

Metal Complexes with Schiff Bases: Data Collection and Recent Developments

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Abstract- Schiff bases, characterized by their azomethine group (-C=N-), are synthesized through the condensation of primary amines with carbonyl compounds, and their ability to form stable complexes with various metal ions has been extensively studied, revealing a broad spectrum of biological activities, including antimicrobial, anticancer, antioxidant, antimalarial, analgesic, antiviral, antipyretic, and antidiabetic properties. The versatility of Schiff bases as ligands allows for the formation of both mononuclear and binuclear metal complexes, each exhibiting unique structural and electronic characteristics that contribute to their diverse pharmacological profiles. Recent studies have focused on the synthesis and characterization of these metal-Schiff base complexes, aiming to enhance their biological efficacy and selectivity. For instance, modifications in the ligand framework, such as the introduction of electron-donating or withdrawing groups, have been shown to influence the stability and reactivity of the resulting complexes, thereby affecting their interaction with biological targets. Additionally, the choice of metal ion plays a crucial role in determining the biological activity of the complex, with transition metals like copper, nickel, and zinc being commonly employed due to their favorable coordination chemistry and biological relevance. The development of these metal-Schiff base complexes has opened new avenues in medicinal chemistry, particularly in the design of novel therapeutic agents with improved efficacy and reduced side effects. However, challenges remain in understanding the precise mechanisms underlying their biological activities and in optimizing their pharmacokinetic and pharmacodynamic properties for clinical application. Future research directions include the exploration of Schiff base complexes with less common metals, the investigation of their interactions at the molecular level using advanced

spectroscopic and computational techniques, and the assessment of their therapeutic potential in vivo. By addressing these challenges, the full potential of metal-Schiff base complexes in drug development can be realized, contributing significantly to the advancement of medicinal chemistry and the development of new treatments for various diseases.

Indexed Terms- Schiff bases, Metal complexes, Azomethine group, biological activities, Transition metals, Medicinal chemistry

I. INTRODUCTION

Schiff bases, first described in the mid-19th century, are compounds characterized by the azomethine functional group (-C=N-) formed through the condensation of primary amines with carbonyl compounds, and their versatility as ligands in coordination chemistry has been widely recognized due to their ability to form stable complexes with a range of metal ions, influencing the properties and reactivities of these complexes in various fields such as catalysis, material science, and medicinal chemistry (Patil et al., 2010; Kumar et al., 2018), while their metal complexes exhibit structural diversity arising from the coordination of azomethine nitrogen and additional donor atoms like oxygen or sulfur to metal centers, resulting in geometrically diverse mononuclear and polynuclear complexes whose formation and stability are significantly influenced by the nature of the metal ion and ligand substituents (Bhattacharjee & Ghosh, 2015), and in catalysis, metal-Schiff base complexes have been employed in organic transformations such as oxidation and polymerization reactions, with cobalt(II) and manganese(III) Schiff base complexes showing remarkable efficiency in epoxidation reactions due to their electron-transfer capabilities (Mahmoud et al., 2013), whereas in material science, Schiff base metal

complexes are explored for their photoluminescent and electrochemical properties, enabling applications in sensors and optoelectronic devices (Ahmed et al., 2017), and their role in medicinal chemistry is particularly significant, with studies highlighting their antimicrobial, anticancer, and antioxidant activities, which are attributed to their interactions with cellular targets like DNA and proteins as well as their ability to induce oxidative stress in pathogens and cancer cells (Pradeep et al., 2014), yet despite extensive research, challenges such as the limited understanding of structure-activity relationships and the optimization of pharmacokinetic profiles for therapeutic applications persist, necessitating advancements in spectroscopic and computational techniques to explore the electronic structures and reactivity of these complexes, thereby offering insights into the development of next-generation Schiff base metal complexes with enhanced selectivity and functionality for diverse applications across catalysis, material science, and therapeutic domains (Kumar et al., 2018; Bhattacharjee & Ghosh, 2015). The formation of metal complexes with Schiff bases involves the coordination of the azomethine nitrogen and, often, other donor atoms present in the ligand framework, such as oxygen or sulfur, to metal ions, leading to the formation of mononuclear or polynuclear complexes with varied geometries and oxidation states (Cozzi, 2004). The nature of the metal ion, the substituents on the Schiff base ligand, and the reaction conditions play crucial roles in determining the structure and stability of the resulting complexes (Cozzi, 2004). In catalysis, metal-Schiff base complexes have been employed as catalysts in various organic transformations, including oxidation reactions, polymerization processes, and asymmetric synthesis, due to their ability to stabilize different oxidation states of metals and facilitate electron transfer processes (Cozzi, 2004). For instance, chiral Schiff base complexes of transition metals have been utilized in asymmetric epoxidation reactions, providing high enantioselectivity and efficiency (Cozzi, 2004).

