Synthesis, Characterization, and Biological Activity of CO (II) and Ni (II) Hetero-bimetallic Complex with [N, N'-1,2-PHENYLENE BIS (2-HYDROXY-3-METHOXY BENZALDEHYDE)] and 8-Hydroxyquinoline

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***Abstract*—In the present research work, the reagent [N,N'-1,2-PHENYLENE BIS (2-HYDROXY-3-METHOXY BENZALDEHYDE)] is synthesized by Schiff base reaction. The reagent is characterized by FT-IR and NMR. This reagent is coupled with CO(II) to get a monometallic complex. Another monometallic complex has been prepared by using 8-Hydroxyquinoline as a reagent with Ni(II). The combination of these two will give a Hetero-bimetallic complex. This prepared complex is characterized by using FT-IR and Elemental analysis. The said hetero-bimetallic complex shows better antifungal & antibacterial activity than the mono-metallic complex.**

***Index Terms*—Schiff base, Hetero-bimetallic**

I. INTRODUCTION

The chemistry of coordination compounds is vast, spanning from theoretical bonding models to organometallic synthesis. Within this field, bimetallic complexes are highly sought after for their unique functional properties. By utilizing two cooperative metal centres, these complexes can easily facilitate multi-electron transition metal processes. [1]This powerful ability to enhance chemical reactivity continues to drive promising new advancements in research.

The synthesis of novel Schiff base mixed ligands represents a critical bottleneck in engineering metal complexes with tailored properties and innovative reactivity profiles. [2]The foundational design of these coordination systems is dictated by a complex interplay of electronic properties (donor-acceptor capabilities), structural-functional groups, spatial orientation within the coordination sphere, and intrinsic complex reactivity.[3,4]

Unlike traditional monometallic systems, bimetallic complexes utilize multidentate ligands to anchor two metal centers simultaneously. [5] This dual-center architecture yields distinct functional advantages:

Enhanced Kinetics: Accelerates reaction rates through cooperative catalysis.[6]

Refined Selectivity: Optimizes product yields and pathways via dual-site steering.[7]

Biological Utility: Drives rapid research expansion due to potent, diverse bioactivities.[8]

Bimetallic architectures are categorized into homobimetallic (identical metal centers) or heterobimetallic (disparate metal centers) frameworks. The localized metal centers cooperate dynamically, altering the complex's collective physical properties and chemical reactivity through individual or synergistic contributions.[9]

While homobimetallic systems rely on identical electronic contributions, heterobimetallic frameworks merge the distinct, complementary traits of two different elements. [10] This heterocentred cooperation frequently yields property enhancements that surpass the performance of homobimetallic analogues. Mechanistically, these sophisticated heterobimetallic structures are assembled via the sequential, stepwise introduction of differing metal ions into the ligand framework.[11]

The pharmacological and chemical capabilities of metal complexes are directly dictated by the intrinsic properties of both the central metal ion and its coordinating organic ligands.[12] Coordinating a

metal ion to an organic ligand frequently amplifies its baseline biological activity. Consequently, tailored bimetallic complexes are extensively researched for specialized applications spanning medicine, agriculture, and industrial manufacturing.[13]

Recent literature shows a major research surge focused on synthesizing and characterizing homometallic transition metal complexes. Investigations primarily target the antimicrobial and therapeutic potencies of systems built with Cu, Co, Mn, Zn.[14]

