, J 7.5 Hz), 6.91 (2H, d, J 7.9 Hz), 6.58 (2H, s), 3.73 (6H, s), 3.62 (3H, s), 3.57 (2H, s).	δ_C (101 MHz, DMSO-d_6) 184.4, 163.4, 159.4, 152.8, 150.7, 148.8, 138.4, 136.0, 125.8, 124.7, 122.8, 121.7, 117.8, 112.2, 106.0, 6.0, 55.8, 32.4

In the ^{13}C-NMR spectra, chemical shifts of (L_1) at (184.4) ppm and (159.4) ppm were attributed to (C=N) and C=O bonds. Chemical shifts of C atoms in the pyrimidine ring were found to be (152.7 ppm and 150.7 ppm), respectively. Signals linked to aromatic carbon at 105.8 and 138.4 ppm. The two chemical shifts at (55.8) ppm and (32.9) ppm were referred to carbon atoms, respectively (Figure 3c-d). Also, the chemical shift at (40.2) ppm is due to DMSO-d_6.

Mass spectrum

To evaluate the molecular weight and fragmentation pattern of the ligand (L_1) and complex [CoL_1(phen)Cl_2], a mass spectrum was carried out (Figure 4a,b).

According to the results of the magnetic susceptibility, conductivity measurements, elemental analysis, electronic spectra, ^{1}H, ^{13}C-NMR and mass spectroscopies, the proposed structures of the above-mentioned compounds can be illustrated as follow (Figure 5a-d).

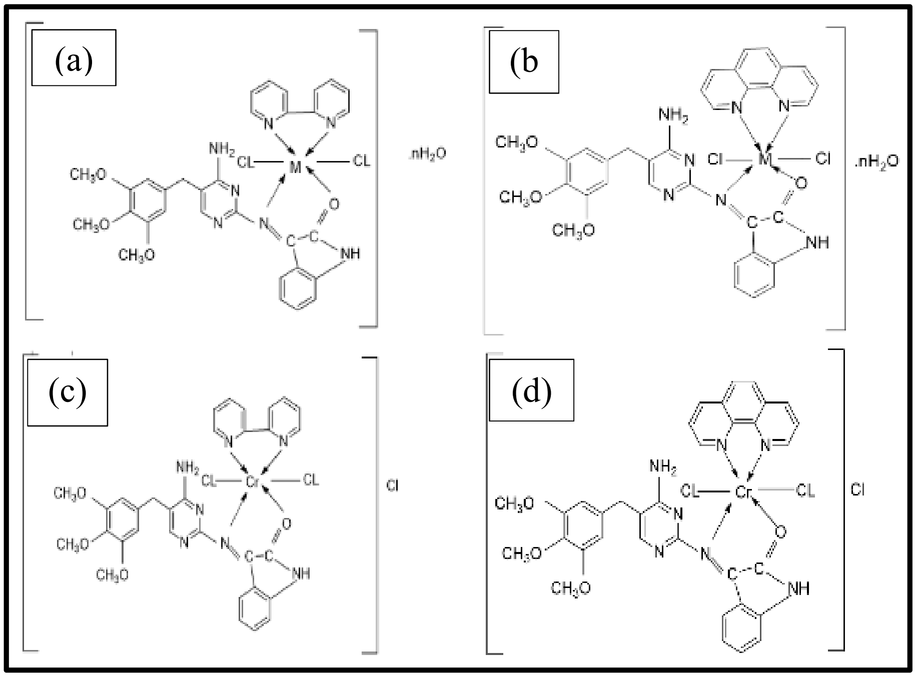

Figure 5. Proposed structure **(a)** ML_1(bipy)Cl_2].nH_2O, **(b)** ML_1(phen)Cl_2].nH_2O, M = M n^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Zn^{2+}, n = 2-3, **(c)** CrL_1(bi PY)Cl_2]Cl and **(d)** CrL_1(p hen)Cl_2]Cl.

Antimicrobial studies

Bacteria , namely *Staphylococcus aureus* and *Bacillius subsitils* using the disc diffusion method, these bacteria were chosen due to their importance in the medical field and the fact that they cause a number of diseases and differ in the nature of their resistance to antibiotics and various medications. The inhibitory results shown in Figure6 indicate that some of the prepared compounds whose effectiveness was tested have the ability to inhibit the bacteria used.

