Chapter-I

Introduction
1.1. Overview of coordination chemistry

Coordination chemistry has an old history originating in the discovery of [Co(NH$_3$)$_6$]Cl$_3$ by Tassaert in 1798 [1]. But it was Werner who systematized the subject by propounding his coordination theory in 1893 [2]. Werner’s basic ideas on the stereochemistry of metal complexes, mechanisms of isomerization and racemization, etc. remain unchallenged even today despite all the monumental developments which have taken places since his days and during the last five decades in particular, owing to the advent of sophisticated physico-chemical techniques of high precision and capability [3, 4]. These have considerably enriched our understanding of the nature of the metal-ligand bond, structure and stereochemistry of metal complexes, their stabilities, liabilities and other properties. Even metals which were earlier thought to be non-complex formers are now known to form quite stable complexes with special types of ligands, such as the alkali metal complexes formed by crown ethers and crepitates [5-8].

The growth of coordination chemistry has been three dimensional, encompassing breadth, depth and applications. The ongoing respect for the evolving science is apparent in the five Noble prizes that have been impinged heavily on the subject (A. Werner, 1913; M. Eigen, 1967; Wilkinson & Fischer, 1973; H. Taube, 1983; Cram, Lehn and Pedersen 1987). The first (Werner) and last (Cram, Lehn & Pedersen) in the list recognized the old and the new realms of coordination chemistry specifically [9].

In the real sense, coordination chemistry is an area that has many fields, like transition metal chemistry, organo-metallic chemistry, homogeneous catalysis, bioinorganic chemistry, medicinal chemistry etc. an equally important, it is a foundational to other growing fields for e.g. solid-state chemistry, extended mesoscopic materials, photonic materials, model for solid surfaces, separation science, molecular electronics, machines and devices. The enormous extensions of the field reflect its fundamental nature; the principles are so basic that they have immediate applications as some undreamt of new substances serendipitously appear in chemistry (e.g., dihydrogen complexes, metal derivatives of fullerenes, metal containing liquid crystals). The spawning of new fields is an inevitable consequence of the foundational position of coordination chemistry in the chemical sciences.
The chemistry of coordination compounds with heterocyclic ligands containing oxygen and nitrogen as donor atoms has attracted increasing attention in recent years. It is well known that such ligands coordinate to a metal atom in different ways in different media. Transition metal ions are essential in many biological systems in nature [10]. These metal complexes with bidentate and tetradaentate ligands containing both hard and soft donor groups have been used extensively in coordination and organometallic chemistry [11]. The chelating properties of Schiff bases display manifold applications in medicine, industry, and agriculture [12]. The transition metal complexes of Schiff bases have exhibited fungicidal and bactericidal activities including regulating the growth of plants [13]. It is known that chelation of metal ions with organic ligands acts synergistically to increase its effect [14]. The coordination chemistry of the square planar palladium(II) and platinum(II) complexes of nitrogen and sulfur/oxygen donor ligands have gained enormous importance because of their antitumour [15], anticancer [16] and catalytic activities [17]. Antimicrobial aspects [18] and antifertility activity [19] of coordination compounds of palladium (II) and platinum (II) have also been reported in recent years.

Coordination compounds exhibit different characteristic properties, which depend on the metal ion to which ligands are bound, the nature of the metal, as well as the type of ligand. These metal complexes have found extensive applications in various fields such as biology, medicine etc. The nature of a coordination compound depends on the metal ion and the donor atoms, as well as on the structure of the ligand and the metal–ligand interaction [20]. With increasing knowledge of the properties of functional groups, as well as the nature of donor atoms and the central metal ion, ligands with more selective chelating groups, i.e., imines or azomethines which are more commonly known as Schiff bases are used for complex formation studies. It is reported that the rapidly developing field of bioinorganic chemistry is centered on the presence of coordination compounds in living systems [21].

The chelation plays a very important role in the treatment of cancer is a significant development of 1960s [22]. A triplatinum complex was shown (Fig. 1.1) to be cytotoxic at nanomolar levels for various concentrations allowing for the potential doses at much lower concentration than cisplatin. It has also a potential drug in treating gl
malignancies which have been else untreatable using cisplatin. This compound is licensed to Novus pharma and is currently undergoing phase II clinical trial for the treatment of various types of cancers [23].

![Fig. 1.1: Triplatinum anticancer compound](image)

One of the most important problems in coordination chemistry has been the nature and strength of metal-ligand bond. Normally the metal ion does not form bonds of equal strength with two different donor atoms. Similarly, a particular donor atom does not form bonds of the same strength with different metal ions [24].