II. STATEMENT OF THE RESEARCH PROBLEM

Metal complexes with Schiff bases, formed by condensing primary amines and carbonyls, have emerged as versatile agents in coordination chemistry

with applications in catalysis, material and medicinal chemistry because of their ability to form stable coordination complexes with transition metals such as copper, nickel, cobalt, zinc, and iron, which improve their structure, electronics, and bioactivity (Schiff et al., 1864; Rao et al., 2015), where the biological activity of the metal complexes (antimicrobial, anticancer and antioxidant effects) is often linked to their ability to interact with biomolecules (like DNA and proteins) or produce reactive oxygen species that disrupt cellular pathways, yet major challenges remain in understanding the mechanisms that mediate these functions and improving their pharmacokinetic and pharmacodynamic plots for therapeutic applications (Ahmed et al., 2017; Patil et al., 2014), and despite advancements in computational methods (e.g. density functional theory (DFT)) and spectroscopies that have revealed the electronic structures and reactivity of these compounds, the relationship between structure and function in Schiff base metal complexes remains poorly understood, especially in relation to their interactions with cellular targets and mechanisms of resistance which is crucial to designing derivatives with greater potency and selectivity (Singh et al., 2018; Kumar et al., 2020), while another challenge is the limited investigation of Schiff base complexes with less common metals or mixed-metal systems that could unveil new catalytic features or synergistic biological responses (Mahmoud et al., 2016), along with further investigations needed to evaluate the therapeutic properties of such complexes through an in-depth in vitro and in vivo studies, pharmacological tests and long-term stability tests that may also help elucidate their metabolism and biocompatibility (Pradeep et al., 2018), whilst innovations in delivery strategies, such as nanoparticle based systems or encapsulated in liposomes, present exciting opportunities to improve their bioavailability and targeting (Cozzi, 2004; Lawrence et al., 2019), and overcoming these issues through a cross-disciplinary approach that combines synthetic chemistry with computational modeling and biological assessment is crucial to unlock the potential of Schiff base metal complexes, as these compounds hold the capacity to not only advance fundamental chemistry, but also catalysis, materials engineering and therapeutics, thus establishing their relevance as an area of active and future investigation (Schiff et al., 1864; Rao et al., 2015; Kumar et al., 2020).

III. SIGNIFICANCE OF THE RESEARCH STUDY

The study of metal complexes with Schiff bases, synthesized through the condensation of primary amines with carbonyl compounds, is of profound significance due to their wide-ranging applications in catalysis, material science, and medicinal chemistry, where these compounds act as bidentate or multidentate ligands coordinating with transition metals such as copper, nickel, cobalt, zinc, and iron, often enhancing the structural, electronic, and biological properties of the resulting complexes, which are extensively researched for their roles in oxidation reactions, polymerization processes, and asymmetric catalysis, as well as their potential to act as therapeutic agents with antimicrobial, anticancer, and antioxidant properties, although the precise mechanisms underlying their biological activities and the optimization of their pharmacokinetic and pharmacodynamic profiles remain incompletely understood, necessitating further research into the molecular interactions between these complexes and cellular targets using advanced spectroscopic techniques and computational modeling, while the exploration of less common metals or mixed-metal systems could reveal new synergistic effects or catalytic efficiencies that have yet to be fully realized, and innovative delivery strategies such as the incorporation of these complexes into nanoparticle-based systems or liposomal carriers offer promising avenues to overcome challenges related to bioavailability and systemic toxicity, thereby emphasizing the need for a multidisciplinary approach that integrates synthetic chemistry, theoretical studies, and biological evaluation to address these gaps, ultimately contributing to the rational design of next-generation Schiff base metal complexes with tailored properties for specific applications in catalysis, advanced materials, and medicine, while simultaneously expanding the fundamental understanding of their coordination chemistry and reactivity patterns, and these efforts underscore the critical role of ongoing research in not only leveraging the therapeutic and functional potential of Schiff base metal complexes but also paving the way for their translation into practical applications that address pressing scientific and industrial challenges, highlighting their importance as a key area of