It is clear from the inhibitory activity table that some of the prepared compounds have activity against the bacteria used, as the compound (Co) showed an inhibitory activity against (*staph. aureus*) bacteria of (**20**), which is a higher value than the ligands and control agents (ceftriaxone, ciprofloxacin. Likewise, the other compounds (Cr, Mn, Ni, Cu, Zn) showed effectiveness inhibitory activity of (**14-16)** respectively against *(Staph. aureus*) bacteria, these values are greater than the values of Ceftriaxone used as control factor. Compounds (Cr, Ni) also showed inhibitory activity against *Bacillus* bacteria of (**12**, **14**) respectively, which is the highest factor than ligands (**15**). The compounds (Mn, Co, Cu, Zn) also showed an inhibitory capacity of (**10**, **11**) against *Bacillus* bacteria, which is a lower value than the control factors used in Figure 6.

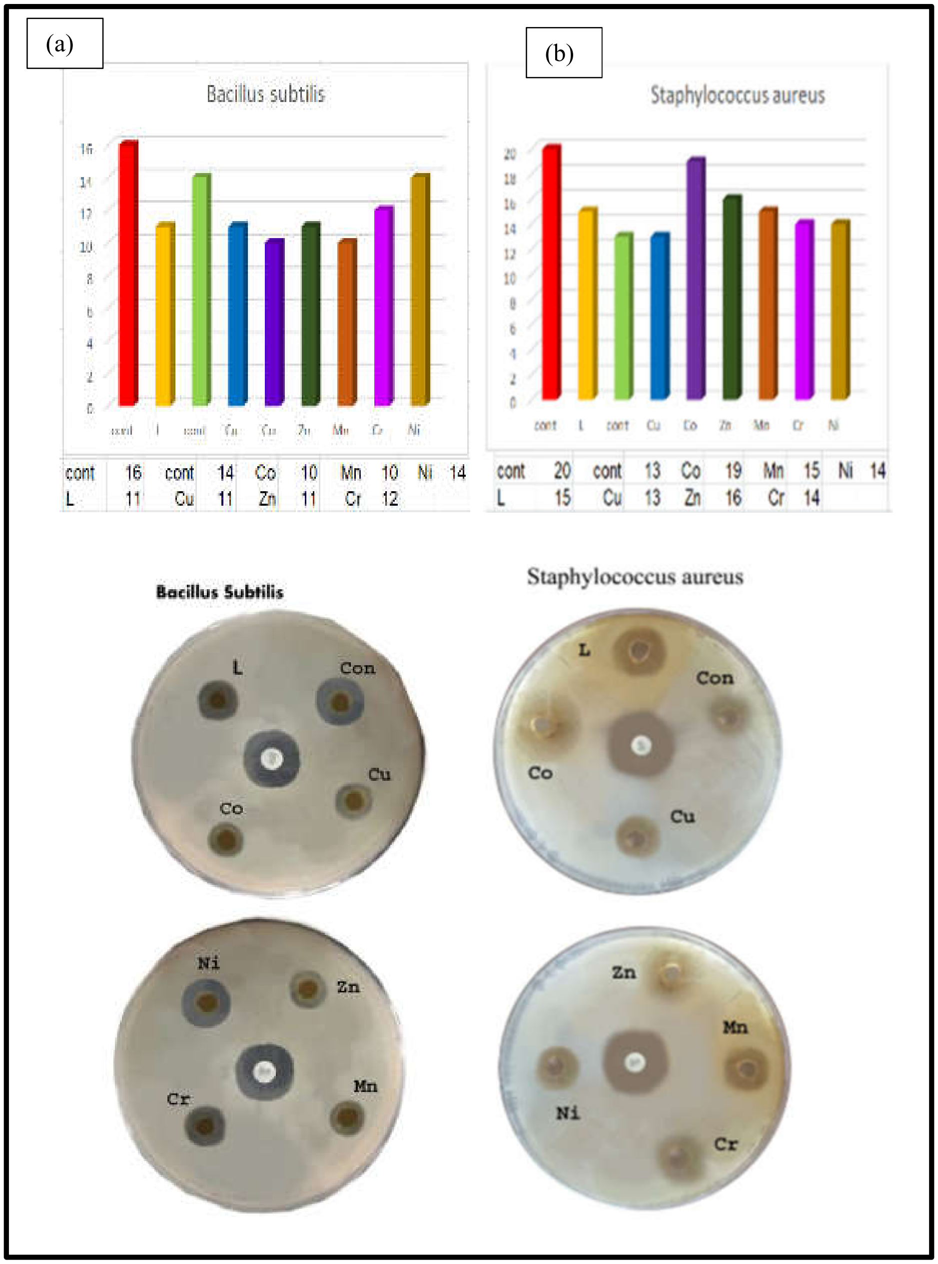

Figure 6. **(a)** Effect different concentration of materials on the growth of *Bacillus subtillis* and *Staph. aureus* and **(b)** inhibition zones(mm) of complexes with ligands for two types of bacteria.

CONCLUSION

Cr^{3+}, Mn^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Zn^{2+} ions and Schiff base L_1, nitrogen bases (L_2, L_3) (bipy, phen) were synthesized and characterized spectroscopically in mixed-ligand compounds. Infrared spectra of Schiff base showed an azomethine peak shift in compounds that coincide synthesis and coordination of Schiff base through nitrogen atom of azomethine (C=N) and oxygen atom of carbonyl groups (C=O) of L_1 with metal ions. L_2 (bipy, phen) coordinated through the nitrogen atoms of the di imine ligands. Conductance measurements indicated the non-conductance nature of all the compounds, with the exception for Cr(III) compounds this result is consistent with the expected molar conductance value for a 1:1 electrolyte in DMF. Magnetic susceptibility analysis and electronic spectra indicated octahedral geometry for all compounds. The biological activity of prepared compounds had been evaluated in contradiction of pathogenic microbes *Staphylococcus aureus, bacillus subtilis*. The antibacterial data showed that complexation improved upon mixed ligands as both were active against the isolates tested. Some compounds possess advanced antibacterial action than Schiff base in contradiction of tested microbes.

