Preparation of new mixed ligand complexes of heterocyclic azo imidazole and 1,10-phenanthrolin ligands with some of transition metal and group (IIB) ions

Husham M. Mubark[1]* Israa N. Witwit[2] Eman H. Sahap[3]
[1]* University of Alkafeel, College of Health & Medical Techniques, Najaf, Iraq.
[2,3] University of Kufa, Faculty of Science, Department of Chemistry, Najaf, Iraq.
*Corresponding Author Email: hushamhassan1974@gmail.com

Abstract
New series of mix ligand complexes were synthesized with Cobalt, Nickel, Copper, Cadmium, and Mercury ions at their divalent oxidation states using primary Azo-imidazole (TBPAM), and 1,10-phenanthroline ligands. The structure of new complexes proposed by some of spectrometric and analytical technicities such as Mass, ^{1}HNMR, FT-IR, UV-Vis., (C.H.N.), Flame Atomic Absorption, Molar Conductivity, and Magnetic susceptibility. Octahedral shape suggested for all complexes in which both of ligands showed bidentate behavior and formatted five member rings with studied ions. Noticeable inhibition ability of the complexes appeared towards *Klebsiella, P. aeruginosa*, and *S. aureus* bacteria at (100mg/ml) in DMSO solvent.
Key Words: Mix ligand, azo, imidazole, complexes, 1,10-phenanthrolin.

1. Introduction

Many research articles have been published on the preparation and characterization of metal complexes with mixed ligands [1-3] due to their varied modes and uses in different of fields, as well the difference of the electronic environments for coordinated ligands effected on increase the interaction between these ligands and central metal ions. Imidazole azo compounds has an important role in the coordination chemistry because of their ability for stabilizing the complexes in low oxidation states of metal ions as result of presence empty π* orbitals in imidazole ring, and their ability to form stable five member ring with central ion, as well as their importance in the biology [4 -6].

1,10-phenanthroline which is a bidentate chelating N-donor ligand forms stable complexes with many transition metal ions, through two nitrogen atoms of the hetero rings to create a five-member ring resulting a variety of shapes and characteristics of the stable complexes, as well as it's importance in the biological field as anti-cancer, anti-bacterial, and antioxidant [7-9].

The purpose of our present study is attended of prepare mixed ligand complexes of heterocyclic Azoimidazole compound as a primary ligand and 1,10-phenanthroline as a secondary ligand with Co (II), Ni (II), Cu (II) , Cd(II) and Hg(II) ions, then characterization the prepared complexes by available spectrophotometric means , and the studying their biological activity against different species of bacteria.

2. Expremintal

Chemicals

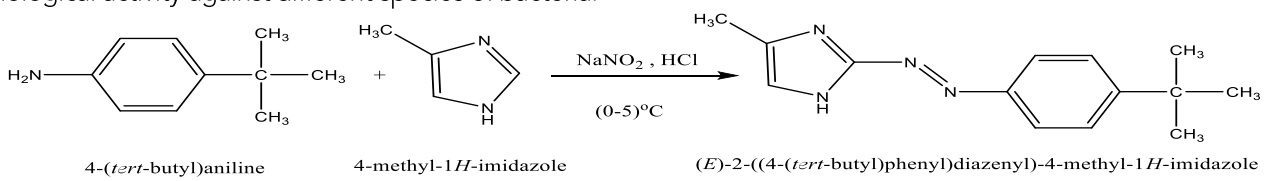
All chemicals, and solvents that used in this research were suppled from Merck, Sigma Aldrich, and Fluka companies with high degree of purity.

Instruments

Mass Spectra recorded by (3200) QTRAP LC-MS/MS System - Sciex, while FTIR measured by using Shimadzu (8400) FTIR Spectrometer . Electronic spectra measured by Shimadzu (1650) UV-Vis Spectrophotometer. Elemental Analysis (C.H.N.) carried out by Thermo Flash EA (1112/2000) CHN , as well as (AA-66300) Spectrophotometer used for determine the metal percentage in the complexes. The Molar conductivity recorded by (470) WTW. The magnetic susceptibility obtained by Sherwood scientific Balance; finally melting point measured by Stuart Melting point (SPM10).

Preparing of Primary ligand (TBPAM), and solid mix ligand complexes

Primary ligand (TBPAM) synthesized by using coupling reaction **[10]** between diazonium salt of (4-tetra-butyl aniline (1.58) which prepared in presences of (3) mL HCl, and $NaNO_2$ (0.71) gm with basic alcoholic solution of 4-methyl imidazole using ice bath at temperature (0-5)°C , Orange precipitate of TBPAM was filtered after neutralized with diluted HCl, dried and recrystallized from hot ethanol, as shown in scheme(1).



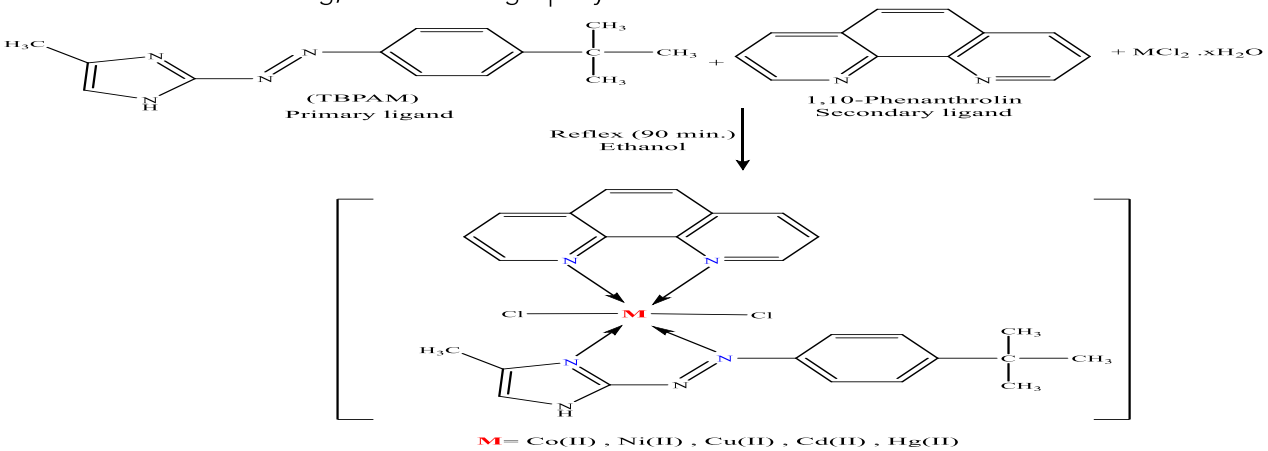
4-(*tert*-butyl)aniline 4-methyl-1*H*-imidazole (*E*)-2-((4-(*tert*-butyl)phenyl)diazenyl)-4-methyl-1*H*-imidazole