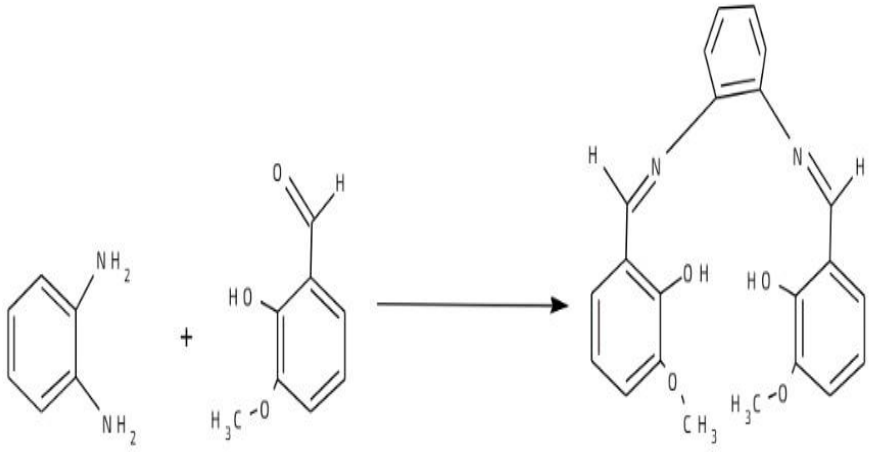
Beyond medical applications, targeted bimetallic systems are engineered to resolve distinct industrial and electronic challenges.Heterobimetallic complexes are engineered for dual-action signal amplification and the chemical degradation of oxalate, a prevalent industrial pollutant.Advanced research highlights how aluminum-containing ligands exert powerful electronic effects within localized heterobimetallic frameworks. [15-18]

We synthesized a Co(II)–Ni(I) heterobimetallic complex by coupling two distinct monometallic units: a Ni(II) Schiff base complex utilizing [N,N'-1,2-PHENYLENE BIS (2-HYDROXY-3-METHOXY BENZALDEHYDE)] and a Co(II) complex featuring 8-Hydroxyquinoline. Biological screening confirmed that the heterobimetallic complex possesses enhanced potency over the monometallic precursors. This study represents the first reported synthesis of a Co(II)–Ni(II) system using this dual-ligand approach.

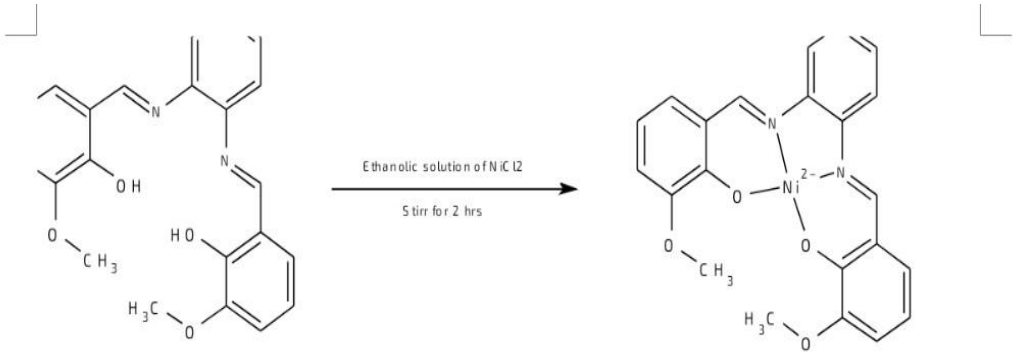
II. EXPERIMENTAL

All reagents and chemicals were obtained from commercial sources and used as received without further purification. Specifically, o-phenylenediamine, o-vanillin, cobalt(II) chloride, nickel(II) chloride, and 8-hydroxyquinoline were purchased from Sigma-Aldrich. Fourier-transform infrared (FTIR) spectra were recorded in the 4000–400 cm^{-1} range using KBr pellets on a Shimadzu 8201 FTIR spectrophotometer.

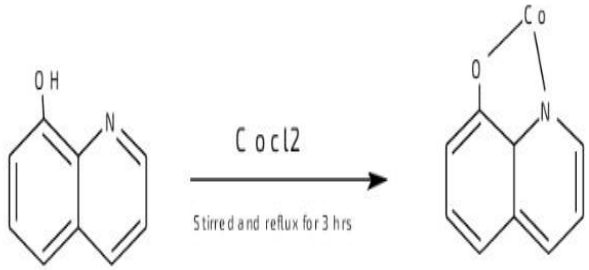
Synthesis of (N,N'-1,2-phenylenebis(2-hydroxy-3-methoxybenzaldehyde) (R1) : To a stirred ethanolic solution of O-phenylenediamine, an ethanolic solution of O-vanillin was added dropwise. The resulting reaction mixture was stirred continuously at room temperature until the formation of a precipitate was complete. The crude product, designated as [R1], was isolated by filtration, washed thoroughly with cold ethanol, and subsequently recrystallized from hot ethanol to yield the pure Schiff base ligand.



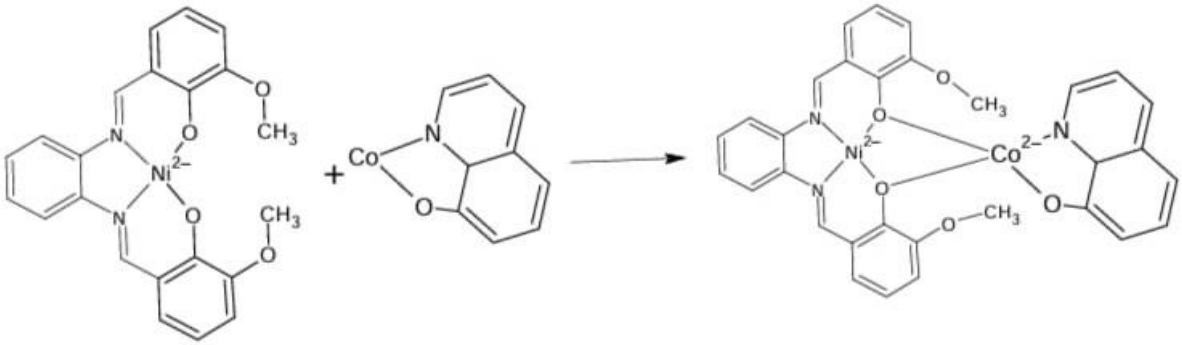
Synthesis of [N,N'-1,2-phenylenebis(2-hydroxy-3-methoxybenzaldehyde)] Ni(II) Complex (R1M1) : An ethanolic solution of nickel(II) chloride was added dropwise to a stirred ethanolic solution of ligand [R1]. Upon stirring at room temperature, a green precipitate formed immediately. The reaction mixture was stirred continuously for one hour to ensure complete complexation. The resulting solid was isolated by filtration, washed successively with hot ethanol and cold distilled water, and finally dried under vacuum.



3) Synthesis of 8-Hydroxyquinoline Co(II) Complex (R2M2) : A hot ethanolic solution of ligand R2 was added dropwise to a stirred ethanolic solution of cobalt(II) chloride. Upon stirring at room temperature, a dark brown precipitate formed immediately. The reaction mixture was stirred continuously for one hour to ensure complete complexation. The resulting solid was isolated by filtration, washed successively with hot ethanol and cold distilled water, and subsequently dried under vacuum.



Synthesis of Heterobimetallic Ni(II)-Co(II) Complex : An ethanolic solution of the monometallic Ni(II) complex (R1M1) was added dropwise to a stirred ethanolic solution of the Co(II) complex (R2M2). The resulting reaction mixture was heated under reflux for 3 hours with continuous stirring. After completion of the reaction, the heterobimetallic product was isolated by filtration, washed successively with hot ethanol and distilled water, and subsequently dried under vacuum to afford the pure target complex.



III. RESULT AND DISCUSSION

Characterization of the synthesized Schiff base ligand via physical analytical methods, H-NMR, and mass spectrometry verified its expected structure and exceptional purity.

FTIR Spectrometric Analysis : The FTIR spectrum of the ligand exhibits a characteristic strong absorption band at 1609 cm^{-1}, attributed to the azomethine (C=N) stretching vibration, confirming successful condensation and Schiff base formation. The broad, low-intensity band observed in the region of 2800–3100 cm^{-1} is assigned to the phenolic O-H stretching

vibration, indicating its participation in strong intramolecular hydrogen bonding (O-H···N) with the imine nitrogen. Aromatic C=C stretching vibrations appear at 1455 cm^{-1}, while the strong bands at 1245 cm^{-1} and 1076 cm^{-1} correspond to the phenolic and methoxy C-O stretching modes, respectively. Out-of-plane C-H bending vibrations for the ortho-disubstituted and 1,2,3-trisubstituted aromatic rings are observed in the fingerprint region at 778 cm^{-1} and 733 cm^{-1}.

^{1}H NMR Spectrometric Analysis : The ^{1}H NMR spectrum of the ligand recorded in DMSO-d_6 displays a sharp singlet at δ 8.923 ppm, corresponding to the azomethine (-CH=N-) protons and confirming successful Schiff base formation. The presence of the phenolic -OH groups is evidenced by a highly deshielded singlet downfield at δ 12.986 ppm, which is characteristic of strong intramolecular hydrogen bonding (O-H···N). The aromatic protons of both the central phenylenediamine ring and the substituted vanillin rings appear in the range of δ 6.890–7.471 ppm. Additionally, a distinct singlet integrating for six protons appears at δ 3.810 ppm, attributed to the methoxy (-OCH_3) groups. These spectral features fully align with the expected symmetrical structure of the 2:1 condensation product.

Mass Spectrometric Analysis (ESI-MS) : The mass spectrum of the ligand ($C_{22}H_{20}N_2O_4$, calculated molecular weight: 376.41 g/mol) displays a prominent base peak corresponding to the protonated molecular ion $[M+H]^+$ at m/z 377.15, confirming the expected formula weight and 2:1 stoichiometry of the condensation reaction. Additional characteristic adduct peaks, such as $[M+Na]^+$ at m/z 399.13, further support the structural integrity of the synthesized Schiff base ligand. The absence of peaks corresponding to mono-condensed intermediates or unreacted starting materials confirms the high purity of the product.

Biological Activity (Antimicrobial Analysis) : The in vitro antimicrobial activity of the heterobimetallic Ni(II)–Co(II) complex was evaluated against Gram-positive (Staphylococcus aureus) and Gram-negative (Escherichia coli) bacterial strains, as well as a fungal strain (Candida albicans), using the agar well diffusion method. Sterile agar medium was inoculated with microbial suspensions, poured into Petri dishes, and punched with 6 mm wells. The Ni(II)–Co(II) complex was dissolved in DMSO at test concentrations of 5 ppm and 10 ppm and loaded into the designated wells. Pure DMSO was used as the negative control, while Streptomycin and Fluconazole served as standard antibacterial and antifungal reference drugs, respectively. Plates were incubated at 30°C–35°C (bacterial) and 20°C–25°C (fungal) for 24–48 hours, and activity was quantified by measuring the diameter of the zone of inhibition (ZI) in millimeters (mm). Percentage Activity Index AnalysisTo quantitatively evaluate efficacy relative to clinical standards, the Percentage Activity Index (% AI) was calculated for the Ni(II)–Co(II) complex at a concentration of 10 ppm. The complex demonstrated minimal antibacterial activity, exhibiting a % AI of 5.71% against S. aureus and 6.25% against E. coli relative to Streptomycin. In contrast, the complex showed pronounced antifungal potential against C. albicans, achieving an Activity Index of 62.86% compared to the standard antifungal drug Fluconazole. This significant percentage clearance at a low concentration threshold (10 ppm) confirms the selective antifungal potential of the heterobimetallic Ni(II)–Co(II) complex.

Test Pathogen	Pathogen Type	Zone of Inhibition (10 ppm)	**Standard Control Zone (1 mg/mL)**	Activity Index (% AI)	Efficacy Level
Staphylococcus aureus	Gram-positive Bacteria	2 mm	35 mm (Streptomycin)	5.71%	Weak / Minimal
Escherichia coli	Gram-negative Bacteria	2 mm	32 mm (Streptomycin)	6.25%	Weak / Minimal
Candida albicans	Fungal Pathogen	22 mm	35 mm (Fluconazole)	62.86%	High / Selective

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REFERENCES

[1] Zhang, Y.; Thompson, J. R.; Radosevich, A. T. Cooperative Activation of CO_2 and Epoxide by a Heterobinuclear Complex via Radical Pair Mechanisms. J. Am. Chem. Soc. 2022, 144 (28), 12560–12571. doi.org

[2] Shibasaki, M.; Kanai, M.; Matsunaga, S. Heterobimetallic Cu–Sm–Schiff Base Complex Catalyzed syn-Selective Asymmetric Nitro-Mannich Reaction. Pubmed / J. Am. Chem. Soc. 2010, 132 (12), 4398–4407. doi.org

[3] Tolman, C. A. Steric Effects of Phosphorus Ligands in Organometallic Chemistry and Homogeneous Catalysis. Chem. Rev. 1977, 77 (3), 313–348. doi.org

[4] Bontamps, V.; Gornitzka, H.; Bouhadir, G.; Bourissou, D. Coordination of Ambiphilic Ligands: Interplay Between Electronic Properties and Spatial Constraints. Coord. Chem. Rev. 2010, 254 (11-12), 1288–1305. doi.org

[5] Akita, M.; Tilley, T. D. Synthesis of O,N,O-P-Multidentate Ligands and Their Heterobimetallic Coordination Preferences. J. Organomet. Chem. 2022, 968, 122359. doi.org

[6] Zhang, Y.; Thompson, J. R.; Radosevich, A. T. Cooperative Activation of CO_2 and Epoxide by a Heterobinuclear Complex via Radical Pair Mechanisms. J. Am. Chem. Soc. 2022, 144 (28), 12560–12571. doi.org

[7] Shibasaki, M.; Kanai, M.; Matsunaga, S. Heterobimetallic Cu–Sm–Schiff Base Complex Catalyzed syn-Selective Asymmetric Nitro-Mannich Reaction. J. Am. Chem. Soc. 2010, 132 (12), 4398–4407. doi.org

[8] Zaltariov, M. F.; Shova, S.; Cazacu, M. Schiff Base Heterometallic Complexes and Their Potential Applications. Cryst. Growth Des. 2026, 26 (4), 1513–1526. doi.org

[9] Sartori, G.; Maggi, R. Cooperative Bimetallic Effects in Biomimetic Catalysis and Medicinal Chemistry. Chem. Eur. J. 2017, 23 (54), 13261–13274. doi.org

[10] Reed, C. J., & Thomas, C. M. (2023). Bimetallic cooperation across the periodic table. Nature Reviews Chemistry, 7(7), 482–501. doi.org

[11] Wong, W.-Y.; Harvey, P. D. Selective One-Pot Syntheses of Heterobimetallic Complexes Using Multidentate Binucleating Ligands. Dalton Trans. 2013, 42 (46), 16343–16350. doi.org

[12] Al-Amiery, A. A.; Al-Majedy, Y. K.; Kadhum, A. A. H. Synthesis and Crystal Structures of New Mixed-Ligand Schiff Base Complexes Containing NN'O Type Unsymmetrical Tridentate Scaffolds. Polyhedron 2022, 218, 115752. doi.org

[13] Sartori, G.; Maggi, R. Cooperative Bimetallic Effects in Biomimetic Catalysis and Medicinal Chemistry. Chem. Eur. J. 2017, 23 (54), 13261–13274. doi.org

[14] Coates, A. R., & Thomas, W. (2025). Mechanisms operating in the use of transition metal complexes to combat antibiotic resistance. Chemical Science, 16(4), 1142–1158. doi.org

[15] Brewster, T. P. Systematic Evaluation of the Electronic Effect of Aluminum-Containing Ligands in Iridium and Rhodium Heterobimetallic Complexes. Inorg. Chem. 2020, 59 (19), 13840–13851. doi.org

[16] Liu, Q., & Wang, J. (2024). Bimetallic coordination polymers: Synthesis and applications in biosensing and biomedicine. Polymers, 16(5), 654. doi.org

[17] Zhang, L., & Wang, X. (2024). Towards a fundamental understanding of heterogeneous iron oxide–oxalate systems in organic pollutant degradation. Applied Surface Science, 645, Article 158812. doi.org

[18] Garden, J. A., & Mosquera, M. E. G. (2023). Aluminum-containing heterobimetallic complexes as versatile platforms for ring-opening polymerization and bond transformations. ACS Catalysis, 13(18), 12345–12359. doi.org