ACKNOWLEDGEMENTS

We extend our gratitude to the Deanship of the Science College and the Chairman of the Chemistry Department for their invaluable support in facilitating the research endeavor. We also appreciate the dedicated efforts of the personnel in the scientific laboratories within the Chemistry Department.

REFERENCES

1. Siraj, I.; Ado H. Synthesis and characterization of potentially bioactive sulfamethoxazole isatin Schiff base and its Mn(II), Fe(II) and Ni(II) complexes. *Chem. Search J.* **2021**,12, 27-33.
2. Khalil, H.M.; Abdullah, F.O. Synthesis, characterisation, and anticancer and antioxidant activities of novel complexes of palladium and an organic Schiff-base ligand. *Bull. Chem. Soc. Ethiop.* **2024**, 38, 605-613.
3. Uddin, N.F.; Ali, R.S.; Tirmizi, S.A.; Ahmad, I.; Zaib, S. Synthesis, characterization, and anticancer activity of Schiff bases. *J. Biomol. Struc. Dyna*. **2020**, 38, 3246-3259.
4. El-Habeeb, A.A.; Refat, M.S. Synthesis, spectroscopic characterizations and biological studies on gold(III), ruthenium(III) and iridium(III) complexes of trimethoprim antibiotic drug. *Bull. Chem. Soc. Ethiop.* **2024**, 38, 701-714
5. Vishwakarmaa, D.; Agrawalb, S.; Noorafshaa, A.K.; Kumar, A.; Kashyap, A.K. Synthesis and characterization studies of novel ternary complexes of Zn(II) and Ni(II) ion with norfloxacin drugs and amino acids. *Eur. J. Mol. Clin. Med*. **2020**, 7, 2181-2202.
6. Hassan, Z.M.; Alattar, R.A.; Abass, S.K.; Mihsen, H.H.; Abbas, Z.F.; Hussain, K.A. Synthesis, characterization and biological activityof mixed ligand (imine of benzidineand 1,10-phenanthroline) complexes with Fe(II), Co(II), Ni(II) and Cu(II) ions. *Chem. Chem. Technol.* **2022**, 16, 15-24.
7. Mohamed, S.; Djamel, B.; Eddine, H.S. Assessing the effects of substitutionand substituent position on the reactivity of salicylideneaniline ligands to coordinate transition metal(II) ions: A DFT study. *Chem. Chem. Technol.* **2021**, 15, 343-351.