Scheme (1): Preparation reaction of (TBPAM)

doi.org/10.31838/hiv23.02.160 Received: 21.10.22, Revised: 27.11.22, Accepted: 13.12.22.

Preparing of solid mix ligand complexes

Solid complexes were prepared by mixing (0.242) gm of primary ligand (TBPAM), and (0.180) gm of secondary ligand 1,10- phenanthroline, and (1) mmole of each metal chloride salt . The mixture dissolved in (25) ml of ethanol, and reflexed for (90) min. with continuous stirring, and following up by (TLC). The resulted precipitations filtered, washed by distilled water then dried, and recrystallized from hot ethanol solution. The percentages of the products mentioned in Table (1), while the path of preparation reaction of studied complexes clarified in scheme (2).



Scheme (2): Reaction equation of preparing solid complexes

Bacterial inhibition application

The antibacterial activity studied by using agar disc diffusion method. The in-vitro antibacterial screening of the new synthesized compounds was tested Klebsiella, P. aeruginosa, and S. aureus, by disc diffusion method using Mueller–Hinton agar (MHA) as a medium. The discs measuring 6 mm in diameter were prepared from filter paper what man number (1) which sterilized at (121)°C for (1.5)hour. The Concentration of (100) mg/mL of each compound prepared by dissolving them in DMSO solvent, after that the solutions loaded on the wall of the culture, and incubated at 37°C for 24 h. The efficiency of inhibition evidenced by the zone of inhibition(mm)by using DMSO as a control

3. Results and Discussion

Mass spectra of Co (II), and Cu (II) complexes showed the molecular peaks at (m/z=552), and (m/z=547) which supported their molecular weights. The suggested fragmentation paths of both synthesized complexes include loss of (N_2) molecule for azo group from the primary ligand at (m/z=454.2) , and (m/z=243.1) respectively, and appearance the molecular peak of the secondary ligand at (m/z=180.2) , the parent ions for these complexes emerged with intensity 100% for (m-1) at (m/z=92.1) for Co(II) complex , and (m-2) at (m/z= 91.5) for Cu(II) complex as a result of fragmentation of the secondary ligand as explained in figures (1,2) , and schemes(3,4).