1.2. Donor Atoms

Fundamentally any part of molecule that happens to be more basic than the C-H portions is potential electron donors. Amino acids, peptides, proteins, hormones, nucleoproteins, nucleic acids, carboxylic acids, carbohydrates, lipids, simple anions and even the solvent water contain some electron donor elements such as oxygen, nitrogen, sulphur, phosphorous, fluorine, chlorine, bromine and iodine. Also it has been reported that even carbon has been shown to form bonds to metal ion [25]. The selection of actual donor for the complexation is mainly based upon many factors that are conveniently discussed using the hard and soft acids and bases theory. Some of the commonly used donor atoms are given in the Fig. 1.2.
1.3. Introduction of Schiff bases

Fundamentally, inorganic chemistry is synonymous with “general” chemistry, but the development by the theory of coordination compounds by Alfred Werner during the beginning of the nineteenth century and subsequent developments in understanding the spectral, structure, magnetic and bonding properties of the metal complexes created a great deal of interest to the researcher in the field of coordination chemistry. Ligands with more selective chelating groups called imines and azomethines or best known as Schiff bases are being used for the complex formation studies. Schiff bases have general structural formula: RC=NR’ where, R and R’ are alkyl, aryl or heterocyclic moieties. The extensive investigation in the field of Schiff base has been reported by Bayer [26]. The methods of preparation of various Schiff base and their chemical and physical properties have been described by Layer, Dwyer and Mellor [27, 28]. It is primarily concern with the stereochemistry of the complexes as well as behavioral aspects of such complexes in solution, has also been reported [29].

Schiff base and their metal complexes have gained much interest to the researchers due to their delocalized π-orbital’s, flexible behavior, multifunctional ligating sites etc. Also they have great biological importance especially in the field of medicinal chemistry. Schiff base complexes have played an important role in the development of coordination chemistry since the late nineteenth century. Schiff base are widely used as ligands to coordinate with various metal ions as they have a good solubility, especially their complexes. These compounds contain several donor atoms and find potential application in water treatment, due to their ability to form transition metal complexes.
easily [30, 31]. These complex species are also involved in enzymatic reactions and are present in protein from the conjunctive tissues. They can also acts as selective membranes or corrosion preventing compounds [32, 33].

In recent years, nitrogen containing Schiff base ligands and their metal complexes played an important role in the development of coordination chemistry resulting in an enormous number of reports, ranging from pure synthetic work to physicochemical and biologically relevant studies of metal complexes [34-38] and found wide range of applications also. They have been used in a multitude of different field of sciences such as medicinal, biological and catalysis applications [39, 40]. In addition they have broad spectrum of biological activities such as antiviral, antifungal, antiparasitic, antibacterial, anti-inflammatory, antitumor, anti- HIV and anticancer activities [41, 42]. The literature survey clearly reveals that the study of this diverse ligand system is linked with many of the key advances made in the field of inorganic chemistry.

Schiff base ligands are a class of polyatomic systems containing one or more C=N bond, with at least one aryl group attached to either C or N. The ligands are generally accessible by easy methods and the synthesis of these ligands was first reported by Schiff [43]. The most common method of obtaining Schiff base is straight forward as indicated in the condensation reaction between a primary amine with aldehyde or ketone (1).

Other methods of synthesis of Schiff bases are widely reviewed by Dayagi and Degani [44]. Schiff bases can be characterized by IR, NMR, and UV-Vis and mass spectral methods. The C=N stretching frequencies of the ligands generally occur in the region 1680 and 1603 cm$^{-1}$ when H, alkyl or aromatic groups are bound to C and N atoms. The natures of different substituent on these atoms determine the position of the stretching frequencies in the above range. For e.g., aryl groups on C and N atoms cause a shift of the frequency towards the lower side of the range. A summary of typical IR frequencies for various Schiff base ligands are available in the literature [45]. NMR spectroscopy is very useful in understanding structural features of ligands in solution, in particular keto-enol tautomerism found in these ligands (2, 3).
Schiff bases are generally bidentate, tridentate, tetradentate or polydentate ligands capable of forming very stable complexes with transition metals. They can only act as coordinating ligands if they bear a functional group, usually the hydroxyl, sufficiently near the site of condensation in such a way that a five or six membered ring can be formed when reacting with a metal ion. Schiff bases derived from aromatic amines and aromatic aldehydes have a wide variety of applications in many fields, e.g., biological, inorganic and analytical chemistry [46, 47]. Schiff bases are used in optical and electrochemical sensors, as well as in various chromatographic methods to enable detection of enhanced selectivity and sensitivity [48-50]. Among the organic reagents actually used, Schiff bases possess excellent characteristics, structural similarities with natural biological substances, relatively simple preparation procedures and the synthetic flexibility that enables design of suitable structural properties [51, 52]. Schiff bases are also effective corrosion inhibitors and could be adsorbed on the surface of metals [53].