investigation in coordination chemistry and beyond (Rao et al., 2015; Kumar et al., 2020; Mahmoud et al., 2016; Ahmed et al., 2017; Patil et al., 2014).

IV. REVIEW OF RELEVANT LITERATURE RELATED TO THE STUDY

Metal complexes containing Schiff bases, which are formed from the condensation of primary amines and carbonyl compounds, have attracted significant interest within coordination chemistry due to their characteristics as multi-functional ligands that give rise to stable complexes with transition metals including copper, nickel, cobalt, zinc, and iron, and the operation of these components in various fields such as catalysis, material science and medicinal chemistry has received extensive attention whereby these complexes have been studied to serve catalytic functions in oxidation reactions, polymerization processes and asymmetric catalysis as well as characteristics of biological activity including antimicrobial, anticancer, antioxidant, and antiviral activities ascribed to interactions with biomolecules such as DNA or proteins or the generation of reactive oxygen species, however, further elucidation on the mechanisms of action and optimization of pharmacokinetic properties is necessary (Raman et al., 2018; Ahmed et al., 2020) and the introduction of new computational methods including density functional theory (DFT) and various spectroscopic techniques have provided insight into the electronic structures and coordination behavior of Schiff base metal complexes with further investigations into their reactivity in association with changes in ligand substituents and metal centers on stability, activity, and selectivity being investigated, evidence has shown that the introduction of electron-withdrawing or donating groups on the Schiff bases can significantly influence the geometry and redox properties of their respective complexes whilst alternate metals and mixed-metal systems remain under-exploited but have potential for new catalytic activities and synergies to emerge, thus extending the potential applications of Schiff base metal complexes (Khan et al., 2019 Singh et al., 2021) and examples in literature for this behavior include the use of copper(II) Schiff base complexes displaying anticancer attributes based on their generation of oxidative agents and a nickel-based system which is an efficient catalyst involved in hydroformylation

processes, besides for material science applications it is the optical and electronic properties of Schiff base metal complexes used in the design of sensors, nonlinear optical devices and molecular magnets, therefore highlighting the importance of modification to their structural and functional features (Gupta & Verma, 2020; Reddy et al., 2021) while new approaches to drug delivery by as just nanoparticle carriers and liposomal formulations have provided alternatives for increasing bioavailability and targeted release of Schiff base complexes and so mitigating problems with systaxis toxicity whilst achieving better therapeutic results, even so, deep mechanistic studies, high-throughput screening of new derivatives, and comprehensive in vitro and in vivo studies are necessary to establish a better understanding of their safety and efficacy profiles to enable the full utilization of Schiff base metal complexes that through epochal allow a platform for research directed towards innovation in catalytic and medical fields (Mahmoud et al., 2017; Kumar et al., 2021).

V. RESEARCH GAP RELATED TO THE STUDY

The study of metal complexes with Schiff bases, synthesized through the condensation of primary amines and carbonyl compounds, is recognized for its extensive applications in catalysis, material science, and medicinal chemistry, with these compounds serving as bidentate or multidentate ligands capable of coordinating with transition metals like copper, nickel, cobalt, zinc, and iron to enhance their structural and biological properties, yet significant research gaps persist, particularly in understanding the precise mechanisms through which these complexes interact with biomolecules such as DNA and proteins or generate reactive oxygen species to exert their biological effects, while limited exploration of Schiff base complexes with less common or mixed metals restricts the discovery of novel properties and synergistic catalytic effects that could broaden their utility (Ahmed et al., 2020; Reddy et al., 2021), and although advancements in computational modeling and spectroscopic techniques have provided valuable insights into their electronic structures and reactivity, there remains a lack of detailed studies linking ligand modifications, metal coordination geometry, and biological activities, especially regarding the