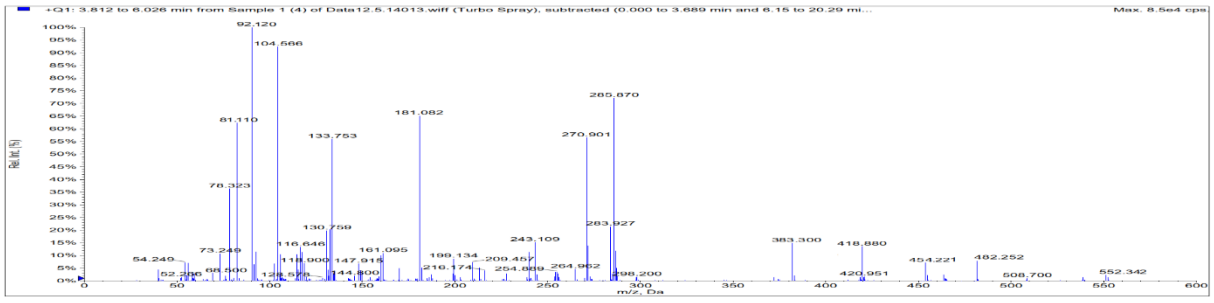


Figure (1): Mass Spectrum of [Co (TBPAM) (Phen) Cl_2] complex

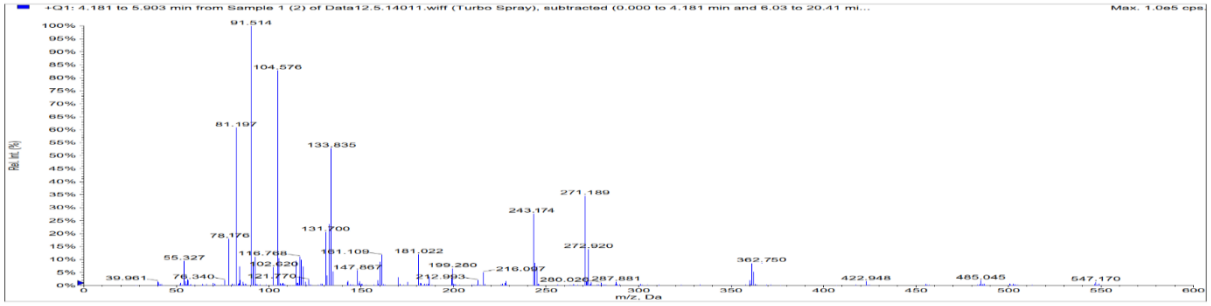
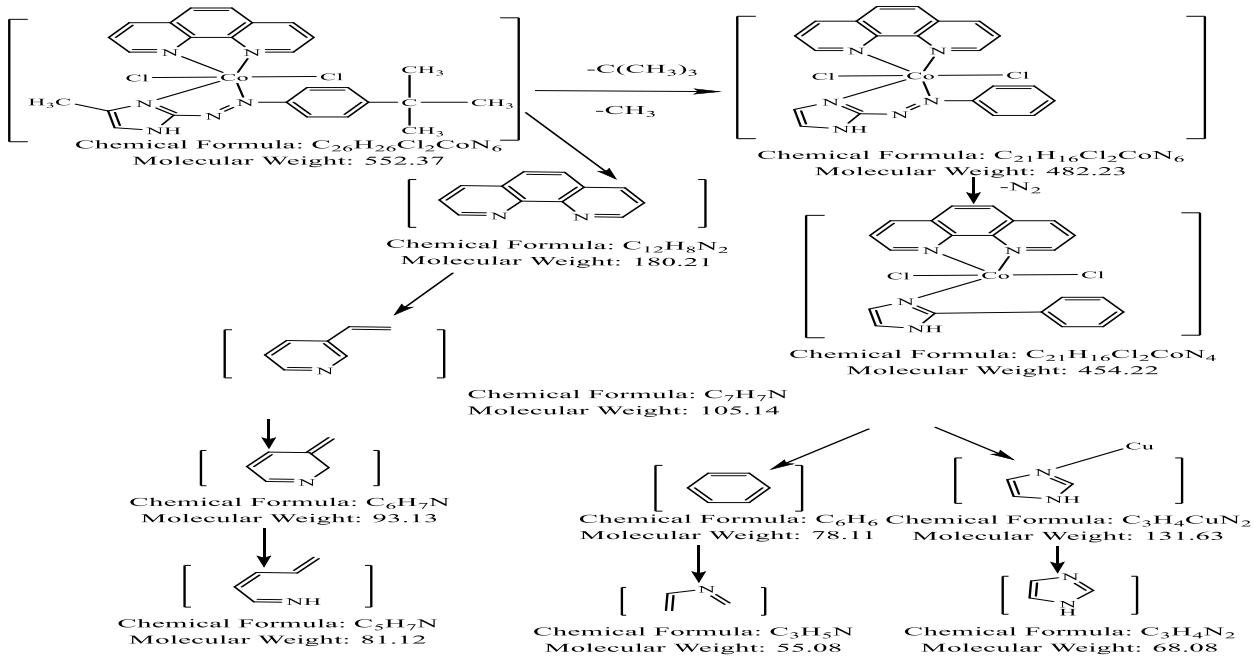
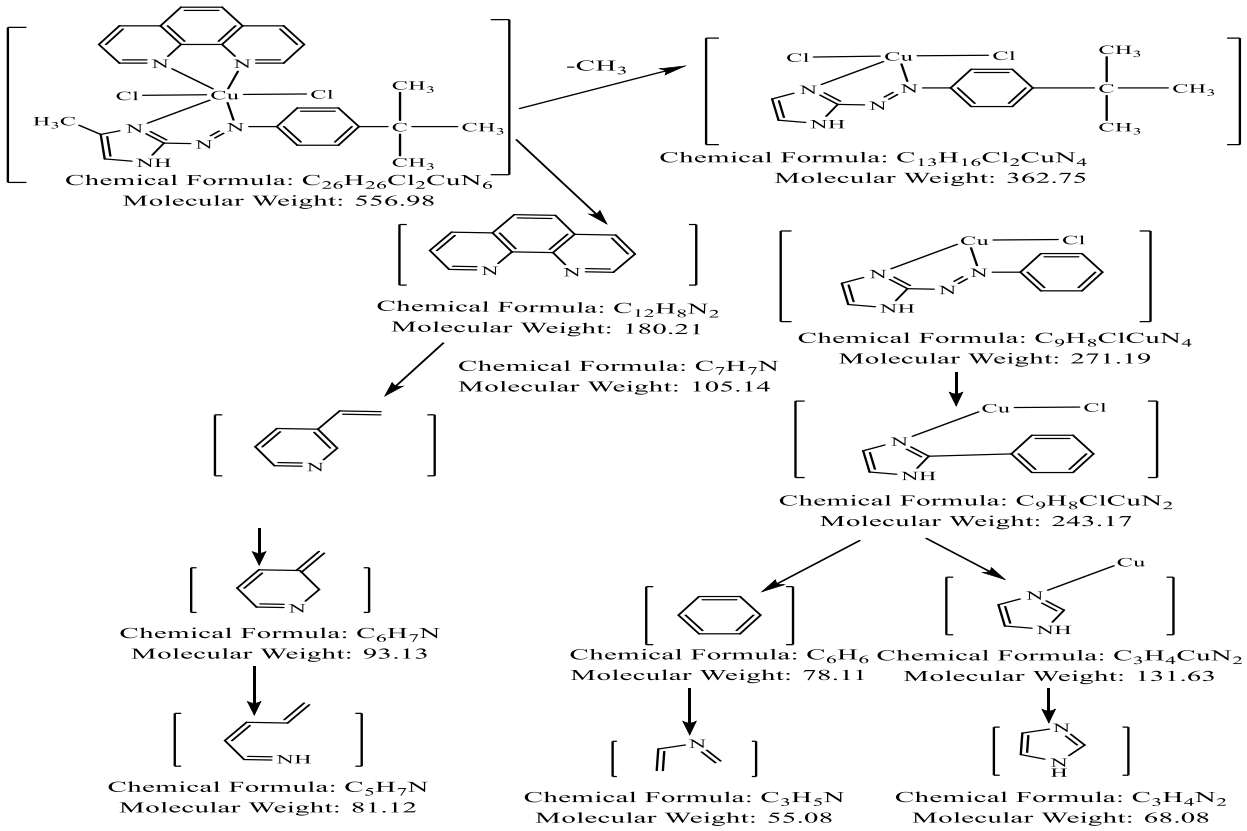