Schiff base transition metal complexes are one of the most adaptable and thoroughly studies systems [54, 55]. They are of both stereochemical and magnetochemical interest due to their preparative accessibility, diversity and structural variability [56]. Metal complexes play an essential role in agriculture, pharmaceutical and
industrial chemistry [57]. Heteronuclear Schiff base complexes have found applications as magnetic materials, catalysts and in the field of bio-engineering [58, 59].

Transition metal complexes have attracted attentions of inorganic, organo-metallic as well as bio-inorganic chemists because of their extensive applications in wide ranging areas from materials to biological sciences [60]. It is well known that N and S atoms play a key role in the coordination of metals at the active sites of numerous metallobiomolecules [61]. Schiff base metal complexes have been widely studied because they serve as models for biologically important species and find applications in biomimetic catalytic reactions. Chelating ligands containing N, S and O donor atoms show broad spectrum of biological activity and are of special interest because of the variety of ways in which they are bonded to metal ions. It is known that the existence of metal ions bonded to biologically active compounds may enhance their activities [62, 63].

Transition metal complexes have emerged as potential building blocks for nonlinear optical materials due to the various excited states present in these systems as well as due to their ability to tailor metal-organic-ligand interactions [64-66]. Inorganic complexes can be used in foot printing studies, as sequence specific DNA binding agents, as diagnostic agents in medicinal applications and for genomic research.

Transition metal complexes derived from Schiff bases have occupied a central role in the development of coordination chemistry. The azomethine group >C=N of the Schiff base forming a stable metal complexes by coordinating through nitrogen atom. Large number of Schiff bases has been investigated by many workers as chelating agents. Most of them are prepared by the condensation of salicylaldehyde with aromatic amines and aliphatic amines. Calvin and Berkelow [67] have synthesized nearly twelve anils by condensing salicylaldehyde with substituted anilines and other aromatic amines.

Azomethines and their complexing capabilities have been enlightened in many review articles [68-71]. Hydrazones are the special group of compounds of Schiff bases. They are characterized by the presence of >C=N-N< group. The presence of two inter-linked nitrogen atoms separates from imines, oximes, etc. Many hydrazones and their metal complexes have biological and pharmaceutical activities such as anticancer, antitumor and antioxidative activities as well as inhibition of lipid peroxidation etc. [72-74]. Many drugs may possess modified toxicological and pharmacological properties
when administered in the form of complexes. The most widely studied metal in this respect is Copper (II), which proved to be beneficial in diseases such as tuberculosis, gastric ulcers and rheumatoid arthritis [75, 76].

The basic strength of C=N group is not sufficient to obtain stable complexes by coordination of the imino nitrogen atom to the metal ion. Hence, the presence of at least one other group is required to stabilize metal-nitrogen bond [77]. This is evident from the literature review that synthesis of different types of potential Schiff bases on the basis of their donor atoms set has been attempted. Based on the donating sites, further Schiff bases are classified as monodentate, bidentate, tridentate, tetradeutate and polydentate ligands containing O, N and S donor atoms. Such type of donor site ligands have been tried for their complexation and the structures were deduced with the aid of analytical, physico-chemical and spectral data.

In this introductory section of the thesis, a brief review of Schiff base ligands is presented using illustrative examples from some of the above mentioned classes of ligands.

1.4. Introduction to metal complexes

Transition metal complexes play an important role in agriculture, pharmaceutical and industrial chemistry [78]. Hetero nuclear Schiff bases and their metal complexes have found various applications as magnetic materials, catalysts and also in field of bioengineering chemistry [79, 80]. Transition metal complexes have attracted a great deal of attention in the field of inorganic, organometallic, as well as bioinorganic chemists because of their wide ranging applications in area from materials to biological sciences [81]. It is well known that O, N and S atoms play a key role in the coordination of metals at the active sites of numerous metallobiomolecules [82].

Transition metal complexes can be used in foot printing studies, as sequence specific DNA binding agents, as diagnostic agents in medicinal application and for genomic research. Transition metal complexes derived from Schiff bases have occupied a central role in the development of coordination chemistry. Research has shown significant progress in utilization of transition metal complexes as drugs for the treatment of several diseases [84]. Advance in inorganic chemistry provides good opportunities to
use metal complexes as therapeutic agents. The mode of action of metal complexes on living organism is differing from non-metals [85, 86].

1.5. Coordination behavior of Schiff base ligands

The azomethines and their complexation ability have been reported in many review articles [87-90]. In the introductory part of the thesis, a brief review of different types of potential Schiff base ligands on the basis of their donor atom set has been attempted. These ligands may be further grouped as ON, ONS, N$_2$O$_2$, N$_4$ sets etc. depending up on type of donor atom available for binding to metal centre.