optimization of pharmacokinetic and pharmacodynamic profiles to improve bioavailability and reduce systemic toxicity (Kumar et al., 2021; Mahmoud et al., 2017), while another critical gap lies in the underdeveloped application of innovative drug delivery systems, such as nanoparticle-based carriers or liposomal formulations, which have demonstrated potential to address challenges related to therapeutic delivery but require further experimental validation to assess their efficacy in vivo (Gupta & Verma, 2020; Raman et al., 2018), and the design of new Schiff base ligands with functional groups that can specifically target diseased cells or stabilize rare metal oxidation states remains an underexplored area that could unlock new catalytic or medicinal applications, while the absence of systematic high-throughput screening for biological activities of diverse Schiff base complexes limits the comprehensive understanding of their therapeutic potential, making it imperative for future research to integrate experimental approaches with computational tools to elucidate structure-activity relationships, expand the repertoire of metal-ligand combinations, and develop sustainable and biocompatible methods for the synthesis and application of Schiff base metal complexes across catalysis, materials science, and therapeutic domains, ultimately addressing these research gaps to fully harness the potential of these complexes in advancing scientific innovation and solving real-world challenges (Ahmed et al., 2020; Reddy et al., 2021; Kumar et al., 2021; Raman et al., 2018).

VI. METHODOLOGY ADOPTED FOR THE PURPOSE OF STUDY

The methodology adopted for the study of metal complexes with Schiff bases, which are synthesized through the condensation of primary amines and carbonyl compounds, involves a comprehensive review of existing literature to collect secondary data on the synthesis, structural characterization, and diverse applications of these complexes in catalysis, material science, and medicinal chemistry, where these Schiff bases act as bidentate or multidentate ligands coordinating with transition metals such as copper, nickel, cobalt, zinc, and iron to form stable complexes with enhanced electronic and biological properties, while the analysis includes the evaluation of synthetic protocols, such as varying reaction

conditions and the incorporation of electron-donating or withdrawing substituents, as well as advanced spectroscopic techniques like NMR, IR, UV-Vis, and XRD to elucidate their coordination geometry and electronic structure (Ahmed et al., 2020; Reddy et al., 2021), and computational studies, particularly density functional theory (DFT), are reviewed to provide theoretical insights into the electronic behavior and reactivity patterns of Schiff base complexes, while the assessment of their applications covers their role as catalysts in organic transformations like oxidation and polymerization, their material properties such as photoluminescence and molecular magnetism, and their therapeutic potential in antimicrobial, anticancer, and antioxidant activities, yet despite these advancements, the methodology highlights critical gaps such as the limited exploration of Schiff base complexes with less common metals, inadequate studies on their long-term stability and biocompatibility, and the need for innovative delivery systems like nanoparticle-based carriers to improve bioavailability and targeted delivery, and by synthesizing data from peer-reviewed journals, patents, and computational databases, the study provides a theoretical framework for guiding future experimental research to bridge these gaps and fully harness the potential of Schiff base metal complexes in addressing challenges across scientific and industrial domains (Kumar et al., 2021; Raman et al., 2018; Mahmoud et al., 2017).

- Major objectives of the present study
1. To evaluate the methodologies for synthesizing Schiff base metal complexes, including variations in reaction conditions and the influence of substituents on their coordination properties and stability
 2. To analyze the coordination geometry, bonding, and electronic structures of Schiff base metal complexes using advanced spectroscopic techniques (e.g., NMR, IR, UV-Vis, and XRD) and computational methods like density functional theory (DFT)
 3. To investigate the role of Schiff base metal complexes in catalytic transformations such as oxidation and polymerization reactions and to explore their potential in material science applications, including photoluminescence and molecular magnetism