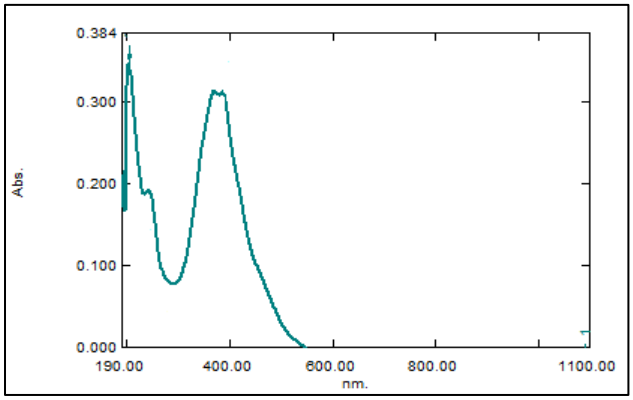
Figure (2): Mass Spectrum of [Cu (TBPAM) (Phen) Cl_2] complex



Scheme (3): Mass fragmentation paths of[Co (TBPAM) (Phen) Cl2] complex



Scheme (4): Mass fragmentation paths of [Cu (TBPAM) (Phen) Cl2] complex



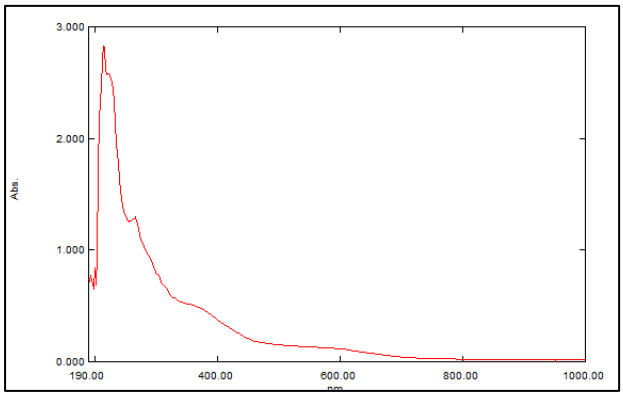


Figure (3): Electronic spectra of primary ligand(TBPAM) Figure (4):Electronic spectra of [Co (TBPAM) (Phen) Cl2]

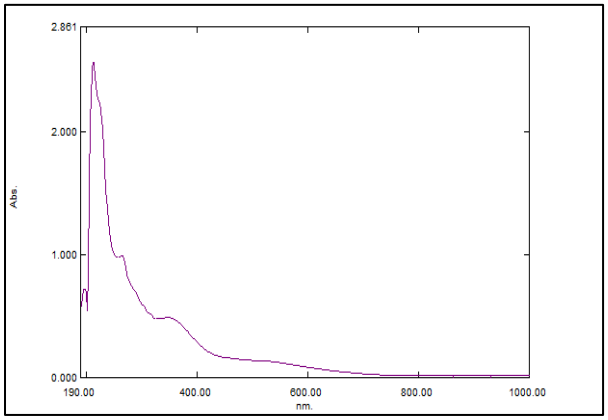
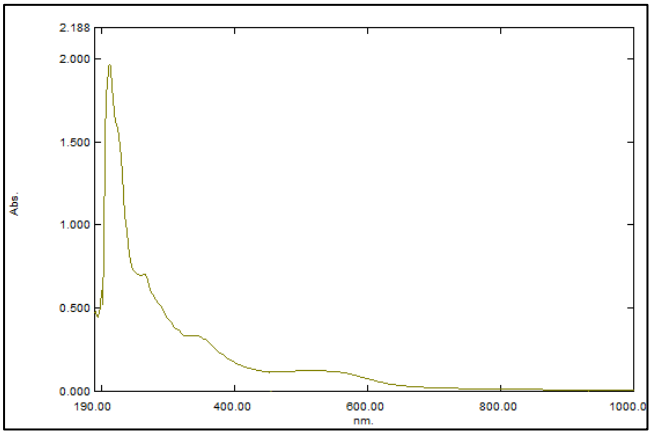


Figure (5): Electronic spectra of [Ni (TBPAM) (Phen) Cl_2]



Figure(6):Electronic spectra of [Cu (TBPAM) (Phen) Cl_2]

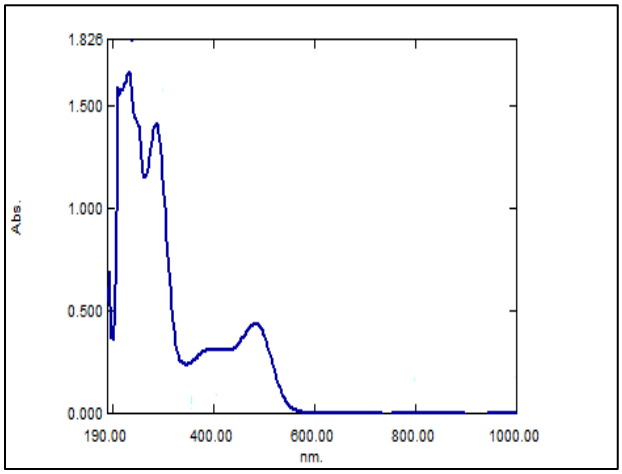


Figure (7):Electronic spectra of [Cd(TBPAM) (Phen) Cl_2]

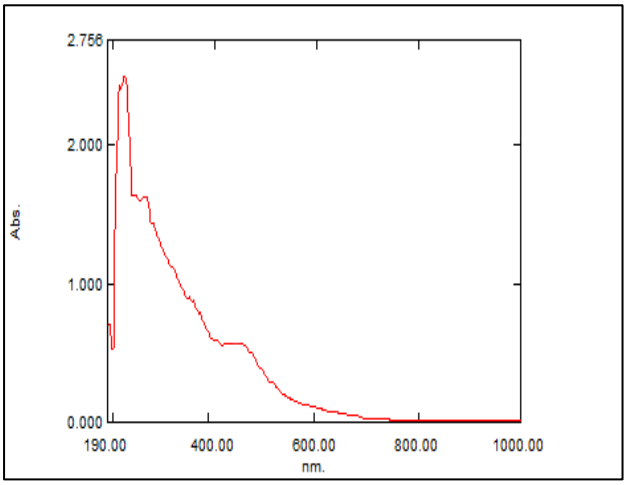


Figure (8):Electronic spectra of [Hg (TBPAM) (Phen) Cl_2]

Table (1): Electronic Transitions , Values of Molar Conductivity , Magnetic susceptibility , and proposed geometries of Primary ligand and it's prepared complexes