8. Ashiq, S.A.; Saad, S.T. Synthesis and characterization of cobalt(II), nickel(II) and copper(II) complexes with schiff base derived from 9,10-phenathrenquinon. *HIV Nursing* **2023**, 23,1068-1071.
9. Abd El-Lateef, H.M.; Ali, M.A.; Khalaf, M.M.; Abdou, A. New iron(III), cobalt(II), nickel(II), copper(II), zinc(II) mixed-ligand complexes: Synthesis, DFT, molecular docking and antimicrobial analysis. *Bull. Chem. Soc. Ethiop.* **2024**, 38, 147-166.
10. Chandraleka, S.; Ramya, K.; Chandramohan, G.; Dhanasekaran, D.; Priyadharshini, A.; Panneerselvam, A. Antimicrobial mechanism of copper(II) 1,10-phenanthroline and 2,2′-bipyridyl complex on bacterial and fungal pathogens. *J. Saudi Chem. Soc.* **2014**, 18, 953-962.
11. Eugene-Osoikhia, T.; Ojeyemi, S.A.; Akong, R.A. Synthesis, characterisation and antimicrobial studies of metal(II) complexes of trimethoprim and 2,2' bipyridine heterocycle. *Niger. Res. J. Chem. Sci.* **2021**, 9, 273-295.
12. Osowole, A.A.; Wakil, S.M.; Alao, O.K. Synthesis, characterization and antimicrobial activity of some mixed trimethoprim-sulfamethoxazole metal drug complexes. *World Appl. Sci. J.* **2015**, 33, 336-342.
13. Osoikhia, T.E. Synthesis, characterisation and antimicrobial studies of metal(II) complexes of ofloxacin and metronidazole. *Chem. Search. J.* **2020**, 11, 74-82.
14. Kareem, M.J. Synthesis, spectroscopic study and biological activity of new bidentate Schiff base (4-(dimethylamino)benzylidene)-5-(3,4,5-trimethoxybenzyl)-5 pyrimidine-2,4-diamine) and transition metal Mn(II), Ni(II) and Cu(II) complexes. *Pakistan J. Med. Healt. Sci.* **2022**, 5, 655-659.
15. Abdul Hassan, M.M.; Abbas, A.H.; Abed, E.H.; Abodi, E.E. Synthesis, characterization and antimicrobial activity of V(IV), Ag(I) and Cd(II) complexes with mixed ligandsderived from sulfamethoxazole and trimethoprim. *Adv. Anal. Chem.* **2018**, 8, 15-21 .
16. Geary, W.J. The use of conductivity measurements in organic solvents for the characterisation of coordination compounds. *Coord. Chem. Rev*. **1971**, 7, 81-122.
17. Dailami, S.; Onakpa, S.; Funtua, M. Fe(III) and Cr(III) complexes with phenolic Schiff base: Synthesis, physico-chemical characterisation, antimicrobial and antioxidant studies. *IOSR J. Appl. Chem*. **2016**, 9, 18-23.
18. Joshi, S.; Pawar, V.; Uma, V. Antibacterial properties of Mn(II), Co(II), Ni(II) and Zn(II) complex of derived from Schiff base trimethoprim. *Der Pharma Chemica* **2010**, 2, 329-336.
19. Abu-Hussen, A.A. Synthesis and spectroscopic studies on ternary bis-Schiff-base complexes having oxygen and/or nitrogen donors. *J. Coord. Chem.* **2006**, 59, 157-176.
20. Eugene-Osoikhia, T.; Akinpelu, I.; Odiaka, T. Synthesis, characterization and antimicrobial studies of transition metal complexes of Schiff base derived from salicylaldehyde and L-tyrosine amino acid. *Niger. J. Chem. Res*. **2019**, 24, 46-56.
21. Huheey, J.; Keiter, E. ; Keiter, R. *Inorganic Chemistry: Principles of Structure and Reactivity. Acid—Base Chemistry*, 4th ed., Harper Collins College Publ.: New York; **1993**.
22. Mumtaz, A.; Mahmud, T.; Elsegood, M.; Weaver, G. Synthesis and characterization of new Schiff base transition metal complexes derived from drug together with biological potential study. *J. Nucl. Med. Radiat. Ther*. **2016**, 7, 310.
23. Lever, A.P. *Inorganic Electronic Spectroscopy, Studies in Physical and Theoretical Chemistry*, Vol. 33, Elsevier: Amsterdam; **1984**; 113, 50.
24. Cotton, F.; Wilkinson, G.; Murillo, C.; Bochmann, M. *Advanced Inorganic Chemistry*, Vol. 2, John Wiley and Sons: New York; **1999**; pp. 573-577.