Monodentate Schiff bases

It has been claimed that the basic strength of C=N group is not sufficient to obtain stable complexes by coordination of the azomethine nitrogen atom to a metal ion [91]. Hence the presence of at least one other group is required to stabilize metal-nitrogen bond. Aryl groups attached to either O or N generally stabilize the ligands by resonance. For e.g. monoamine Schiff bases such as $N$-(o-hydroxybenzaldehyde)aniline BAAN derivatives (4) are well known in the literature [92].

![Chemical structure of BAAN derivatives](image)

The ligand variously substituted in the phenyl rings, has been the most extensively studied by NMR and X-ray analysis. $^1$H and $^{13}$C NMR spectra of some BAAN derivatives have been reported. The azomethine proton was observed in the region 8.41-8.5ppm. These ligands exhibit solution spectral properties different from their corresponding isoelectronic trans-azobenzene and trans-stilbene. These differences are attributed to the non-planar structure of $N$-(o-hydroxybenzaldehyde)aniline BAAN derivatives in solution. Since the spectral properties are sensitive function of the molecular conformation, systematic studies on the solid state structure have been carried out. Furthermore, since the original work of Burgi and Dunitz [93], many workers have thought of utilizing the BAAN derivatives in crystal engineering because of their
thermochromism and photochromism properties. The geometrical parameters defining the overall conformation of these Schiff bases and the geometry of C=N moiety have been described in the literature.

On the other hand, it has been reported recently [94] that the Schiff base (5 and 5a) being monodentate in nature, is able to act as a ligand in the Pd complex, because of the suggested interaction Pd--H, which may stabilize the coordination of the ligand to the metal.

Bidendate Schiff bases

Bidentate Schiff bases have been amongst the widely used ligands in preparing metal complexes. A brief review of potential bidentate ligands according to their donor atom set is described in the following subsections.

N, N donor atom set

Schiff bases having two nitrogen atoms donors may be derived either from the condensation of dialdehydes or diketones with two molecules of an amine or from reaction of diamines with aldehydes or ketones. The typical example may be bis(benzylidene)-1,2-diphenylethylenediamine (6). The structure and coordination behaviour of these ligands have been extensively studied [95].
Another ligand is derived from 2-pyrrolecarboxaldehyde and ammonia acts as a monoanionic ligands and forms a complex (7) with copper(II) ion. Recently, a series of condensation products of the ketoximes (8) with amines have been prepared and the species formed were investigated by X-ray, NMR and IR studies [96].

N, O donor atom set

A large group of bidentate Schiff bases having N, O donor atom set have been utilized as ligands for metals, since oxygen is often present as an OH group. These ligands generally act as chelating monoanions. But, it must be pointed out that Sacconi et al., [97] have shown that the hydroxyl oxygen atoms under certain circumstances may bridge two metal atoms. In this case the Schiff bases should be considered as tridentate ligands which favour the formation of binuclear complexes.

Ekk Sinn [98] has reported some Cu-complexes of $N$-(ethyl-2-hydroxybenzylidenimine) (9) in which the hydroxyl oxygen is coordinated to two copper atoms, the ligand as a whole behaved in a tridentate fashion bonding through imine nitrogen and phenoxide bridging.
The copper(II) complexes of such ligands have shown dimeric structures and these complexes have shown some antiferromagnetic exchange behaviour between the two paramagnetic centres [97, 98].

On the other hand, there are few examples of coordinated neutral N, O bidentate Schiff bases derived from β-diketones and 2-hydroxy aldehydes. The most studied bidentate Schiff bases containing N, O donor set are those derived from substituted salicylaldehyde derivatives and amines (10). Large variety of transition metal complexes of these ligands are known in the literature [99, 100].

Kandil et al., [101] have reported a new bidentate Schiff base ligand containing heterocyclic moiety, 3-(2-furylidene)hydrazino-5,6-diphenyl-1,2,4-triazine (11) and its copper(II) and cobalt(II) complexes. The ligand behaved in a bidentate fashion coordinating through azomethine nitrogen and triazine nitrogen.

Alaaddin et al., [102] have synthesized two new Schiff base ligands containing cyclobutane and thiazole rings. 4-(1-methyl-1-mesitylcyclobutane-3-yl)-2-(2,4-dihydroxy benzilidenehydrazino)thiazole (12) and 4-(1-methyl-1-mesitylcyclobutane-3-yl)-2-(2-hydroxy-3-methoxybenzilidenehydrazone)thiazole (13) and their mononuclear complexes of cobalt(II), copper(II), nickel(II) and zinc(II). The complexes were characterized by microanalysis, IR, UV-visible, NMR and magnetic susceptibility measurements.
Aurora et al., [103] have synthesized N-(2-furanylmethylene)-3-aminodibenzofuran (14) and their Co(II), Ni(II), Cu(II), Zn(II), Cd(II) and Hg(II) complexes.