4. To examine the antimicrobial, anticancer, and antioxidant activities of Schiff base metal complexes, identify their interaction mechanisms with biomolecules, and propose strategies for improving their bioavailability and therapeutic efficacy through advanced delivery systems like nanoparticles

- Methodologies for synthesizing Schiff base metal complexes, including variations in reaction conditions and the influence of substituents on their coordination properties and stability

Different reaction conditions and substituents used to synthesize Schiff base metal complexes by condensation of primary amines and carbonyl compounds affect the coordination properties and stability of the complexes. Other reaction conditions like the solvent used in the process, temperature and pH can significantly affect the yield and purity of Schiff base ligands and the complexes formed with the metal ions. Refluxing reactions in methanol or ethanol increases Schiff base formation, and the addition of dehydrating agents such as magnesium sulfate can push the condensation to completion. The removal of water generated during the reaction with a Dean-Stark apparatus also helps improve the yields, particularly in syntheses performed in toluene or benzene. The resulting metal complexes are also dependent on the metal salts and molar ratios of the reactants used. Different substituents on these aromatic rings in amines or a carbonyl compound can be in different nature and position so that their electronic and steric properties could be very diverse, which could greatly alter the capacity of coordination of Schiff base ligands with metal ions. For this reason, providing an increase the electron density on the imine nitrogen by the presence of electron donating groups, such as methoxy or methyl groups, can enhance the nucleophilicity of imines and their coordination capability towards metal ions. On the other hand, the electron withdrawing groups such as nitro or halogen substituents are capable to decrease the density of the electrons, which can decrease the coordination force, while enhancing the ability of the ligand to stabilize the higher oxidation states of metals. The steric effects caused by bulky substituents could alter the geometry and stability of the metal complexes and therefore enable the formation of monomeric or dimeric species in a different metal-

coordination environment. It is therefore critical to understand these influences in the context of tailoring the properties of Schiff base metal complexes for various applications, including catalysis, where the electronic environment surrounding the metal center for instance can modulate catalytic activity and selectivity, or medicinal chemistry, in which the stability and solubility of the complexes are dynamically important determinants of biological efficacy. Characterization of these complexes is achieved using advanced spectroscopic techniques such as NMR, IR, UV-Vis, and X-ray crystallography, allowing for an in-depth understanding of the structural and electronic characteristics of the complexes. Incorporating computational methods, like density functional theory (DFT), aids in visualizing the electronic distribution and reactivity of these complexes. Through careful investigation of how reaction conditions and substituents influence the properties of Schiff bases, and the subsequent design of metal complexes thereof, researchers can obtain tailored properties that can address the needs of a diverse range of industrial and biomedical optimizations.

- Coordination geometry, bonding, and electronic structures of Schiff base metal complexes using advanced spectroscopic techniques (e.g., NMR, IR, UV-Vis, and XRD) and computational methods like density functional theory (DFT)

The coordination geometry, bonding, and electronic structures of Schiff base metal complexes are elucidated through advanced spectroscopic techniques and computational methods, providing comprehensive insights into their chemical behavior and potential applications. Nuclear Magnetic Resonance (NMR) spectroscopy offers detailed information on the local environments of hydrogen and carbon atoms within the ligand framework, enabling the determination of ligand conformation and its coordination to metal centers. Infrared (IR) spectroscopy identifies characteristic vibrational modes, such as the azomethine (C=N) stretch, which shifts upon metal coordination, indicating successful complex formation. Ultraviolet-Visible (UV-Vis) spectroscopy analyzes electronic transitions, including ligand-to-metal charge transfers and d-d transitions, providing insights into the electronic structure and confirming the geometry of the metal center. X-ray Diffraction

(XRD) techniques, particularly single-crystal XRD, determine the precise three-dimensional arrangement of atoms, revealing the coordination geometry, bond lengths, and angles within the complex. Computational methods, notably Density Functional Theory (DFT), complement experimental data by modeling the electronic structure, predicting reactivity patterns, and visualizing molecular orbitals, thereby enhancing the understanding of bonding interactions and stability. For example, in a study by Latif et al. (2021), Ni (II) and Zn (II) complexes with a Schiff base ligand were characterized using these spectroscopic techniques, and DFT calculations provided insights into their electronic properties and stability. Similarly, Tadarwal et al. (2024) synthesized a tetradentate Salen-type Schiff base ligand and its transition metal complexes, utilizing spectroscopic methods and DFT studies to elucidate their structures and electronic configurations. These combined methodologies facilitate a comprehensive understanding of Schiff base metal complexes, guiding the design of compounds with tailored properties for applications in catalysis, material science, and medicinal chemistry.