Chemical Structure of the compound	Value of λ max (nm)	Type of transition	Values of Molar Conductivity S.Cm^2. mole		$\mu_{eff.}$ (B.M.)	Proposed Geometry
			DMF	DMSO		
(TBPAM)	214, 268 380	π–π* π–π* ICT	-------	-------	------	-------
[Co (TBPAM) (Phen) Cl_2]	216 271 376 ,550	π–π* π–π* ILCT, MLCT	18.45	16.76	4.76	Octahedral
[Ni (TBPAM)(Phen) Cl_2]	217 272 379, 542	π–π* π–π* ILCT, MLCT	18.36	16.53	2.88	Octahedral
[Cu (TBPAM) (Phen) Cl_2]	217 270 379, 542	π–π* π–π* ILCT, MLCT	17.77	15.88	1.75	Distorted Octahedral
[Cd (TBPAM) (Phen) Cl_2]	21 274 387,510	π–π* π–π* ILCT, MLCT	23.05	21.38	Dia	Octahedral
[Hg (TBPAM) (Phen) Cl_2]	217 273 380, 513	π–π* π–π* ILCT, MLCT	22.48	19.64	Dia	Octahedral

Electronic Transitions of the primary ligand showed (π–π*) at (214) nm , (π–π*) transition at (268) nm, and (280) nm for Intra ligand charge transfer[10,11-13] , as a result of the coordination positions and intensities for these transitions were changed in the complexes spectra for the transitions of (π–π*) , Intra ligand Charge Transfer (ILCT) , and Metal-ligand Charge Transfer (MLCT) in the complexes as shown in Table (1) , and figures (3- 8).

FT-IR spectra of the purified solid complexes showed a significantly shifting of ν(C=N) of primary ligand (TBPAM) for imidazole ring at (1577) cm^- [14,15], and secondary ligand (1,10-phen.) at (1580) cm^- [16] as a result of participation the heterocyclic ring in coordination through their nitrogen atom, Thus the frequencies of ν(C-N) of imidazole ring and

(1,10-phen) at (1374) cm^{-}, and (1406) cm- were also appeared a change for their position and frequency in the complexes spectra. The frequency of ν(N=N) **[17-19]** for the primary ligand at (1428) cm^{-} demonstrated shifting in position due to the attachment with metal ions through one of nitrogen atoms, while new peaks belong to the ν(M-N) **[20-22]** were appeared, as shown in Table (2).

Molar Conductivity values for the complexes at (10^{-3}) M in both of DMSO and DMF solvents as shown in the Table (1) indicated non-polar character [23] for all of the prepared complexes, also the addition a drop of (10) % silver nitrate to the complexes solutions without appearance of AgCl precipitate give evidence that chloride ions coordinated with each of studied metal ions inside the coordination sphere.

Magnetic susceptibility used as a common technique to investigate the electronic configuration of the metallic center in the complexes, and lead to predict their hybridization and geometrical shapes, The measurements of the synthesized complexes refers to the diamagnetic properties of Cd(II) , and Hg(II) complexes while the values (4.76) B.M. , (2.88)B.M, and (1.74)B.M. of Co (II) complex, Ni (II), and Cu (II) respectively indicated the octahedral shapes for the complexes with high spin electronic configuration, and hybridization (sp^3d^2)[24,25], as explained in the Table (1).

Table (2): Values of FT-IR frequencies of Primary, Secondary ligands, and their purified complexes

Frequencies	TBPAM	Phen.	[Co (TBPAM) (Phen) Cl_2]	[Ni (TBPAM) (Phen) Cl_2]	[Cu (TBPAM) (Phen) Cl_2]	[Cd (TBPAM) (Phen) Cl_2]	[Hg (TBPAM (Phen)Cl_2]
ν (C=N) of imidazole	1577 m	----	1508 m	1508 m	1506m	1512 m	1502 m
ν (C=N) of Phen.	------	1617m	1589m	1593 m	1587 m	1591 m	1583 m
ν (N=N)	1428 m	----	1421m	1421m	1420m	1418 m	1416m
ν (C-N) of imidazole	1374m	------	1359 w	1354 w	1355 ws	1352 w	1307w
ν (C-N) of Phen.		1406 m	1385 w	1382w	1379 w	1400 w	1369 w

Some physicochemical properties of the pure solid studied complexes were summarized in table (1), the values of element analysis (C.H.N) , and the percentage of metals showed good agreement between the calculated and found percentages that indicating the molecular formula of them , also there is an noticeable changing of melting points of the complexes comparing to their free ligands due to the differences of the geometrical arrangements for the molecules , as well the obvious change of colors as a result of electronic transitions , and complexes shapes .

Table (3): Some of physical and chemical properties of the synthezid complexes

Compound (Molecular Formula)	Color	M.wt. (Product)	M.P. (°C)	Element analysis Calculated (Found)			
				C	H	N	M
[Co(TBPAM)(Phen)Cl_2] $C_{26}H_{26}Cl_2CoN_6$	Brown	552.37	238-240	56.54 (56.52)	4.74 (4.76)	15.21 (15.30)	10.67 (10.68)
[Ni(TBPAM)(Phen)Cl_2] $C_{26}H_{26}Cl_2NiN_6$	Brown	552.13	242-245	56.56 (56.53)	4.75 (4.77)	15.22 (15.26)	10.63 (10.60)
[Cu(TBPAM)(Phen)Cl_2] $C_{26}H_{26}Cl_2CuN_6$	Brown	556.98	253-255	56.07 (56.04)	4.71 (4.72)	15.09 (15.13)	11.41 (11.43)
[Cd(TBPAM)(Phen)Cl_2] $C_{26}H_{26}Cl_2CdN_6$	Red	605.85	258-260	51.55 (51.53)	4.33 (4.34)	13.87 (13.90)	18.55 (18.56)
[Hg(TBPAM)(Phen)Cl_2] $C_{26}H_{26}Cl_2HgN_6$	Red	694.03	264-267	45.00 (45.03)	3.78 (3.81)	12.11 (12.13)	28.90 ------

The values of the previous measurements were relied upon to reach the geometrical shape of the synthezid complexes, which confirmed the octahedral structure for all of the complexes. Both of primary and secondary ligands behaved as a bidentate, and formed two five member rings with the central metal ions while The remaining two sites occupied by chloride ions, as shown in figure (9).

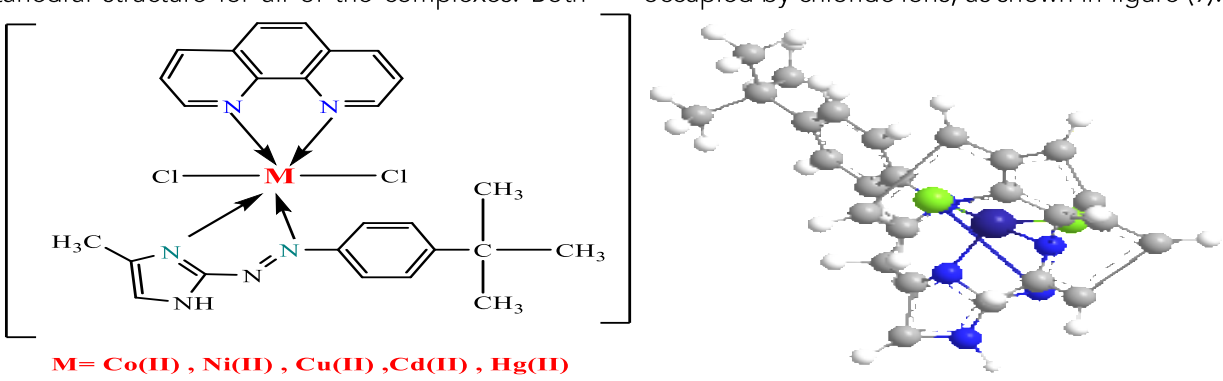


Figure (9): Proposed Stereo-Chemical Structure of the synthesized solid complexes

Bacterial Inhibition behavior results which demonstrated in figures (10-13) of the primary

ligand and the synthesized complexes investigated towards *S. aureus* as gram positive, *P. aeruginosa* and *Klebsiella* as gram negative at a concentration (100) mg/ml in DMSO solvent indicated that the complexes have greater inhibition ability comparing with free primary ligand. on the other hand, gram negative type showed more resistance towards the ligand and it's complexes may be due to the impermeable nature of the cell membrane while the activity of the complexes arranged according to the following sequence that attributed to the affinity of DNA to coordinate with central metal ions:

[Co(TBPAM)(Phen)Cl_2] < [Ni(TBPAM)(Phen)Cl_2]< [Cu(TBPAM)(Phen)Cl_2]< [Cd(TBPAM)(Phen)Cl_2]< [Hg(TBPAM)(Phen)Cl_2]

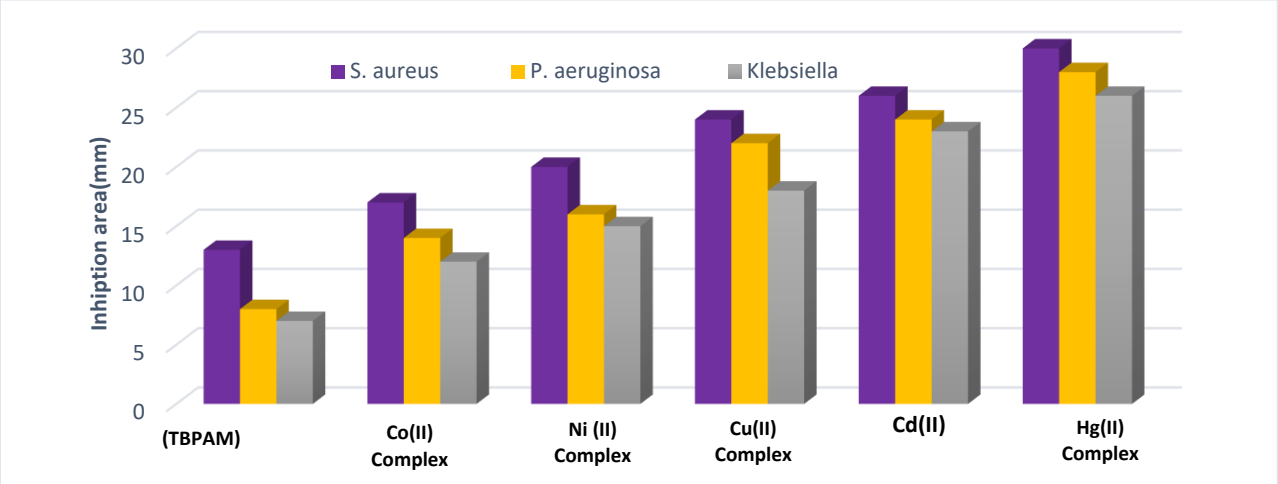
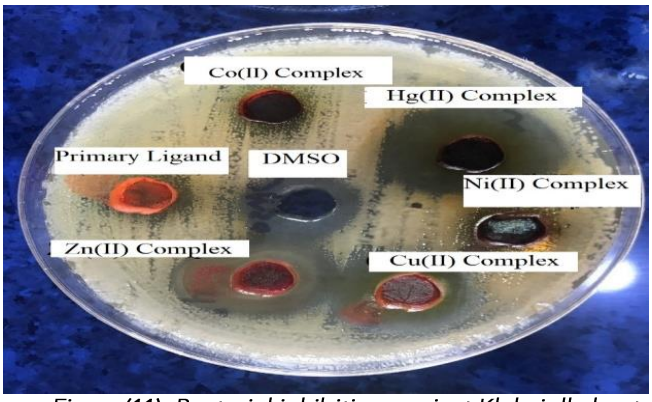
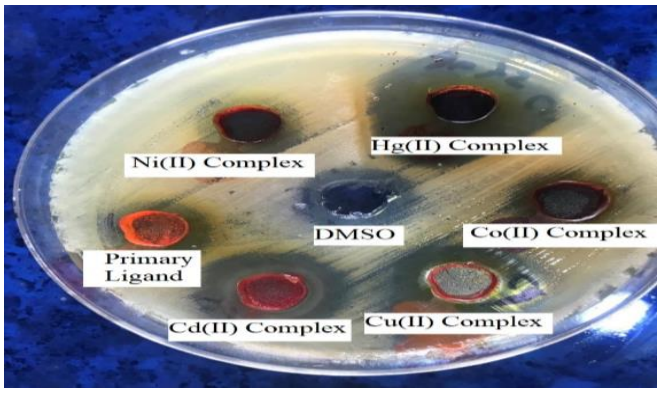


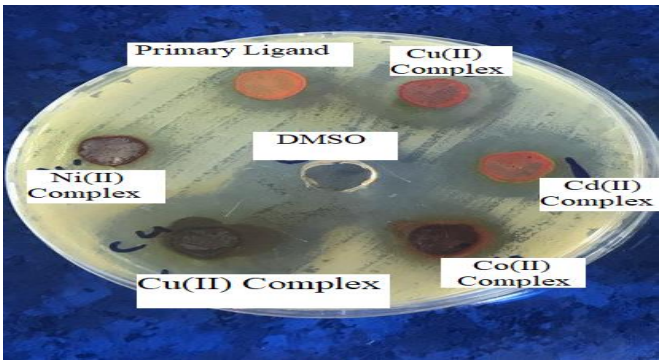
Figure (10): Bacterial inhibition areas (mm) of the primary ligand and it's complexes against S.aureus , P.aeruginosa , and Klebsiella resistance bacteria



Figure(11): Bacterial inhibition against Klebsiella bacteria



Figure(12): Bacterial inhibition against P.aeruginosa bacteria



Figure(13): Bacterial inhibition against S.aureus bacteria

4. Conclusion

New synthezid mixed ligand complexes of Transition, Cd(II), and Hg(II) divalent ions were characterized with primary Azo-imidazole ligand (TBPAM), and 1,10-phenanthroline as a secondary ligand with a good agreement to their molecular structures and percentage , both of ligands behavios as bidentate , and all of complexes have an octahedral geometry with a general formula[M(TBPAM)(Phen)Cl_2].The complexes appeared noticeable inhibition comparing to the free primary ligand against *S. aureus, P. aeruginosa* ,and *Klebsiella* bacteria.

References

[1] Liana Ghasemi , Mahdi Behzad , Ali Khaleghian , Alireza Abbasi , and Anita Abedi . Synthesis and characterization of two new mixed-

ligand Cu(II) complexes of a tridentate NN'O type Schiff base ligand and N-donor heterocyclic co-ligands: In vitro anticancer assay, DNA/human leukemia/COVID-19 molecular docking studies, and pharmacophore modeling. . Appl Organomet Chem. 2022 May;36(5):e6639. doi: 10.1002/aoc.6639.

[2] Alex Ujong Obeten, Ededet Akpan Eno, and Offiong Effanga Offiong. Synthesis and characterization of copper (II) mixed ligand complexes with 3-proply-5-mercapto-1,2,4- triazole and 1,10-phenanthroline. World Scientific News .2022.1(66). DOI: 10.1016/j.molstruc.2021.131498.

[3] Saifun Nesa, Md. Sajjad Hossain, Saiyad Nasira, Nayon Uddin, Md.Ashrafuzzaman, Md. Ahsan Habib, Md. Al Mamunur Rashid and Md.Masuqul Haque.Mixed ligand complexes: Synthesis, characterization and antibacterial activity investigation. International Journal of Chemical Studies.2021. 8(1): 306-312.

[4] Sajjad H.Jawad , and Khalid J.Al-Adilee. Synthesis, spectroscopic characterization and biological activities as an anticancer and antioxidant of the Pd(II) and Pt(IV) complexes with a new azo dye ligand derived from 5-methyl imidazole. Journal of Molecular Structure.2022. 134846, doi.org/10.1016/j.molstruc.2022.134846.

[5] Abhijit Chhetri , Sailesh Chettri , Pranesh Rai , Dipu Kumar Mishra , Biswajit Sinha , and Dhiraj Brahman. Synthesis, characterization and computational study on potential inhibitory action of novel azo imidazole derivatives against COVID-19 main protease (Mpro: 6LU7). Journal of Molecular Structure. 2021 Feb 5; 1225:129230. doi: 10.1016/j.molstruc.2020.129230.

[6] Fatema Jabbar Ali, Esraa Rasool Radhi, and Khdeeja Jabbar Ali. Synthesis and Characterization of a New Azo Ligand Derivative from 4,5-BIS(4-Methoxyphenyl) Imidazol and its Metal Complexes and Biological Activity Study of its Pd (II) Complex. Pakistan Journal of Medical & Health Sciences .2022.16(7). DOI: 10.53350/pjmhs22167431.

[7] Azal Shakir Waheeb. Spectroscopic, characterization and bioactivity studies of new Ni (II), Cu (II) and Ag (I) complexes with didentate (N,N) donor azo dye ligand. Journal of Molecular Structure.2022. 1276.doi:10.1016/j.molstruc.2022.134729.

[8] Mutlu Gençkal H, Erkisa M, Alper P, Sahin S, Ulukaya E, Ari F. Mixed ligand complexes of Co(II), Ni(II) and Cu(II) with quercetin and diimine ligands: synthesis, characterization, anti-cancer and anti-oxidant activity. J Biol Inorg Chem.2020. 25(1):161-177. doi: 10.1007/s00775-019-01749-z.

[9] Leela DS, Ushaiah B, Anupama G, Sunitha M, Kumari CG. Synthesis, characterization, antimicrobial, DNA binding and cleavage studies of mixed ligand Cu(II), Co(II) complexes. J Fluoresc. 2015 Jan;25(1):185-97. doi: 10.1007/s10895-014-1496-7.