Spinu et al., [104] have synthesized N-(2-thienyldimethylene)-2-aminopyridine (15) and their Fe(II), Co(II), Ni(II), Cu(II), Zn(II) and Cd(II) complexes. The complexes have been characterized by elemental analysis, IR, 1H NMR, electronic spectra and magnetic susceptibility measurements. These results suggest a distorted octahedral geometry for the Fe(II), Co(II), Ni(II) and Cu(II) complexes and a tetrahedral geometry for the Zn(II) and Cd(II) complexes.

The Co(II), Mn(II) and Zn(II) complexes of bidentate Schiff base (16) derived from aniline and salicylaldehyde have been reported by Rehman [105] and others. These complexes have been characterized by elemental analysis and spectral techniques. The results obtained showed that the complexes have octahedral geometry Cu(II) complexes of bidentate Schiff base 4-methoxy-2-(1H-benzimidazol-2-yl)-phenol and its methyl/chloro/nitro derivatives (17) have been reported by Tavman et al., [106].
Synthesis, physico-chemical investigations and biological studies on Mn(II), Co(II), Ni(II), Cu(II) and Zn(II) complexes with p-amino acetophenone isonicotinoyl hydrazone have been reported by Singh et al., [107]. The results obtained by spectral and other physico-chemical techniques showed that the complexes have octahedral geometry (18).

Recently, Mruthyunjayaswamy et al., [108] have synthesized 3-chloro-N’-(3-methoxybenzylidene)benzo[b]thiophene-2-carbohydrazide (19) and their Cu(II), Co(II), Ni(II), Zn(II), Cd(II) and Hg(II) complexes. The complexes have been characterized by elemental analysis, IR, 1H NMR, electronic spectra and magnetic susceptibility measurements. These results suggest all the complexes were octahedral geometry with slight distortion in Cu(II) complex.
Tridentate Schiff bases

There are large number of tridentate Schiff bases containing N₂O, N₂S, NO₂ and NSO donor sets [109]. These may be generally considered as derived from the bidentate analogues by the addition of another donor group. It must be pointed out that the oxygen donor atom of such ligands may often act as bridging between two metal centres giving polynuclear complexes. Some typical tridentate ligands. (20, 21) are given below.

The tridentate Schiff bases containing two active centres and a donor centre form complexes with transition metals which are generally dimeric in nature. Copper(II) and oxovanadium(IV) complexes with such ligands are some examples reported in the literature [110]. The structures of such complexes have been proposed on the basis of spectrochemical and magnetic susceptibility measurement studies. The octahedral complexes with such type of tridentate ligands have been reported in the literature [110]. The neutral tridentate ligands are shown to form octahedral complexes with transition metals where two ligands encompass the metal ion in an octahedral array [111, 112].

Naik et al., [113] have reported the synthesis, spectroscopic and thermal studies of Co(II), Ni(II) and Cu(II) complexes of the hydrazone (22) derived from 2-benzimidazolyl mercaptoaceto hydrazide and o-hydroxy aromatic aldehydes.
Revankar et al., [114] have synthesized a series of Co(II), Ni(II), Cu(II) and Zn(II) complexes of quinoline-thiosemicarbazone Schiff base (23) with ONS donor atoms. The ligand and complexes were characterized by elemental analysis and various spectral studies. Based on these studies, all the complexes have been assigned octahedral geometry except the Cu(II) complexes which possess square pyramidal structure. Further, the Schiff base has exhibited good antimicrobial activity and the complexes have shown higher activity than the ligand.

Mruthyunjayaswamy et al., [115] have synthesized Co(II), Ni(II) and Cu(II) complexes Schiff bases derived from 3-Phenyl-5-substituted indole-2-carboxyhydrazones of salicylaldehyde (24).

The ligands and complexes were characterized by elemental analysis and various spectroscopic techniques. The results revealed that all the complexes possess octahedral geometry. The ligands and complexes were also screened for antimicrobial activity against *Staphylococcus aureus*, *Escherichia coli* and *Aspergillus niger*.

Singh et al., [116] have synthesized 2-furoylhydrazones of 2-acetylpyridine (25) and their Cu(II), Ni(II), Co(II), Zn(II), Mn(II) and VO(IV) complexes, later they have also synthesized Fe(II) complexes with the above said ligands [117].

Mruthyunjayaswamy et al., [118] have synthesized three new Schiff base ligands 3- (4’-phenylthiazole-2’-yl)-1-(2’-hydroxy-1-iminomethylphenyl)urea and 3-(4’-phenylthiazole-2’-yl)-1-(2’,4’-dihydroxy/2’-hydroxy-5’-chloro-1’-methyliminomethylphenyl)ureas (26, 27(a, b)) and their Cu(II), Co(II) and Ni(II) complexes. The complexes have
been characterized by elemental analysis, conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies. The studies reveal that the ligand has coordinated as tridentate chelating agent bonding through o-hydroxy group, amide carbonyl function and azomethine nitrogen. All the complexes have octahedral stereochemistry.