- Role of Schiff base metal complexes in catalytic transformations such as oxidation and polymerization reactions and to explore their potential in material science applications, including photoluminescence and molecular magnetism

Schiff base metal complexes play a pivotal role in catalytic transformations, notably in oxidation and polymerization reactions, and exhibit significant potential in material science applications, including photoluminescence and molecular magnetism. In oxidation reactions, these complexes act as efficient catalysts by facilitating electron transfer processes. For instance, copper (II) Schiff base complexes have been employed in the oxidation of alcohols to aldehydes and ketones, demonstrating high selectivity and turnover numbers. Similarly, manganese (III) Schiff base complexes have been utilized in the epoxidation of alkenes, showcasing their versatility in oxidative catalysis. In polymerization reactions, Schiff base metal complexes serve as catalysts for the polymerization of olefins and other monomers. Nickel (II) and palladium (II) Schiff base complexes have been reported to catalyze the polymerization of

ethylene and propylene, yielding polymers with controlled molecular weights and distributions. The steric and electronic properties of the Schiff base ligands can be tuned to influence the activity and selectivity of the polymerization process. Beyond catalysis, Schiff base metal complexes exhibit intriguing properties in material science. Their photoluminescent characteristics make them candidates for applications in light-emitting devices and sensors. For example, zinc (II) Schiff base complexes have been studied for their strong luminescence, which can be modulated by altering the ligand environment. Additionally, certain iron (III) and cobalt (II) Schiff base complexes display molecular magnetism, making them suitable for applications in magnetic storage devices and spintronics. The ability to design Schiff base ligands with specific electronic and steric attributes allows for the fine-tuning of the magnetic properties of these complexes. Advanced spectroscopic techniques, such as NMR, IR, UV-Vis, and X-ray crystallography, alongside computational methods like density functional theory (DFT), are employed to elucidate the coordination geometry, bonding, and electronic structures of these complexes, providing insights that guide their application in various fields. For instance, a study by Sönmez et al. (2018) synthesized and characterized pyrimidine-based Schiff base metal complexes, revealing their photoluminescent properties and potential applications in optoelectronic devices. Another study by Latif et al. (2021) investigated the catalytic activities of Schiff base metal complexes in oxidation reactions, highlighting their efficiency and selectivity. These findings underscore the versatility of Schiff base metal complexes and their significant contributions to both catalysis and material science.

- Antimicrobial, anticancer, and antioxidant activities of Schiff base metal complexes, identify their interaction mechanisms with biomolecules, and propose strategies for improving their bioavailability and therapeutic efficacy through advanced delivery systems like nanoparticles

Schiff base metal complexes have garnered significant attention for their antimicrobial, anticancer, and antioxidant activities due to their ability to interact with biomolecules and the potential to enhance therapeutic efficacy through advanced delivery

systems such as nanoparticles, where their antimicrobial properties are attributed to the disruption of microbial cell membranes and interference with enzymatic processes facilitated by the increased lipophilicity upon metal coordination, which improves cell penetration and activity against bacterial and fungal strains (Awolope et al., 2021; Singh & Barwa, 2021), while in anticancer applications, these complexes bind to DNA through intercalation or groove binding, disrupting replication processes and inducing apoptosis by generating reactive oxygen species (ROS), a mechanism particularly observed in copper (II) and nickel (II) complexes that target cancer cell proliferation effectively (Singh & Barwa, 2021), and their antioxidant activity stems from their ability to scavenge free radicals and protect biomolecules from oxidative stress, with electron-donating groups in the ligand structure enhancing this property by stabilizing radical intermediates, as demonstrated in manganese(III) and cobalt(II) Schiff base systems (Awolope et al., 2021), but challenges in bioavailability and systemic toxicity limit their clinical potential, necessitating the use of advanced delivery systems like nanoparticles, which improve solubility, protect complexes from premature degradation, and enable targeted delivery to diseased tissues, reducing side effects and increasing therapeutic indices (Theetharappan & Murugan, 2021), while polymeric nanoparticles and liposomal encapsulations have shown particular promise in improving cellular uptake and providing controlled release, as seen in studies where Schiff base complexes loaded onto nanoparticles exhibited enhanced antimicrobial and anticancer efficacy compared to free complexes, thus establishing that integrating advanced delivery strategies with Schiff base metal complexes not only maximizes their therapeutic potential but also minimizes limitations associated with traditional drug formulations, paving the way for their effective application in clinical medicine (Theetharappan & Murugan, 2021; Awolope et al., 2021).

VII. DISCUSSION RELATED TO THE STUDY

The discussion on Schiff base metal complexes emphasizes their synthesis through the condensation of primary amines with carbonyl compounds, their role as versatile ligands coordinating with transition metals such as copper, nickel, cobalt, zinc, and iron to

enhance biological and chemical properties, and their significant applications in catalysis, material science, and medicine, with catalytic applications including their use as effective catalysts in oxidation reactions like alcohol oxidation and alkene epoxidation, and polymerization reactions where nickel(II) and palladium(II) complexes are particularly prominent, while in material science, Schiff base metal complexes exhibit photoluminescent properties useful in light-emitting devices and sensors as well as molecular magnetism critical for developing magnetic materials, and in medicine, their antimicrobial, anticancer, and antioxidant activities are attributed to mechanisms such as disrupting microbial membranes, DNA intercalation, and ROS generation, supported by studies like those by Nandaniya et al. (2021) which detail their efficacy in antibacterial applications and research by Mane and Swamy (2018) that highlights their catalytic efficiencies, but despite these advancements, challenges persist in fully elucidating their interaction mechanisms with biomolecules and optimizing their pharmacokinetic properties for therapeutic applications, necessitating the integration of advanced characterization techniques like NMR, IR, UV-Vis, and X-ray crystallography with computational approaches such as density functional theory (DFT) to analyze coordination geometry, bonding, and electronic structures, as seen in Theetharappan and Murugan's (2021) work on water-soluble Schiff base complexes that bridge these gaps, and future research must address the limited exploration of Schiff base complexes with less common metals and expand their applications through innovative drug delivery systems like nanoparticles to enhance bioavailability and therapeutic efficacy, ultimately positioning Schiff base metal complexes as a pivotal area of research with significant potential in advancing catalytic, material, and medicinal sciences (Nandaniya et al., 2024; Mane & Swamy, 2018; Theetharappan & Murugan, 2021).

VIII. CHEMICAL IMPLICATIONS RELATED TO THE STUDY

The chemical implications of Schiff base metal complexes are profound, encompassing their synthesis, structural versatility, and diverse applications in catalysis, material science, and medicine. These complexes are typically synthesized

through the condensation of primary amines with carbonyl compounds, forming Schiff bases that act as ligands coordinating with various metal ions, including transition metals like copper, nickel, cobalt, zinc, and iron. The resulting metal complexes exhibit enhanced stability and reactivity, attributed to the formation of stable chelate rings and the delocalization of π -electrons across the ligand framework. In catalysis, Schiff base metal complexes serve as efficient catalysts in a variety of reactions. For instance, they have been employed in oxidation reactions, such as the oxidation of alcohols to aldehydes and ketones, and in polymerization reactions, including the polymerization of olefins. The catalytic activity is often increased by complexation, and the high thermal and moisture stability of these complexes makes them suitable for reactions at elevated temperatures. In material science, Schiff base metal complexes have been explored for their photoluminescent properties, making them candidates for applications in light-emitting devices and sensors. Additionally, certain complexes exhibit molecular magnetism, which is valuable in the development of magnetic materials and devices. In medicine, the biological activities of Schiff base metal complexes, including antimicrobial, anticancer, and antioxidant properties, have been extensively studied. The coordination of metal ions to Schiff base ligands often enhances these activities, making the complexes promising candidates for pharmaceutical applications. Advanced spectroscopic techniques, such as NMR, IR, UV-Vis, and X-ray crystallography, along with computational methods like density functional theory (DFT), have been instrumental in elucidating the coordination geometry, bonding, and electronic structures of these complexes. These analyses provide insights that guide the design and application of Schiff base metal complexes in various fields. Despite the progress, challenges remain in fully understanding the mechanisms underlying the biological activities of these complexes and in optimizing their properties for specific applications. Future research directions include exploring Schiff base complexes with less common metals, investigating their interactions at the molecular level using advanced spectroscopic and computational techniques, and assessing their therapeutic potential in vivo. In conclusion, Schiff base metal complexes represent a significant area of research in coordination chemistry, with wide-ranging

applications in catalysis, material science, and medicine. The ability to tailor the properties of these complexes through modifications of the ligand framework and choice of metal ion offers exciting opportunities for the development of new functional materials and therapeutic agents. Ongoing research continues to expand our understanding of these versatile compounds, paving the way for innovative applications and technologies.

CONCLUSION

Schiff base metal complexes represent a crucial area of research in coordination chemistry due to their ability to form stable and versatile complexes with transition metals, which significantly enhance their chemical, biological, and physical properties, enabling diverse applications across catalysis, material science, and medicine, with their catalytic roles exemplified in oxidation and polymerization reactions where metal centers like copper, nickel, and manganese demonstrate exceptional activity and selectivity under tunable reaction conditions, while in material science, these complexes exhibit photoluminescent properties and molecular magnetism that are harnessed in light-emitting devices, sensors, and advanced magnetic materials, and in medicinal chemistry, Schiff base metal complexes show significant promise as antimicrobial, anticancer, and antioxidant agents, often acting through mechanisms such as ROS generation, DNA intercalation, and microbial membrane disruption, although challenges such as limited bioavailability, potential systemic toxicity, and the lack of fully elucidated structure-activity relationships restrict their immediate clinical translation, necessitating advancements in synthetic methods, spectroscopic and computational characterization, and the development of innovative delivery systems like nanoparticles or liposomal encapsulations to enhance their stability, efficacy, and targeted delivery, thereby addressing these limitations while expanding their utility in therapeutic applications, and despite these challenges, the flexibility in ligand design and the ability to fine-tune electronic and steric properties ensure that Schiff base metal complexes remain a vibrant field of study, offering significant potential for the development of sustainable catalytic systems, cutting-edge materials, and next-generation pharmaceuticals, which

collectively underscore their importance in addressing critical scientific and industrial challenges and highlight the need for ongoing multidisciplinary research to unlock their full potential in contributing to technological innovation and societal advancement. Scope for further research and limitations of the study The scope for further research on Schiff base metal complexes is extensive, particularly in exploring their potential applications in catalysis, material science, and medicine, where the synthesis of novel Schiff base ligands incorporating diverse functional groups and their coordination with less commonly studied metals such as lanthanides and actinides could open new avenues for discovering unique catalytic activities, electronic properties, and biological interactions, while limitations of current studies include the incomplete understanding of structure-activity relationships that govern their reactivity and selectivity in catalytic and biological systems, as well as challenges related to the scalability of synthesis methods, the stability of the complexes under physiological and industrial conditions, and the lack of advanced delivery systems to enhance their bioavailability and minimize systemic toxicity in therapeutic applications, necessitating the integration of high-throughput computational modeling techniques like density functional theory (DFT) with experimental approaches to design optimized complexes with tailored properties, while another critical area of future research lies in the development of hybrid materials combining Schiff base metal complexes with nanomaterials to create multifunctional platforms for targeted drug delivery, environmental remediation, and energy storage, addressing gaps in the current understanding of their long-term stability, degradation pathways, and interactions with complex biological and environmental systems, thereby ensuring that the ongoing efforts to expand the utility and safety of Schiff base metal complexes not only maximize their scientific and industrial potential but also overcome existing limitations to achieve sustainable and impactful solutions to contemporary challenges across diverse fields.

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