[10] Husham M. Hasan Mubark , Israa N.Witwit , and Abid Allah M. Ali. Synthesis of new azo imidazole ligand and fabricating it's chelate complexes with some metallic ions. Journal of Physics: Conference Series.2020.1660. **DOI** 10.1088/1742-6596/1660/1/012031.

[11] I.S. Hamza, W.A. Mahmmoud, A.A. Al-Hamdani, S.D. Ahmed, A.W. Allaf, and W. Al Zoubi. (4-Amino-N-(5-methyl-isaxazol-3-yl)-benzenesulfonamide). Inorganic Chemistry Communications.2022.144(1):1-23. doi.org/10.1016/j.inoche.2022.109776.

[12] Serbest K, Dural T, Kızıl D, Emirik M, Zengin A, Dinçer B. Ternary Transition Metal Complexes with an Azo-Imine Ligand and 2,2'-Bipyridine: Characterization, Computational Calculations, and Acetylcholinesterase Inhibition Activities. Acta Chim Slov. 2022 . 69(3):604-618. doi: 10.17344/acsi.2022.7511.

[13] Shaima Mohammed Reda, and Abbas Ali Salih Al-Hamdani. Mn(II),Fe(III),Co(II)and Rh(III) complexes with azo ligand: Synthesis, characterization, thermal analysis and bioactivity.2022.3(1):1-19. DOI: https://doi.org/10.21123/bsj.2022.7289.

[14] Waleed A. Mahmoud, Abid Allah M. Ali, and Tamara A. Kareem. Preparation and Spectral Characterization of New Azo Imidazole Ligand 2-[(2`-Cyano Phenyl) Azo]-4,5-Diphenyl Imidazole and its Complexes with Co(II), Ni(II), Cu(II), Zn(II), Cd(II) and Hg (II) Ions. Baghdad Science Journal .2015. 12(1):96-109.

[15] Yuan Lai, Yuji Liu, Wei Huang, Zhiwei Zeng, Hongwei Yang, and Yongxing Tang. Synthesis and characterization of pyrazole- and imidazole- derived energetic compounds featuring ortho azido/nitro groups .Fire Phys Chem.2022.2(2): 140-146. doi.org/10.1016/j.fpc.2021.09.003.

[16] C. R. Luman, and F. N. Castellano. 1,10-Phenanthroline: A versatile building block for the construction of ligands for various purposes. Coordination Chemistry Reviews .2010. 254(17):2096-2180. DOI: 10.1016/j.ccr.2010.04.008.

[17] Enamm S.Abdullah , Mohammed R. Al-lami ,Thamer Al-Alwany , Yahya Al-Khafaji, and Noor Al-Mamory. Preparation, Characterization and Biological Activity of new Transitions Metals Complexes with Benzoic Acid AZO-Derivative. Test Engineering and Management.2020. 83: :12899-12904.

[18] Maliyappa, M.R., Keshavayya, J. Cu(II), Co(II), Ni(II), Zn(II) and Cd(II) complexes of novel azo ligand 6-hydroxy-4 methyl-2 oxo-5-[(4,5,6,7-tetrahydro-1,3-benzothiazol-2-yl)diazenyl]-1,2-dihydropyridine 3-carbonitrile as potential biological agents: synthesis and spectroscopic characterization. Chemical Papers. 2022. 76:3485–3498 .doi.org/10.1007/s11696-022-02101-7.

[19] Jinan Mohammed Mahmood Al-Zinkee, Amer J. Jarad. Synthesis, Spectral Studies and Microbial Evaluation of Azo Dye Ligand Complexes with Some Transition Metals. Journal of Pharmaceutical Sciences and research. 2019. 11(1): 98-103.

[20] Azal Shakir Waheeb, Hussein Ali Kadhim Kyhoiesh, Abbas Washeel Salman, Khalid J. Al-Adilee, Mustafa M. Kadhim, Metal complexes of a new azo ligand 2-[2′-(5-nitrothiazolyl) azo]-4-methoxyphenol (NTAMP): Synthesis, spectral characterization, and theoretical calculation, Inorganic Chemistry Communications,2022.138.
[21] Hanadi M. Jarallah, Mouayed Y. Kadhum, Adnan S. Abdulnabi. Synthesis, Spectral and Thermal Studies of New Azo Dyes Complexes Derived From 3-tert-butyl-4-hydroxyanisol. Journal of Kufa for Chemical Science .2022.2(8):144-156.
[22] Abaas Obaid Husseina, Rana Abdulilah Abbasb, Jasim S. Sultanc, and amer J.Jaradd. Synthesis And Characterization Of Metal(II) Complexes With Azo Dye Ligand And Their Industrial And Biological Applications. Egyptian Journal of Chemistry.2021.64(11): 6717 – 6724. DOI: 10.21608/EJCHEM.2021.68770.3530.
[23] Bello U., Shallangwa G. A, Idris S. O., Musa M., and Aisha A.A. SYNTHESIS, SPECTROSCOPIC CHARACTERIZATION AND IN VITROANTIBACTERIAL ACTIVITY STUDIES OF Cu (II) COMPLEXES DERIVED FROM 6HYDROXYFLAVONE SCHIFF BASEs. Bayero Journal of Pure and Applied Sciences.2018. 11(2): 136 – 141.http:// dx.doi.org/10.4314/bajopas. v11i2.16.
[24] Arab Ahmadi R., Hasanvand F., Bruno G., Amiri Rudbari H., and Amani, S.. Synthesis, Spectroscopy, and Magnetic Characterization of Copper(II) and Cobalt(II) Complexes with 2-Amino-5-bromopyridine as Ligand. ISRN Inorganic Chemistry, 2013;2013: 1–7. doi:10.1155/2013/426712.
[25] Obaid SM, Jarad AJ, Al-Hamdani AA. Synthesis, Characterization and Biological Activity of Mixed Ligand Metal Salts Complexes with Various Ligands. InJournal of Physics: Conference Series 2020 Nov 1;1660(1):12-28. IOP Publishing. doi: 10.1088/1742-6596/ 1660/1/012028 .