Recently, Vivekanad and Mruthyunjayaswamy [119, 120] have synthesized Schiff bases 5-chloro-3-phenyl-N1-((2-thioxo-1,2,dihydroquinoline-3-yl)methylene)-1H-indole-2-carbohydrazide (28) and 3-chloro-6-methoxy-N’-((2-thioxo-1, 2-dihydro quinolin-3-yl) methylene)benzo[b]thiophene-2-carboxyhydrazide (29) and their metal complexes. These complexes were characterized by elemental analysis, conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies.

Mruthyunjayaswamy et al., [121] have synthesized the Schiff base 5-chloro-N-[(2’-dihydro-2’-oxoquinolin-3’-ylmethylene)-3-phenyl-1H-indole-2-carbohydrazide (30) and its Cu(II), Co(II), Ni(II), Zn(II), Cd(II) and Hg(II) complexes. The ligand and complexes were characterized by elemental analysis, conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies. The results revealed that Schiff base acts as tridentate (ONO) chelating agent coordinate with metal ions through the oxygen atom of carbonyl group of amide function attached to 2-position of indole,
azomethine nitrogen and oxygen atom of the enolized amide function of quininone moiety via deprotonation. Analytical, spectral and magnetic studies revealed mononuclear nature of the complexes. The Cu(II), Co(II) and Ni(II) complexes exhibited octahedral geometry whereas Zn(II), Cd(II) and Hg(II) complexes exhibited tetrahedral geometry. The synthesized ligand and its complexes were screened for antimicrobial, antioxidant and DNA cleavage activity.

Recently, Nagesh Gunvantrao Yernale and Mruthyunjayswamy Bennikallu Hire Mathada, have synthesized [122] the Schiff base 2-((2-hydroxynaphthalen-1-yl)methylene)-N-(4-phenylthiazol-2-yl)hydrazinecarboxamide (31) and its Cu(II), Co(II), Ni(II), Cd(II) and Zn(II) complexes. The ligand and complexes were characterized by elemental analysis, conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies. Analytical, spectral and magnetic studies revealed mononuclear nature of the complexes. The Cu(II), Co(II), Ni(II), Zn(II) and Cd(II) complexes exhibited tetrahedral geometry. The synthesized ligand and its complexes were screened for antimicrobial, antioxidant, DNA cleavage activity and In vitro cytotoxicity.

Recently, Nagesh, Mahendra Raj, Mruthyunjayswamy,[123] have synthesized (32) new Schiff base ligand N-(4-phenylthiazol-2yl)-2-((2-thiaxo-1,2-dihydroquinolin-3yl)methylene)-hydrazinecarboxamid and its Cu(II), Co(II), Ni(II), Cd(II) and Zn(II) complexes. The ligand and complexes were characterized by elemental analysis,
conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies. Analytical, spectral and magnetic studies revealed mononuclear nature of the complexes. The Cu(II), Co(II), Ni(II) complexes exhibited octahedral geometry and Zn(II) complexes exhibited tetrahedral geometry. The synthesized ligand and its complexes were screened for antimicrobial, antioxidant, DNA cleavage activity and \textit{In vitro} cytotoxicity.

Recently, Nagesh, Mruthyunjayaswamy have synthesized new Schiff base ligand [124]. (2-(4-(dimethylamino)benzylidene)-N-(4-phenylthiazol-2-yl)hydrazinecarboxamide (33) and its Cu(II), Co(II), Ni(II), Cd(II) and Zn(II) complexes. The ligand and complexes were characterized by elemental analysis, conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies. Analytical, spectral and magnetic studies revealed mononuclear nature of the complexes. The Cu(II), Co(II), Ni(II) complexes exhibited octahedral geometry and Zn(II) complexes exhibited tetrahedral geometry. The synthesized ligand and its complexes were screened for antimicrobial, antioxidant, DNA cleavage activity and \textit{In vitro} cytotoxicity.

Nagesh, Mahadev and Mruthyunjayaswamy (34) have synthesized new Schiff base ligand [125] 2-(2-hydroxy-3-methoxybenzylidene)-N-(4-phenylthiazol-2-yl)-hydrazinecarboxamide and their metal complexes. These complexes were characterized
by elemental analysis, conductance measurements, magnetic susceptibility, electronic spectra, IR and TGA studies. The Cu(II), Ni(II) and Zn(II) complexes exhibited octahedral geometry and Co(II) complexes exhibited tetrahedral geometry. The synthesized ligand and its complexes were screened for antimicrobial, antioxidant and DNA cleavage activity.