25. Osowole, A.A.; Agbaje, O.B.A.; Ojo, B.O. Synthesis, characterization and antibacterial properties of some heteroleptic metal(II) complexes of paracetamol and vanillin. *Asian J. Pharm. Clin. Res.* **2014**, 7, 145-149.
26. Ajibade, P.A.; Kolawole, G.A. Synthesis, characterization and antiprotozoal studies of some metal complexes of antimalarial drugs. *Trans. Met. Chem.* **2008**, 33, 493-497.
27. Figgis, B.N.; Hitchman, M.A. *Ligand Field Theory and Its Applications*, Vol. 18, Wiley–VCH: New York, **2000**; p. 354.
28. Imam, H.; Kumar, B. Mixed ligand complexes of transition metal chelates of 1-nitroso-2-naphthol and 8-hydroxyquinoline with picolinic acid and quinaldinic acid. *Orient. J. Chem.* **2011**, 27, 287.
29. Scarborough, C.C.; Wieghardt, K. Electronic structure of 2,2′-bipyridine organotransition-metal complexes. Establishing the ligand oxidation level by density functional theoretical calculations. *Inorg. Chem.* **2011**, 50, 9773-9793.
30. Wojciechowska, A.; Staszak, Z.; Bronowska, W.; Pietraszko, A.; Cieślak-Golonka, M. Spectroscopic and structural studies of chromate ions in zinc complexes with 2,2′-bipyridine. Analysis of the lowest triplet states in the CrO_4^{2-} entity. *Polyhedron* **2001**, 20, 2063-2072.
31. Emara, A.A.; Abu-Hussein, A.A.; Taha, A.A.; Mahmoud, N.H. Spectroscopic, solvent influence and thermal studies of ternary copper(II) complexes of diester and dinitrogen base ligands. *Spectrochim. Acta Part A: Mol. Biomol. Spectrosc.* **2010**, 77, 594-604.
32. Madhupriya, S.; Elango, K.P. Synthesis, spectral characterization and catalytic activity of Co(II) complexes of drugs: Crystal structure of Co(II)–trimethoprim complex. S*pectrochim. Acta Part A: Mol. Biomol. Spectrosc*. **2014**, 118, 337-342.
33. Maples, D.L.; Maples, R.D.; Hoffert, W.A.; Parsell, T.H.; Asselt, A.V. Synthesis and characterization of the chromium(III) complexes of ethylene cross-bridged cyclam and cyclen ligands. *Inorg. Chim. Acta* **2009**, 362, 2084-2088.
34. Hassan, Z.M.; Alattar, R.A.; Abass, S.K.; Mihsen, H.H.; Abbas, Z.F. Synthesis, characterization and biological activity of mixed ligand (imine of benzidine and 1,10-phenanthroline) complexes with Fe(II), Co(II), Ni(II) and Cu(II) ions. *Chem. Chem. Technol.* **2022**, 16, 15-24.
35. Majdi-Nasab, A.; Heidarizadeh, F.; Motamedi, H. Synthesi and antimicrobial activities of salicylaldehyde Schiff base Cu(II) complex and its catalytic activity N,N-arylation reactions. *Chem. Chem. Technol.* **2023**, 17, 557-566.
36. Rakitskaya, T.; Truba1, A.; Radchenko, E.; Golub, A. Mono- and bimetallic complexes of Mn(II), Co(II), Cu(II), and Zn(II) with Schiff bases immobilized on nanosilica as catalysis in ozone decomposition reaction. *Chem. Chem. Technol.* **2018**, 12, 1-6.