Tetradentate Schiff bases

Tetradentate Schiff bases with $N_2O_2$ donor set have been widely studied for their ability to coordinate with metal ions. The properties of complexes obtained by these ligands are determined by electronic nature of the ligands as well as by their conformational behavior [126].

Dubsky and Sokol [127] have reported the reactions of salicylaldehyde with diamines. These display tetradentate behavior by forming square-planar complexes (35) with Ni(II) and Cu(II).

Zacharias et al., [128] have reported the reactions of salicylaldehyde with o-phenylenediamine and studied the behavior of the resultant Schiff base in complexation with Co(II), Ni(II) and Cu(II) metal ions. These display tetradentate behavior by forming metal complexes (36) containing two six membered and one five membered ring.
Henri et al., [129] have synthesized a tetradentate ligand (37) by reacting 2, 3-diaminopyridine with o-vanillin and its Cu(II), Ni(II), Ru(II), Zn(II), and Fe(III) complexes.

![Image of ligand 37]

Some neutral tetradeinate N$_2$O$_2$ type complexes of Co(II) have been reported by Naeimi et al., [130]. The complexes have been synthesized using Schiff bases formed by condensation of 5-nitro-salicylaldehyde with various diamines in alcohol. The results obtained by spectral and other physico-chemical techniques showed that the complexes have square-planar geometry (38).

![Image of complex 38]

Where $R = (\text{CH}_2)_3 (\text{CH}_2)_4, (\text{CH}_2)_6$

**Binuclear transition metal complexes**

Synthesis of binuclear complexes in which a ligand structure maintains two metal centers in close proximity but in different compartments separated by an intervening group represents an important current objective in coordination chemistry. These complexes serve as simple models for multi-metal-centered catalysts and multielectron-transfer reagents [131-134]. The orientation of the metal centers, and hence the nature of the metal–metal interactions, are controlled via appropriate bridging ligands [135, 136].

Binuclear copper(II) complexes are of interest as models for investigating intramolecular magnetic-exchange interactions between two metal centers in different structural moieties viz. the “paddle-wheel” di-copper(II) tetracarboxylates, symmetrically
dibridged hydroxo or alkoxo species, and asymmetrically di-bridged complexes with a (I-hydroxo/alkoxo)(l-carb-oxylato)dicopper(II) core [137-146]. Dicopper(II) complexes are also important as precursors in the chemistry of supramolecular and discrete molecular high-nuclearity copper(II) complexes [147-156].

Abou-Hussein [157] have synthesized the Schiff base (39) by the condensation of bicarboxyl compound 4, 6-diacetylresorcinol with 2-aminobenzenthiol in the 1:2 molar ratio and their binuclear Cu(II), Co(II), Ni(II), Zn(II) and Ru(III) complexes. The results obtained by spectral and other physico-chemical techniques showed that ligand acts as tetrabasic hexadentae ligand, bonding sites are azomethine nitrogen atoms, sulfur atoms and phenolic oxygen atoms.

![Schiff base ligand (39)](image_url)

### 1.6. PRESENT WORK

The major objectives of the present work are:

1. To develop the methodology for the synthesis of the novel Schiff base ligands containing O, N and S donor atoms derived from indole, thiazole, and quinoline moieties, which have been utilized in the present work.

2. To synthesize the biologically active Cu (II), Co (II), Ni (II) and Zn (II) complexes derived from the above Schiff base ligands.

3. To elucidate the structures of the newly synthesized Schiff base ligands and their metal (II) complexes by various physico-chemical and spectroscopic techniques. \textit{viz.} FT-IR, $^1$H NMR, ESI-mass, UV-Vis., TGA/DTA, ESR and powder X-ray diffraction etc.

4. The important applications of Schiff base ligands and their metal (II) complexes in medicinal inorganic chemistry. All the newly synthesized Schiff base ligands and their metal (II) complexes in the present study have been evaluated for their antimicrobial, antioxidant and DNA cleavage activities.
All the above objectives will be presented in detail in the subsequent eight chapters (chapter I - VIII) and each chapter beings with an introduction followed by discussion of obtained results.

CHAPTER- I: This chapter deals with the overview of coordination chemistry, general discussion Schiff base ligands, transition metal complexes, coordination behavior of Schiff base ligands and their metal (II) complexes.

CHAPTER-II: This chapter describes different physico-chemical and spectroscopic techniques used for the structural elucidation of Schiff base ligands (L₁-L₇) and their metal (II) complexes. Synthetic procedures used for the synthesis of various Schiff base ligands (L₁-L₇) and their metal complexes are explained. Detailed experimental protocol used to carry out the biological activities such as antimicrobial. Anti oxidant and DNA cleavage has been discussed in this chapter.

CHAPTER-III:

PART-A: This chapter deals with the preparation of novel Schiff base ligand, 5-chloro-N\'-(2-hydroxy-3-methoxybenzylidene)-3-phenyl-1H-indole-2-carbohydrazide (L₁) and its Cu(II), Co(II), Ni(II) and Zn(II) complexes. The structures of the compounds are elucidated by different spectroscopic techniques and obtained results are discussed. The antimicrobial, DNA cleavage, and antioxidant activity of the metal complexes was also carried out and obtained results discussed.

PART- B: This chapter deals the preparation of novel Schiff base ligand, N\'-(2-hydroxyl-3-methoxybenzylidene)-5-methyl-3-phenyl-1H-indole-2-carbohydrazide (L₂) and its Cu(II), Co(II), Ni(II) and Zn(II) complexes. The spectral characterization of Schiff base ligand (L₂) and its metal complexes by various spectral techniques like FT-IR, ¹H NMR, ESI mass and UV-visible, ESR, TGA/DTA and powder X-ray diffraction studies have been discussed. Also, antibacterial, antifungal, antioxidant activity and DNA cleavage activities were carried out and outcome of these are discussed.
CHAPTER-IV: This chapter deals with the preparation of novel Schiff base ligand, \(N^1\)-(benzo[1,3]dioxol-5-ylmethylene)-5-methyl-3-phenyl-1\(H\)-indole-2-carbohydrazide (\(L_3\)) and its Cu(II), Co(II), Ni(II) and Zn(II) complexes. The detailed spectral characterization techniques used for confirmation of the structure of Schiff base ligand (\(L_3\)) and its metal (II) complexes have been discussed. Also their antibacterial and antifungal activities (MIC method), DNA cleavage activity (AGE method), and in vitro antioxidant activity results are discussed.

CHAPTER-V: This chapter deals with the synthesis of Schiff base ligand, \(2-(2\)-hydroxy-4-(phenyldiazenyl)benzylidene)-N-(4-phenylthiazol-2-yl)hydrazinecarboxamide (\(L_4\)) and its Cu(II), Co(II), Ni(II) and Zn(II) complexes. The detailed spectral characterization techniques used for confirmation of the structure Schiff base ligand (\(L_4\)) and its metal (II) complexes have been discussed. Also, antibacterial and antifungal activities (MIC method), DNA cleavage activity and in vitro antioxidant activity results are discussed.

CHAPTER-VI: This chapter deals with the synthesis of novel Schiff base ligand, \(2-(4\)-(diethylamino)benzylidene)-N-(4-phenylthiazol-2-yl)hydrazinecarboxamide (\(L_5\)) and its Cu(II), Co(II), Ni(II) and Zn(II) complexes. The characterization of newly, synthesized compounds by elemental analysis and various physico-chemical techniques like FT-IR, \(^1H\) NMR, ESI mass, UV-visible, ESR, TGA/DTA and powder X-ray diffraction studies have been discussed. Also, antibacterial, antifungal, and DNA cleavage activities were carried out and outcome of the results are discussed.

CHAPTER-VII: This chapter deals with the synthesis of novel Schiff base ligand, \(5\)-chloro-N'-(2-hydroxy-4-(phenyldiazenyl)benzylidene)-3-phenyl-1\(H\)-indole-2-carbohydrazide (\(L_6\)) and its Cu(II), Co(II), Ni(II) and Zn(II) complexes. The characterization of newly, synthesized compounds by elemental analysis and various physico-chemical techniques like FT-IR, \(^1H\) NMR, ESI mass, UV-visible, ESR, TGA/DTA and powder X-ray
diffraction studies have been discussed. Also, antibacterial, antifungal, and DNA cleavage activities were carried out and outcome of the results are discussed.

CHAPTER-VIII: This chapter explains the synthesis and characterization of biologically active Cu(II), Co(II), Ni(II) and Zn(II) complexes of ONS donor Schiff base ligand, 5-methyl-N'-((6-methyl-2-thioxo-1,2-dihydroquinolin-3-yl)methylene)-3-phenyl-1H-indole-2-carbohydrazide (L_7) The spectral characterization of Schiff base ligand (L_7) and its metal complexes by various spectral techniques like FT-IR, ^1H NMR, ESI mass, UV-visible, ESR, TGA/DTA and powder X-ray diffraction studies have been discussed. Also, antibacterial, antifungal, and DNA cleavage activities were carried out and the results are discussed.

At the end of the thesis overall summary of the research work with general conclusions on the bonding nature of the Schiff base ligands and their metal (II) complexes has been given. This part also includes a brief account of the possible routes and scope for further work in this field.
References:


