Synthesis and characterization of 1:4 Cobalt(II) complexes with Pyrazine based ligands

By

Candidate

Gokilavani.C

REG NO: 16PCH006

A Dissertation submitted to

Avinashilingam Institute for Home science and

Higher Education for Women

Coimbatore-641 043, Tamil Nadu, India

In Partial Fulfillment of the Requirement for the Degree of

Master of Science in Chemistry

APRIL 2018

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Signature of the

Supervisor

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Signature of the

Head of the Department

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Chapter I

Introduction

1.1. COORDINATION COMPLEXES

The development of transition metal complexes as drugs is not an easy task; considerable effort is required to get a compound of interest. Besides all these limitations and side effects, coordination compounds are still the most widely used chemotherapeutics in a way that was unimaginable a few years ago. The number of platinum complexes that show antitumor activity is still rapidly growing, because of attempts to and complexes with their greater therapeutic potency and lower toxicity than existing clinical drugs. As a consequence, the attention has turned to other platinum group metals, like ruthenium, osmium, iridium and rhodium. A special attention has been focused on ruthenium compounds because they exhibit cytotoxicity against cancer cells and no cross-resistance with cis-platin.(**Meng. X *et al.*, 2009**) Ruthenium complexes demonstrate similar ligand exchange kinetics to those of platinum(II) antitumor drugs already used in clinical treatment, while displaying only low toxicity.(**Brabec.V., 2006**) This is partially due to the ability of ruthenium complexes to mimic the binding of iron to molecules of biological significance, exploiting mechanisms the organism has evolved for iron transport.(**Bergamo.A *et al.*, 2007**)

Fig: 1.1.Pictorial representation of Metal complexes and its applications

Transition metal complexes of N-donor heterocyclic ligands are of interest due to their applications in biology, pharmacology, magnetism, and so forth (**Sastri.C.V *et al.*, 2003**). A large amount of structural data for coordination complexes of selected

transition metal ions with various ligand types has been accumulated, giving rise to an opportunity to look into their structural varieties in a systematic manner. Emphasis has been directed to the structural patterns, redox properties, and reactivity aspects. Importance and relevance of coordination chemistry of pyridine carboxamide ligands in the context of bioinorganic chemistry.

1.2. ROLE OF COBALT

Natural Co is composed of one stable isotope, ^{59}Co. This element is found in minerals, such as erythrite [$Co_3(AsO4)_2 \cdot (8H_2O)$], glaucodot [(Co0.50Fe0.50)AsS] and skutterudite ($CoAs_3 - x$), as well as substituting into pyrite (FeS_2). It is mainly produced as a by-product of Cu or Ni smelting (**Shedd, 2013**). Its association with Cr and Ni could be considered a marker of the presence of mafic rocks, where it is generally enriched (**Albrecht, 1999**) reports an average Co abundance of 150 and 48 mg/kg in ultramafic rocks and basalt, respectively. A more recent estimate for continental basalt by **(Farmer, 2014),** Co varies from 29.9 to 197 mg/kg. After weathering, Co is most mobile in the surface environment under acidic and reducing conditions; it co-precipitates under oxidising, near neutral or alkaline conditions as Fe and Mn secondary oxides (**Taylor,1968**). Humic and fulvic acids and inorganic colloids could reduce Co mobility in soil while some bacteria are known to mobilise Co from metal chelates The main industrial application of Co is in alloys with Fe, Ni and other metals to produce both corrosion-resistant products (designed for high temperature applications) and high abrasion-resistant steels. Because of its unique blue colour, Co oxide is used worldwide as an additive in paint, glass and ceramics. Other anthropic sources of Co in the environment include coal combustion, fertilisers, Pb, Fe and Ag mining and processing.

Cobalt is sourced from the diet, particularly green vegetables and cereals and is also a common supplement in vitamins. Approximately 1mg is present in the body. Transition metals such as iron, cobalt, copper, zinc and manganese plays an important role in biological processes whereas lead, cadmium, and mercury are toxic for many living system. Cobalt is an essential trace the fields of medicine, bio-inorganic chemistry, functional materials. Cobalt-containing blue pigments have been found in ancient artifacts. Cobalt exhibits two important oxidation states as +2 and +3 and salts ofCo(II) are more stable, as they are not easily oxidised to Co(III) state. However, in basic solutions, oxidation of Co^{2+} to Co^{3+} takes place relatively easily. It is usually

found that when both oxidation states of an element are subjected to complex formation, the overall formation constant is greater for the higher oxidation state and thus complexation makes it difficult to be reduced. Thus, Co(III) is stabilized by complexation and Co(II) forms relatively few complexes, which are not as stable as the corresponding complexes of Co(III). However, highspin six coordinate, high/low spin five coordinate and four coordinate complexes of Co(II) are widely reported. The different oxidation states of these complexes showed a strong role in bioinorganic chemistry and redox enzyme system. This may provide the basis of models for active sites of biological systems or act as catalysts.

Cobalt(II) forms complexes of both octahedral and tetrahedral geometries. They are labile and many of them with more π bonding ligands have strong tendency to be oxidized by molecular oxygen. Hence, cobalt(II) complexes must be prepared in an inert atmosphere. Cobalt(II) in some cobaloximes form 1:1 and 1:2 adducts with molecular oxygen and are diamagnetic in the solid state. Like vitamin-B_{12}, cobaloximes interact with oxygen to give a peroxo adduct as a charge-transfer complex, whose structure was evidenced by EPR analysis .Cobalt (II)-corrinoids are excellent catalysts for the auto oxidation of thiols to disulfides The vitamin-B_{12} dependent reactions involving reversible hemolytic fission of the cobalt- adenosyl bond in the coenzymes to give cobalt(II) and the adenosyl radical, has been a significant study in the red-ox properties of cobalt(II). At the same time, the cobalt compounds are often used in chemical reactions as oxidation catalysts, such as typical catalysts that are the cobalt carboxylates, which are also used in paints, varnishes, and pigments industry.

Divalent cobalt forms numerous complexes with various geometries. Octahedraland tetrahedral are most common.But,more number of square planner (**Jean.P.B *et al*.,1985**) complexes are also known. Cobalt(II) forms simple salts with all common anions. Octahedral high spin cobalt(II) complexes with three unpaired electrons (4.8 – 5.2 BM) are the most common. Low spin cobalt(II) complexes with one unpaired electron(2.1-2.9BM) are found only with strong donors such as CN – (or) multidentate ligands such as 1,2-bis(dimethylarsino)benzene **(diars**),2,2'-ethylenebis(nitrilomethylidene)diphenol,N,N'-Ethylenebis(salicylimine) (salen), etc. Tetrahedral high spin cobalt(II) complexes with three unpaired electrons (4.4-4.8 BM) on the other hand are nearly as common as corresponding octahedral complexes. The ligand field stabilization energies are much less for octahedral

cobalt(II) complexes than cobalt(III). For this reason cobalt(II) complexes undergo substitution more readily than the cobalt(III) complexes and so much wider variety in their geometrical and electronic configurations8. Many of the hydrated salts and their aqueous solutions contain the octahedral pink $[Co(H_2O)_6]^{2+}$ ion. The bidentate N-donor ligands such as ethylene diamine (en), bispyridine (bipy), 1,10-phenanthroline (phen) form octahedral cationic complexes of the type [Co(L-L)3]2+ , which are stable. The bidentate ligands form high spin cobalt(II) complexeswith magnetic moment about 5.0.BM.Many cobalt(II) complexes are readily oxidized by O_2 and gives conventional cobalt(III) complexes as ultimate product4.

1.3. BIOLOGICAL EFFECTS OF COBALT

Cobalt plays a number of crucial roles in many biological functions in the form of vitamin-B_{12}, which is necessary for DNA synthesis, formation of red blood cells, and maintenance of the nervous system, growth and development of children. Being involved in the regulation of some definite processes of the animal organisms, cobalt behaves like biological response modifier. While cobalt is an essential metal, it has systematic toxicity, including neurological, cardiovascular and endocrine impairment, attributed largely to free ionic Co(II), with blood concentrations of over 300 μg/L suggested to be of concern. The toxicity of cobalt has been attributed to its redox activity, leading to the generation of ROS, and to its ability to substitute iron in metalloenzymes to form substitutionally-inert complexes. For example, cobalt substitution for iron in prolyl 4-hydroxylase inhibits the normal activity of the enzyme in activating hypoxia-responsive transcription, thus causing hypoxia in mammalian cells. However, in contrast to toxic heavy metals to which cells have only been exposed since the industrial revolution, the body has evolved mechanisms to efflux excess cobalt from cells, including hijacking of iron export pathways. The study of cobalt coordination complexes for biological applications has flourished only more recently. Different cobalt containing compounds have been proved to have antineoplastic activity. It has recently been reported that cobalt(II) is a topoisomerase-2 poison. Some complexes of cobalt(II) with different ligands (cholic acids, Mannich bases, mixed ligands) reduced significantly viability and proliferation of cultured tumor cells and induced DNA damages in the treated cells. Based on this

various properties cobalt complexes have demonstrated therapeutic potential as reduction-activated complexes, or can be applied in imaging by MRI is fluorescence.

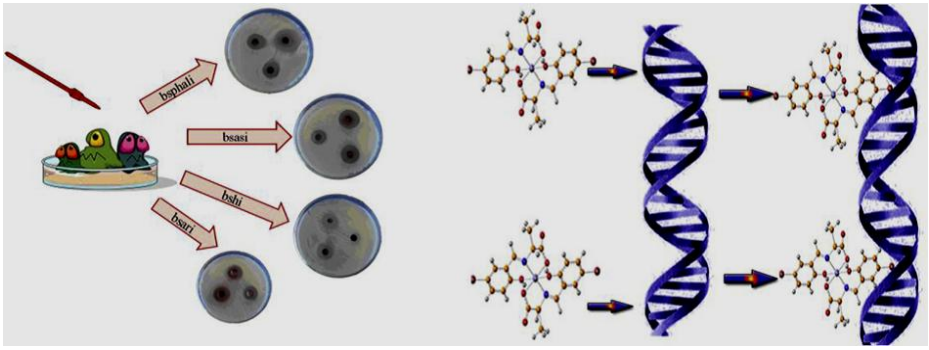


Fig: 1.2. Schematic diagram for antibacterial activity and DNA interaction of the investigated complexes.

1.4. IN MEDICINE

Beyond the treatment of pernicious anaemia arising from cobalamine deficiency, the use of cobalt in medicine began in 1940 with the first metallic hip replacement, employing a cobalt-chrome alloy, in a protocol still widely used today. 1951 saw the first Co-60 radiation therapy, which soon superseded X-ray radiation as the primary form of radiotherapy, and is still heavily used in developing countries. Co-60 a beta-emitter with a half-life of 5.3 years has also been used for brachytherapy, in which a sealed radiation sources is implanted close to the tumour, although it has been largely replaced by Ir-1923

1.5. HETEROCYCLIC COMPOUNDS AS LIGANDS

One of the reasons for widespread use of heterocyclic compound is that their structures can be manipulated to achieve required modification in function, i.e. by changing one hetero atom for another and the different positioning of thesame hetero atoms with in the ring leads to differences in acidity (or) basicity, different susceptibility to attack by electrophiles (or) neutrophils, and different polarity (**Thomas.L.G ,1997**). In nature, there are more heterocyclic rings asbio molecules such as vitamins, coenzymes, porphirins, DNA. The plant kingdom contains thousands of nitrogen heterocyclic compounds, most of which are weakly basic called alkaloids. Marine mammals and plants are also sources of complex heterocyclic

compounds and are receiving much attention in current research. All disaccharides and polysaccharides have rings that contain an oxygen atom.

Pyridine and its derivatives are known for their use in the design and synthesis of multifunctional compounds as well as their biological and pharmacological applications as anticoagulants, antihistamines, antiseptics, antiarrhythmics, and antirheumatics [**Forood.B, 2002 & Yenikaya.C 2009 & Kapinos.L.E 2002**]. Pyrazine ring is a part of polycyclic derivative and plays important biological and industrial roles. (**Kamal.M.R *et al*.,1962**)

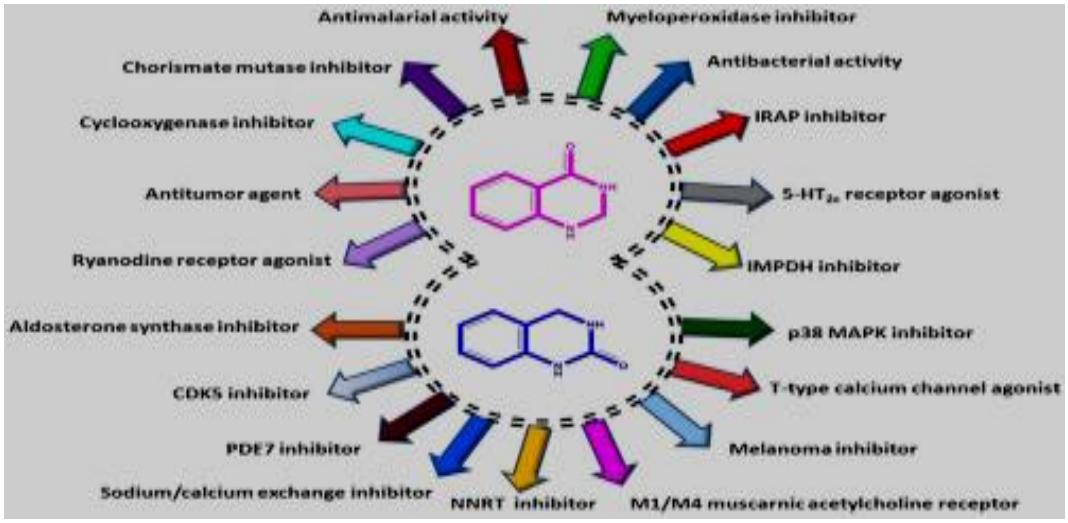


Fig: 1.3. Pictorial representation of Pyridine based ligand and its application

The pharmacological activities of the pyrazine derivatives vary and include substances with multidirectional actions. A low toxicity of these groups of compounds allows us to use them as a pharmacophore in designing new compounds to be used as drugs. The discovery of natural pyrazine derivatives, that showed the pharmacological effect, initiated the search for novel and more effective synthetic compounds exhibiting biological activities. There is a number of substances having antituberculotic (**Pancechowska-Ksepko.D *et al*., 1988**) and antibacterial activities, (**Gobis.K *et al*.., 2006**) antifungal and cytotoxic effects, (**Dolezal.M *et al*.,**) respectively, in the group of synthetic pyrazine derivatives. In addition, the compounds belonging to this group display antioxidant, (**Frederic.D 2010**) antiproliferative, (**Dubinina.G.G *et al*.,2006**) and antitumor activities. (**Shailaja.M *et al*.,2010**) The compounds containing S, N and N, O donor atoms are important owing to their significant antifungal, antibacterial and anticancer activities.(

Beckford.F *et al,* 2011) Cytotoxicity can be further improved by using ligands with O, N or N, N donor systems. A type of chelating ligands does not only have an influence on the biological properties but also bears impact on the stability of the formed complex.(**Pizarro.A.M *et al.,* 2010**&**Kandioller.W et al., 2009**) Furthermore, the ligand can modify the interaction with different biomolecules such as albumin, transferrin or various cellular proteins. It is well known that some drugs have increased their activities when administered as metal complexes rather than administered as free organic compounds. (**Agarwal.R.K 2004**) A large number of reports are available on the chemistry and biological activity of transition metal complexes containing O, N and S, N donor atoms, but reports on Ru(III)coordination compounds are limited. (**Chylewska.A 2014**)

In this project, I have focused mainly on the transition metal Cobalt and made an attempt to synthesize and study the antimicrobial properties of some pyrazine based cobalt complexes.

Chapter II

Scope of the work

Metal ions play many functions in humans. Hence, there is a significant progress to understand the coordination and biochemistry of various metal ions. The transition metals and tailor made ligands provide wide range of coordination numbers and geometries, accessible red-ox states, thermodynamic and kinetic characteristics and hence offer the real possibility of truly novel drugs with new mechanisms of action (**Raman.N *et al.*, 2010**). Many metal complexes are found to exhibit antibacterial activity (**Colak.A.T *et al.*, 2010**) and several metal complexes have been found to exhibit antifungal agents (**Venkateswar Rao.P *et al.*, 2011**).

Several hetero cycles and their derivatives have been studied for their medicinal values and as ligands for transition metals. The lignds containing N and S atoms play key role in the coordination of metals at the active sites of numerous metallo biomolecules**(Singh, K.,2007).** Chelating ligands containing N, S and O donor atoms show broad 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(**Canpolat, E.,2004 & Yildiz M *et al.*, 2004**)**.**

Most of the pyridine and pyrazine derivatives possess insecticidal, anti fertile and anti arrhythmic activities **(Heintzelman,G.R.., *et al.*,2002)**. The drugs like *streptonigrin*, *streptonigrone* and *lavendamycin*, having pyridine moiety, are reported as anti cancer drugs. Similarly, drugs such as *itavastatin* and *cerivastatin* act as HMG-CoA (3-Hydroxy-3-methyl glutaryl-coenzyme - A) inhibitors for serum cholesterol levelsand are widely prescribed in the treatment of *hypercholesterolemia***(Istvan,*et al.*,2001)**.

Bridging *N*-heterocyclic ligands are extensively used in coordination and metallosupramolecular chemistry [**Gavrilova.A.L,2002**]. The simplest such ligand is pyrazine which has two nitrogen donors that can be used to form simple binuclear complexes, such as the Creutz–Taube mixed-valence complex [**Demadis.K.D *et al.*, 2001**], or larger discrete assemblies, such as molecular squares [**Wurthner.F, *et al.*, 2004**], or even larger coordination polymers [**Janiak.C,2003 & Papaefstathiou.G.S *et al.*, 2003 & Kesanli.B *et al.*, 2003 & Kitagawa.S *et al.*, 2004**]. Such

metallosupramolecular assemblies have been the subject of much study in recent years [**Hofmeier.H *et al*., 2004, Steel.P.J., 2005 & Hosseini.M.W, 2005**].

There has been an explosion of growth in the coordination chemistry of pyridine/pyrazine ligands in both the non biological and biological areas. There is thus a scope and this research work is therefore attempts to highlight some notable results in the coordination chemistry of pyrazine ligands.

We report here the preparation of some cobalt(II) complexes containing Pyrazine derivatives of the type

$[Co(B)_4(H_2O)_2]X_2$

Where, **X^-** = Cl^- or Br^-

B = Pyrazine(Pz), Pyrazine Carboxylic acid(PzCA),

Methyl Pyrazine(MPz), Pyrazine Carbonitrile(PzCN), Pyrimidine(Pym)

Chapter III

Review of literature

- The author Nora H. Al- Shaalan **(2011)** explained the preparation of the schiff base hydrazone ligand by the condensation reaction of 7-chloro -4-quinoline with o-hydroxyacetophenone. It reacts with Cu(II), Ni(II), Co(II), Mn(II),Uo_2(VI), and Fe(II) to form either mono- or binuclear complexes. The Cu(II) complexes has a square planar geometry distorted towards tetrahedral, the Ni(II) complexe is octahedreral while the Uo_2 (VI) complex has its favoured heptacoordination. The Co(II), Mn(II), complexes and also other Ni(II) and Fe(III) complexes, which were obtained in the presence of Li(OH), as deprotonating agent, are binuclear and coordinated via the NNNO sites of two ligand molecules. All the binuclear complexes have octahedral geometries and their magnetic moments are quiet low compared to the calculated value for two metal ion complexes and thus antiferromagnetic interactions between the two agent metal ions. The ligand HL and metal complexes were tested against a strain of gram positive bacteria,(*staphylococcus aureus*), gram negative bacteria (*Escherichia coli*) and fungi (*Candida albicans*). the tested compounds exhibited high antibacterial activities.

- TheComplexes of 2-aminobenzimidazole (L) with nitrates of cobalt(II), nickel(II), copper(II), zinc(II), and silver(I) were synthesized by Sanja O. Podunavac-Kuzmanovic et al **(2004)** The molar ratio metal:ligand in the reaction of the complex formation was 1:2. It should be noticed, that the reaction of all the metal salts yielded bis(ligand) complexes of the general formula $M(L)_2(NO_3)_2 \times n\ H_2O$(M=Co, Ni,Cu,Zn or Ag; n=0,1,2 or 6). The complexes were characterized by elemental analysis of the metal, molar conductivity, magnetic susceptibility measurements and IR spectra. The effect of metal on the ligand antimicrobial activity is discussed.
- Nouria A.Al-Awadi *et al*., **(2007)** synthesized a new series of Zn^{2+}, Cu^{2+}, Ni^{2+}, and Co^{2+}, complexes of N^1-methyl-2(1H-1,2,3-brnzitriazol-1-yl)3-oxobutanethioamide(MBOBT). IR spectral data indicates the (MBOBT) exists only in the thione form in the solid

state while ^{13}C NMR spectrum indicates its existence in thione and thiole tautomeric forms. The IR spectra of all complexes indicates that (MBOBT) acts a monobasic bidentate ligand coordinating to the metal(II) ions via the keto-oxygen and thiolato-sulphur atoms. The electronic spectral studies showed that (MBOBT) bonded to all metal ions through sulphur and nitrogen atoms based on the positions and intensity of their charge transfer bands. Furthermore the spectra reflect four coordinate tetrahedral zinc(II), tetragonally distorted copper(II), square planar nickel(II), and cobalt(II) complexes. Thermal decomposition study of the complexes was monitored by TG and DTG analyses under N_2 atmosphere. The decomposition course and steps were analyzed and the activation parameters of the nonisothermal decomposition are determined. The isolated metal chelates have been screened for their antimicrobial activities and the findings have been reported and discussed in relation to their structures.

- Anitha.C *et al.,* **(2011)** were explained the preparation and characterization of metal(II) complexes, where M=VO (II), Co(II), Ni(II), Cu(II) and Zn(II) using the ligand (N'E)-N'-(5-((4-chlorophenyl)diazenyl)-2-hydroxybenzylidene)-2-hydroxybe nzohydrazide. Conductivity measurements reveal that complexes are nonelectrolytes. Spectroscopy and other analytical studies reveal distorted square planar geometry for copper, square-pyramidal geometry for oxovanadium, and tetrahedral geometry for other complexes. Redox behaviour of the copper (II) complex has been studied with cyclic voltammetry, and the biological activities of the ligand and metal complexes have been studied against several microorganisms by the well diffusion method. All synthesized compounds can serve as potential photoactive materials as indicated from their characteristic fluorescence properties. The second harmonic generation (SHG) efficiency of the ligand was measured and found to be higher than that of urea and KDP. The SEM image of the copper (II) complex implies that the size of the particles is 50 nm.

- Yuvaraj T.C.M. *et al*., **(2014)** prepared a ligand (N-{[2-(pyridin-4-ylmethyl)hydrazinyl]carbonothioyl}thiophene-2-carboxami

de) and then prepared Cobalt Nickel complexes. Metal complexes were subjected to structure elucidated by elemental analysis, conductivity measurements, UV-Visible, FT-IR, ^{1}H NMR and thermal analysis. The complexes were soluble in most of the organic solvents and were non-electrolytic in nature. The Cobalt and nickel complexes posses tetrahedral geometry while that of copper complexes have octahedral geometry. The antimicrobial activities of title compounds have been screened against Gram-positive and Gram-negative bacteria with comparing standard ciprofloxacin as reference. Antifungal activities against two different fungi have been evaluated and compared with *Flucanazole* as reference. The MIC result showed comparable activity as standard drug. Obtained compound also subjected to antioxidant activity and they show potent activity when compared with ligand.

- A series of iminopyridine ligated Co(II) and Ni(II) complexes were synthesized by Quanquan Dai *et al.,* **(2016)**. The structure of complexes was determined by X-ray crystallographic analyses. The nickel atom in complex features distorted trigonal-bipyramidal geometry with one THF molecule ligating to the metal center. All the complexes activated by ethylaluminum sesquichloride (EASC) were evaluated in 1,3-butadiene polymerization. The catalytic activity and selectivity were significantly influenced by the ligand structure and central metal. Comparing with the nickel complexes the cobalt complexes exhibited higher catalytic activity and cis-1,4-selectivity. For both the cobalt and nickel complexes, the aldimine-based complexes showed higher catalyst activity than their ketimine counterparts.

- In this study fourteen novel cobalt (II) or zinc (II) complexes of benzimidazoles were synthesized from the 1-(4-substitutedbenzyl)-1H-benzimidazoles and $Cocl_2.6H_2O$ or $Zncl_2$. [Elif Apohan *et al.,* **(2016)]** Cytotoxic activities of complexes were investigated against lung cancer cells (A549) and BEAS-2B. Three of the examined compounds showed high cytotoxic activity against A549. Three of the compounds have also high antimicrobial activity against all the microorganisms used.

- A series of schiff base ligands and their cobalt (II) complexes were designed and synthesized by Hongyue Li *et al.*,**(2017)**. The biological evaluation results showed that Bis(N,N^1-disalicylidene)-3,4- phenylenediamine-cobalt(II) and Bis(N,N^1-disalicylidene)-1,2-cyclohexanediamine-cobalt(II) were much more effective than the parent schiff bases. Docking study was used to elucidate the binding modes of complex with MEKI. Thus cobalt(II) complex may be further developed as a novel MEKI inhibitor.

- Anna K. Renfrew *et al.*, **(2017)** reviewed that Cobalt is an essential metal that is found in very low abundance in the body and the environment. Cobalt coordination complexes exhibit interesting redox and magnetic properties that make them suitable for a remarkable breadth of applications in biology and medicine. Here they review the diversity of uses of cobalt complexes in imaging and therapy and highlight the most promising directions for future research.

- Na Zhang *et al.*,**(2017)** explained preparation and characterization of hyperbranched iminopyridyl and its complexes. The nickel complexes exhibited better catalytic properties than iron and cobalt complexes for ethylene oligomerization. On activation with methylaluminoxane (MAO), the nickel complex exhibited moderate catalytic activitie. The influence of the solvent and reaction parameters such as reaction temperature, ethylene pressure and Al/Ni molar ratio on the catalytic behavior of the nickel complex was also investigated. Moreover, in comparison with the catalytic activity and the distribution of oligomers obtained with related hyper branched salicylaldimine nickel complex and other non-hyperbranched iminopyridyl nickel complexes the catalytic activity and the content of low carbon number olefins obtained in this work possessed relatively higher.
- This study describes the synthesis and characterization of three α-diimine-cobalt complexes of the type [$CoCl_2$(R-DAB)] (R-DAB - R-N=CH=N-R; R - Mes, Dipp and Dipp*) and their application as mediators for the cobalt-mediated radical polymerization (CMRP) of vinyl acetate (VAc) using 2,2'-Azobis(2-methylpropionitrile) (AIBN) as initiator. [Beatriz A. Riga

et al., **(2017)]**The systematic variation of the reaction conditions, such as [initiator]/[Co] and [monomer]/[Co] molar ratios at 65^{o}c, affected the polymerization rates and the molecular weights, reaching a certain level of control. The VAc polymerization was initiated by AIBN in the presence of DMSO using the α-diimine-cobalt complexes as mediators with [DMSO]/[Co] - 1 at 65^{o}c. The control over the polymer produced was not improved after the addition of DMSO. Kinectic studies and computational investigations support a tailorable cobalt complex reactivity mainly altered by steric factors of the α-diimine ligands.

- Novel cobalt-pyrazine-2,3-dicarboxylate complexes with 1,10-phenanthroline and its derivatives have been synthesized and characterized by elemental and thermal analyses, spectroscopic (IR and UV-vis) and X-ray diffraction techniques. The complex containing pyrazine-2,3-dicarboxylate as a ligand showed distorted octahedral geometry. In vitro antimicrobial activities of new complexes were tested against selected wild type and clinical microorganisms by MIC. Complexes exhibited antimicrobial activity at high concentrations against the bacteria, fungi and clinical isolate tested. Okan Zafer Yesilel *et al.,* **(2009)**

- A pyrazine-modulated oligo-α-pyridylamine ligand H_3pzpz and its mononuclear copper(II) and cobalt(II) complexes have been synthesized and structurally characterized by Wen-Zhen Wang *et al.,***(2010).** The protonated ligand exhibits an anti-anti-anti-anti-syn-anti conformation. H_3pzpz can be a quadridentate ligand and coordinates to metal atoms with all-antimode in both copper and cobalt mononuclear complexes. The copper(II) ion infive-coordinated in tetragonal pyramid geometry with one of the perchlorate anions being weakly coordinated in the apex position. Extensive hydrogen bonds are formed. X-band EPR spectra of showed well-resolved hyperfine structures resulting from the two paramagnetic isotopes ^{63}Cu and ^{65}Cu, yielding g-2.16 and A^{o}-$67\times10^{-4}cm^{-1}$. Complexes also showed spin-orbital coupling and zero-field splitting that is reflected in the magnetic properties.

- Brina Dojer *et al.,***(2016)** synthesized and characterized two new cobalt(II) complexes. Difluoridotetrakis(3-hydroxypyridine-κN)cobalt(II), $[CoF_2(C_5H_5NO)_4]$ and hexa(2-pyridone-κO)cobalt(II) tetrachloridocobaltate(II), $[Co(C_5H_5NO)_6][CoCl_4]$. The complexes were prepared by solvothermal synthesis. A methanol solution of hydroxypyridine was added to water solution of cobalt(II) acetate dihydrate followed by a few drops of concentrated hydrofluoric or hydrochloric acid into the mixture. The crystals of the compound are stable on air. Thermal analysis showed that the final product of both complexes after heating to 900^oc is elemental cobalt. The interactions between building units in the crystal structures include intra- and intermolecular hydrogen bonds in both compounds and π-π interactions in compound.

- Mustafa Burak Coban *et al.,(***2017)** were synthesized new defect dicubane cobalt(II)/cobalt(III). $[(Co^{II}_2Co^{III}_2L_42(H_2O)(CH_3COO)(CH_3COOH)]$. $4H_2O$ complex(**1**) where H_2L = [1-(3-hydroxypropyliminomethyl)naphthalene-2-ol]. has been synthesized and characterized by elemental analysis, FT-IR, solid UV-Vis spectroscopy and singe crystal X-ray diffraction. The crystal structure determination shows a cationic tetrameric arrangement consisting of a defect dicubane core with two missing vertexes. Each cobalt ion has a distorted octahedral geometry with six coordinate ordered Co^{II} and Co^{III} ions. The solid state photoluminescence properties of complex (**1**) and its ligand H_2L have been investigated under UV light at 349 nm in the visible region. H_2L exhibits blue emission while complex shows red emission at room temperature. Variable-temperature magnetic susceptibility measurements on the complex in the range 2-300 k indicate an antiferromagnetic interaction.

- Linda Xiao *et al.,* **(2017)** explained the ligand(2,6-bis(pyrazol-1-yl)pyridine and 2,6-bis(benzimidazol-2-yl)pyridine) and complex preparation. The blue five-coordinate complex $[Co(L^1)Cl_2]$ isolated initially from the reaction mixture rapidly absorbed water vapour from the atmosphere to yield the pink six-coordinate complex $[Co(L^1)(H_2O)_3]Cl_2$. This change is reversible upon desiccation or transferring $[Co(L^1)(H_2O)_3]Cl_2$ into acetonitrile. The five coordinate complex $[Co(L^2)Cl_2]$, however, remains stable under similar

coditions. The structures of the complexes $[Co(L^1)Cl_2]$, $[Co(L^1)(H_2O)_3]Cl_2$ and $[Co(L^2)Cl_2]$ have been determined by x-ray crystallography. The magnetic susceptibilities and the electronic spectra for $[Co(L^1)Cl_2]$, $[Co(L^2)Cl_2]$ and $[Co(L^1)(H_2O)_3]Cl_2$ were presented.

- Hemicryptophanesare covalent molecular cages, constructed from a cyclotriveratrylene-based host unit and a functional unit linked by covalent spacers, which have been designed to accommodate endohedral functionalities in the cavity. In this study, the synthesis and characterization of the rigid, biphenyl-linked hemicryptophane were investigated by NMR, ESI-MS, and X-ray crystallography. [Yoshimasa Makita *et al.*, **(2017)**] An endohedral, cobalt(II) hemicryptophane complex was also synthesized and characterized ESI-MS and X-ray crystallography. The X-ray crystal structure of showed that the biphenyl- linked hemicryptophane had three components-a molecule each of chloroform and acetonitrile, and a cobalt(II) ion-within this cavity.

- Cobalt(III) complexes were obtained with the ligands 2-acetylpyridine-N(4),-phenylthiosemicarbazone,2-acetyl-pyridine-N(4)-para-chlorophenylthiosemicarbazone 2-acetylpyridine-phenylhydrazone and 2-acetylpyridine-para-chlorophenylhydrazone. The complexes were characterized by (Camila V.Garcia *et al.,* **(2016)**)means of microanalyses, molar conductivities and their infrared and ^1H and ^{13}C NMR spectra. Electrochemical studies showed that the Co^{III}/Co^{II} reduction potential. The results suggested that coordination of 2-acetylpyridine-derived hydrazones with cytotoxic activity to cobalt(III) results in compounds which are able to release the bioactive ligand upon reduction. In addition, the cobalt(III) complexes under study interacted with human serum albumin (HSA), indicating that they could be transported by this protein.

- By using tetranaphthyridyl-triamine ligand,N^2-(2-(1,8-naphthyridin-7-ylamino)-1,8-naphthyridin-7-yl)-N^7-1,8-naphthyridine-2,7-diamine(H_3tentra), double stranded dinuclear helical compounds $[M_2(H_3tentra)_2(ClO_4)_4]$ [M - Ni^{II}(1), Co^{II}(2), Fe^{II}(3),Zn^{II}(4)] were

synthesized and structurally characterized by Rayyat Huseyn Ismayilov *et al.*,**(2017)**. The single X-ray crystal structure of iron(II) complex showed that both of H_3tentra ligands wrap around the metal-metal axis giving rise to a double-stranded dinuclear helical compound with Fe-Fe separation of ca 5.326A. Each ligand uses two nitrogen atoms from two different naphthyridine rings, to coordinate one metal centre (Fe or Fe(A)) and therefore, the geometry about the metal ions was described as distorted tetrahedral, with both ligands acting as a bisbidentate N4 donors. This distortion is shown by the angles between nitrogen and iron atoms, which range from 80.45(15) to 143.32(14)^o. Distorted tetrahedral environment was also proposed for the other complexes on the basis of the magnetic measurement and X-ray results. Strong π-π interactions were observed for all synthesized double stranded helicates of H_3tentra ligand. The measured χ_mT values at 300k for complexes 2 and 3 found larger than the expected values for two high-spin Co(II) with S - 3/2 and for Fe(II) ions with s -2 and g - 2, which attributed to the unquenched orbital coupling.

- Junbo Zhou *et al.*,**(2016)** studied the cobalt alkylene polyamine complex, known as kind of cobalt complexes, is mixed with VB and VIB compounds (in the periodic table VB and VIB)such as vanadium pentoxide, sodium molybdate etc. According to a certain portion. Then it is added to alkaline electrolyte. In the process of water electrolysis, metal ions in lower overvoltage are introduced into the cathode chamber of the electrolytic cell and are plated onto the nickel-based electrode, which increases the cavity of cathodic electrolyis, thereby reducing the electrolysis power consumption of cell voltage.

- Ligand modifications with electron-withdrawing and electron-donating groups were applied to afford three novel mononuclear cobalt-based catalysts $[Co(TPA\text{-}R)]^{2+}$ (TPA = tris(2-pyridylmethyl)amine; R = tri-αF,1; R = tri-αOMe,2; R = mono-αF,3) for water oxidation. This work was carried out by Si Liu *et al.,* **(2017).** Characterization of the catalysts shows that steric and electronic factors play important roles in inhibiting spontaneous intermolecular dimerization of two cobalt centers, and influence the catalytic

behaviour. Complex 1 exhibits the best catalytic ability and stability, showing a good efficiency with TOF of 6.03±0.02 mol (O_2)/(mol $(cat)^*$s) in photo-induced water oxidation experiments using Ru $(bpy)_3^{2+}$ as photosensitizer and $Na_2S_2O_8$ as electron acceptor. The bulky electron donating groups in 2 led to degradation of the complex and formation of CoO_x particles acting as the real catalyst. Elctron-withdrawing substituents on the TPA ligand can stabilize the catalyst under both electrochemical and photo-induced conditions, with the enhancement increasing with the number of the electron-withdrawing groups.

- Cobalt(III) complexes such as $[Co(acac)(bpy)(N_3)_2.H_2O]$, $[Co(acac)(en)(N_3)_2]$ and $[Co(acac)(2\text{-pic})(N_3)_2]$ (where, acac = acetylacetone, bpy = 2,2'-bipyridine, en = ethylenediamine, 2-pic = 2-picolylamine and NaN_3 = sodium azide) were synthesized and characterized by V. Thamilarasan *et al.*, **(2016).** The structure of complexes has been determined by singe crystal X-ray diffraction studies and the configuration around cobalt(III) ion was distorted octahedral coordination geometry. Density functional theory calculations were performed to examine the molecular geometry and frontier molecular orbital properties of complexes. DNA binding properties of the cobalt(III) complexes with calf thymus DNA (CT-DNA) were investigated by UV-Visible absorption, fluorescence, circular dichroism spectroscopy and viscosity measurements. The docking studies showed the preferred orientation of sterically acceptable Co(III) complexes inside the DNA through the mode of intercalation, whereas complex 3 exhibited minor groove binding modes. The intrinsic binding constants K_b of complexes with CT-DNA were in the following order **1**>**3**>**2** complexes exhibit a good binding propensity to bovine serum albumin (BSA) and gel electrophoresis assay demonstrated that the complexes promote the cleavage of the pBR322 DNA in the presence of 3-mercaptopropionic acid (MPA) and cleavage process was found to proceed by singlet oxygen cleavage mechanism. Further, the in vitro cytotoxicity studies of complexes were tested on human breast cancer cell line (MCF-7).

- Inorganic complexes are versatile platforms for the development of potent and selective pharmaceutical agents. Cobalt possesses a diverse array of properties

that can be manipulated to yield promising drug candidates. Investigations into the mechanism of cobalt therapeutic agents can provide valuable insight into the physicochemical properties that can be hamessed for drug development. The reviewers of this paper (Marie C Heffern *et al.,* **(2012)**) presents examples of bioactive cobalt complexes with special attention to their mechanisms of action. Specifically, cobalt complexes that elicit biological effects through protein inhibition, modification of drug activity, and bioreductive activation are discussed. Insights gained from these examples reveal features of cobalt that can be rationally tuned to produce therapeutics with high specificity and improved efficacy for the biomolecule or pathway of interest.

- New 2D-polymeric compound $[Co(\mu\text{-}OH_2)(\mu\text{-}piv)_2(piv)_2(\mu\text{-}L^1)_2]_n$ was synthesized in the reaction of the cobalt(II) pivalate $[Co(piv)_2]_n$, (piv : pivalic acid) and pyrimidine (L^1)in MeCN. 3D-poly-mer $[Co_5(\mu\text{-}OH_2)(\mu_3\text{-}OH)(\mu_3\text{-}piv)(\mu\text{-}piv)_5(piv)_3(\mu\text{-}L^2)_4]_n$ was prepared by the reaction of the polymer $[Co(piv)_2]_n$ (**1**) with pyrazine (L^2). Complexes **2** and **3** were characterized by the X-ray diffraction and magnetic susceptibility. It was shown that compound **2** undergoes antiferromagnetic ordering with weak ferromagnetism at T_N - 4.5 k with σ_o(2 k) - 4000 G cm^3/mol. (Mikhail A. Kiskin *et al.,* **(2008))**

- The cobalt(II) complex of 2-piclonic acid (Hpic), namely, $[Co(pic)_2(H_2O)_2]$.$2H_2O$, was synthesized with the reaction of cobalt acetate and 2-piclonic acid as the reactants by solid-solid reaction at room temperature. The composition and structure of the complex were characterized by elemental analysis, infrared spectroscopy, single crystal X-ray diffraction, and thermogravimetry differential scanning calorimetry (TG-DSC). This study was executed by Di Li *et al.,* **(2014).** The crystal structure of the complex belongs to monoclinic system and space group P2(1)/n, with cell parameters of a = 9.8468(7) Å, b = 5.2013(4) Å, c =

14.6041(15) Å, β = 111.745(6) Å, V = 747.96(11) $Å^3$, Z = 2, D_c = 1.666 g cm^{-3}, R_1 =0.0297 and wR_2 = 0.0831.

- A series of 2-aminosubstituted (5Z)-3-phenyl-5-(pyridine-2-ylmethylene)-3,5-dihydro-4H-imidazole-4-ones (L) was prepared by the reaction of the corresponding 2-alkylthio-3,5-dihydro-4H-imidazole-4-ones with morpholine or piperidine in the presence of ytterbium(III) triflate.(Olga O. Krasnovskaya *et al.,* **(2016).** The resulting ligands were subsequently reacted with $CuCl_2.H_2O$ and $CoCl_2.6H_2O$ to give the corresponding copper(II) and cobalt(II) complexes,respectively. Analysis revealed that the complexes were formed with an $LMCl_2$ (M = Cu, Co)- type composition in all cases. The structures of the three cobalt complexes prepared in this way were determined by X-ray crystallography. The results revealed that the cobalt ions in these complexes were tetrahedrally coordinated to two chloride anions and two nitrogen atoms from the pyridine and imidazole moieties of the ligand. The electro-chemical properties of the ligands and thier complexes were evaluated by cyclic voltammetry, and the results revealed that the first stage in the reduction of the Co(II) and Cu(II) complexes involved the reversible formation of the corresponding Co(I) and Cu(I) complexes, respectively. The cytotoxicity activities of the organic ligands and their complexes were evaluated against several cancer cell lines, including MCF-7, A549 and HEK293 cells. The copper complexes of the organic ligands bearing a phenyl or allyl moiety at their N(3) position together with a piperidine substituent at the 2-position of their imidazolone ring exhibited the greatest cytotoxicity of all of the compounds tested in the current study.

- G. D. Howard *et al.,* **(1969)** was explained the equilibrium constant of, $[CoPy_2Cl_2][Py]^2/[CoPy_4Cl_2]$, from ^{14}N chemical shift data to be 2.3 ± 1.2 M^3 at 38°, with ΔH and ΔS for the equilibrium being 13.0 ± 0.9 kcal/mol and 43.4 ± 2.2 eu, respectively. The mean lifetime of pyridine on $CoPy_4Cl_2$ was determined from ^{14}N nuclear magnetic resonance data to be (1.5 ± 0.2) × 10^{-7} sec at 25°, with ΔH and ΔS for the exchange being 13.2 ± 0.5 kcal/mol and 17 ± 2 eu, respectively. T_{10} for $CoPy_4Cl_2$ was estimated to be 8 × 10^{-12} sec.

- Kristin Alexis Boles **(2014)** studied asynthesis for the mixed-valence bis(tetrachlorocatecholato)tetrachlorosemiquinonatocobalt(III)dianion, $[Co(C_{14}Cat)_2(C_{14}SQ)]_2–$, is presented, as well as syntheses for tris(tetrachlorosemiquinonato)iron(III), $Fe(C_{14}SQ)_3$, and tris(tetrachlorocatecholato)ironn(III) trianion, $[Fe(C_{14}Cat)_3]_3–$.These confirm mononuclear, homoleptic complexes of MnIV, hs-FeIII, and ls-CoIII. These complexes undergo ligand-based redox chemistry, which has been studied using cyclic voltammetry and differential pulse voltammetry. The separation in potential between the ligand based redox couples has been used to gauge the degree of interligand electron coupling though the metal center, which acts as a bridge for electron transfer. The dianion manganese complex,$[Mn(C_{14}Cat)_3]_2–$, has complicated electrochemical behavior, with strong solvent dependence. The neutral iron complex $Fe(C_{14}SQ)_3$ and the trianion complex $[Fe(C_{14}Cat)_3]_3–$ have the same electrochemistry, which occurs over a narrow potential range. The iron complexes have unique electrochemical properties, as three distinct oxidation peaks are observed, but only one broad reduction peak at scan rates greater than 10 mV/s, which resolves into three peaks at slower scan rates. This is observed in multiple solvents. The dianion cobalt complex, $[Co(C_{14}Cat)_2(C_{14}SQ)]_2–$, is unusual in that it is synthesized as a mixed-valence compound, with ligands in different oxidation states. Cyclic voltammetry of this complex shows two reversible one-electron couples at nearly the same potential, which have been resolved using differential pulse voltammetry.

- The following complex cations of cobalt(III) and rhodium(III) containing 1,4,7,10-tetraazacyclododecane (cyclen) havc been prepared and characterized by James P. Collman **(1966)** [Co[cyclen)Clz] +, [Co(cyclen)Brz] +, [Co(cyclen)COs] +, [Co(cyclen)CnO4] +, [Co(~yclen)(NOz)~] , and [Rh(cyclen)Clz] +. Comparison of the visible absorption spectra of these cyclen complexes with the spectra of corresponding tetraammine, bis(ethylenediamine), trietlirlerietetrainine, and 4-(2-aminoethyl)dietliylenetriamine complexes strongly suggests that the

cyclen ligand in these complexes adopts a configuration such that the remaining two coordination positions are cis. The significantly higher molar absorptivities of the cyclen complexes are discussed in terms of steric constraint and distortion of the octahedral field.

- Terminal cobalt(IV)–oxo (Co^{IV}–O) species have been implicated as key intermediates in various cobalt-mediated oxidation reactions. Herein they(Bin Wang*et al.*,**(2017)**) report the photocatalytic generation of a mononuclear non-haem $[(13\text{-TMC})Co^{IV}(O)]^{2+}$ (**2**) by irradiating $[Co^{II}(13\text{-TMC})(CF_3SO_3)]^{+}$ (**1**) in the presence of $[Ru^{II}(bpy)_3]^{2+}$, $Na_2S_2O_8$, and water as an oxygen source. In particular, the resonance Raman spectrum of reveals a diatomic Co–O vibration band at 770 cm^{-1}, which provides the conclusive evidence for the presence of a terminal Co–O bond. In reactivity studies, was shown to be a competent oxidant in an intermetal oxygen atom transfer, C–H bond activation and olefin epoxidation reactions. The present results lend strong credence to the intermediacy of Co^{IV}–O species in cobalt-catalysed oxidation of organic substrates as well as in the catalytic oxidation of water that evolves molecular oxygen.

- The synthesis of the novel Co(III)(15,15-difluoro-1,4,7,10,13-pentaazacyclohexadecane-14,16-dicone) acetate complex from different cobalt sources is described by Da pieve et al., **(2012)**. Furthermore, the corresponding nickel complex and its new analog with the 15-fluoro-15-methyl-1,4,7,10.13-pentaazacyclohexadecane-14,16-dione ligand were studied in great detail including cyclic voltammetry and single crystal analyses of a total of 6 complexes. The result for the nickel compounds showed that depending upon ligand substitution and solvent, an N3 or, after a double deprotonation, an N5 coordination mode could be observed and characterized in the solid state and in solution. Moreover, cyclic voltammetric analyses were performed revealing that the Ni(II/III) oxidation potentials are becoming more positive with the increasing number of fluorine atoms. This

effect is due to the electron withdrawing property of fluorine that is reducing the electron richness of the metal ion.

- Michael P Bubnov *et al.,* **(2015)** illustrated divalent cobalt and nickel form four-coordinate complexes with sterically hindered 3,6-di-tert-butylcatecholato dianion (3,6-DBCat) and neutral bidentate 1,4-disubstituted-1,3 (DAB). Structural study of (1,4-di-tert-butyl-1,4-diazabutadiene-1,3)(3,6-di-tert-butyl-catecolato)nickel and(4-bis-(2,6-di-iso-propylphenyl)-2,3-dimethyl-1,4-diazabutadiene-1,3)(3,6-di-tert-butyl-catecolato)cobalt indicates square-planar environment of metals. Chemical one-electron oxidation of nickel complexes proceeds through catecholate ligand and leads to o-semiquinonato adducts. EPR spectral parameters indicates preservation of square-planar configuration after oxidation. Complexes (DAB)M(Cat)(M = Ni, Co) undergo neutral ligand substitution reactions.

- A new series of Co(II), Ni(II), Cu(II) and Zn(II) metal complexes of a novel ligand 3-(2-(1-(2,4-DihydroxyPhenyl)ethylidene)hydrazinyl)-2H-benzo[b][1,4]oxazin-2-one, (DPE-HBO) were prepared and characterized by N.Kavitha *et al.,* **(2017)**. Microwave synthesis of the ligand was also carried out which gave a high increase in its yield within very short time. 3D molecular modeling structure of the ligand is obtained by using ArgusLab software. The nature of bonding and the stereochemistry of the complexes have been deduced from elemental analysis, thermal, infrared, electronic spectra, magnetic moments and conductivity measurements. ESR spectrum of Cu(II) complex is studied. All the complexes show subnormal magnetic moments. ONNO donor atoms participate in coordination with Cu(II) and Zn(II) complexes exhibiting octahedral geometry. Co(II) and Ni(II) complexes behave differently with ONNO donor atoms showing two types of geometries i.e., octahedral and square planar within the same complex.

- A new series of Co(II), Ni(II), Cu(II) and Zn(II) complexes were prepared with bidentate ligand derived by condensation of

4-amino-3-mercapto-6-methyl-5-oxo-1,2,4-triazine with 3-(p-bromophenyl)-1-phenyl-1H-pyrazolecarboxaldehyde(Kiran singh *et al.,* **(2016)**). The Schiff base and its metal complexes were characterized on the basis of various spectroscopic investigation like IR, NMR, fluorescence and thermal analyses. The coordinated water molecules were confirmed by IR and thermal data, while the geometry of the complexes was confirmed by electronic spectra, magnetic moment measurements and ESR analysis. Cyclic voltammetry shows the redox behavior of copper complexes. All the complexes were colored, stable in air and non-electrolytic in nature. Schiff base and its metal complexes were screened for *in vitro* antimicrobial activity and it was observed that metal complexes show enhanced biological activity as compared to ligand or metal salts. In addition, Zn(II) complexes show enhanced biological activity against most of the microbial strains as compared to ligand and other metal complexes.

- In the present study two new series of Copper(II), Nickel(II) and Cobalt(II) complexes with two newly synthesized Schiff base ligands 4,6-bis(1-(4-bromophenylimino)ethyl)benzene-1,3-diol (H2L1), 4,6-bis(1-(4-methoxyphenylimino) ethyl)benzene-1,3-diol (H2L2) and organic ligands 8-hydroxy quinoline, 1,10-phenanthroline have been prepared by Jignesh H.Pandya et al.,**(2014).** The Schiff bases H2L1 and H2L2 ligands were synthesized by the condensation of 4,6-diacetyl resorcinol with 4-bromo aniline and 4-methoxy aniline. The ligands and their metal complexes have been characterized by FT-IR, Mass, 1H NMR, UV–Vis., elemental analysis, ESR and Thermal gravimetric analysis. The Schiff base and their metal complexes were tested for antimicrobial activity against gram positive bacteria *Staphylococcus aureus, Streptococcus pyogenes* and gram negative bacteria *Escherichia coli, Pseudomonas aeruginosa* and fungus *Candida albicans, Aspergillus niger* and *Aspergillus clavatus* using Broth Dilution Method.

- In the present study a series of Co(II) complexes of formyl chromone Schiff bases have been synthesized characterized by P.Kavitha *et al.,* **(2016).** In all

the Co(II) complexes 1:2 metal to ligand molar ratio was obtained from analytical data. The molar conductance data confirm that all complexes are non-electrolytic in nature. Based on the electronic and magnetic data, an octahedral geometry is ascribed for all the Co(II) complexes. Thermal behaviour of the synthesized complexes illustrates the general decomposition patterns of the complexes. The X-ray analysis data show that all the Co(II) complexes have triclinic crystal system with different unit cell parameters. Metal complexes have greater antimicrobial activity than ligands. Antioxidant and nematicidal activities indicate that the ligands exhibit greater activity when compared to their respective Co(II) complexes. All ligands and Co(II) complexes of HL1 and HL2 showed considerable anticancer activity against Raw, MCF-7 and COLO 205 cell lines. All ligands and their Co(II) complexes showed more pronounced DNA cleavage activity in the presence of H2O2.

- Cobalt(II), nickel(II), copper(II), zinc(II) and cadmium(II) complexes of new 3-acetyl-4-[(4-aminophenyl)amino]-6-methyl-2H-pyran-2-one (HL1) derived from dehydroacetic acid and 1,4-diaminobenzene were prepared and characterized by Sanaa M. Emam *et al* .,**(2017)**. The structural features were determined from their elemental analyses, 1H, and 13C-NMR spectra, molar conductivities, magnetic moments, IR, UVvis. spectra, thermal analyses (D.T.A. and T.G.A.) and E.S.R. measurements. Their magnetic susceptibility measurements and low conductance data provide evidence for the mono- or dimeric and non-electrolytic nature of the solid complexes. The E.S.R. spectra of copper(II) complexes show axial type symmetry with covalent or ionic bond character. The electrochemical behavior of the complexes in DMF (dimethylformamide) solvent at 298 K was studied. The biological activity of the ligand and its metal(II) complexes was also studied. The obtained complexes showed higher activities than the free ligand in protecting the Egyptian cotton fields from *Spodoptera littoralis* larvae.

- 1:2 Complexes of Co(II), Ni(II), Cu(II) and Zn(II) with the Schiff base ligand Indal-4-AAP, derived from indole-3-carboxaldehyde and 4-aminoantipyrine were synthesized and characterized by M. Sivasankaran Nair *et al.,* **(2016).** The complexes were found to have the general formulae [ML2Cl2]

(M = Co(II), Ni(II), Cu(II) and Zn(II)). The IR results demonstrate that the co-ordination sites are the azomethine nitrogen and carbonyl oxygen atoms of the Schiff base ligand. The electronic spectral and magnetic measurement data indicate that the complexes exhibit octahedral geometry around the metal center. The *in vitro* biological screening effects of the synthesized compounds were tested against various microbial species and the results show that the metal complexes are more biologically active than the ligand. The DNA cleavage activity of the ligand and its complexes was assayed on pUC18 DNA using gel electrophoresis. The result shows that Ni(II), Cu(II), and Zn(II) complexes have completely cleaved the DNA.

- A series of Co(II), Ni(II), Cu(II), Cd(II), Zn(II) and Hg(II) complexes of the type $CuLCl_2$. $2H_2O$ and ML_2Cl_2 [M = Co(II), Ni(II), Cd(II), Zn(II) and Hg(II)], respectively, where L = Schiff's base derived from condensation of citral and naphthofuran-2-carbohydrazide have been synthesized by M.B. Halli *et al.*,**(2017)**. The proposed structures of the obtained complexes have been established from elemental analyses, IR, Electronic, Mass, 1H NMR, ESR spectral data, magnetic and thermal studies. From the above spectral studies it is concluded that the ligand acts as a bidentate coordinating through azomethine nitrogen and amide oxygen. The measured low molar conductance values in DMF indicate that the complexes are non-electrolytic in nature. The electron transfer mechanism of the Cu(II) complex is investigated by the aid of cyclic voltammetry. The free ligand and its metal complexes have been screened for their antioxidant activity by the DPPH method and *in vitro* antibacterial (*Escherichia coli, Staphylococcus aureus, Bacillus subtilis* and *Pseudomonas aeruginosa*) and antifungal (*Aspergillus niger, Aspergillus flavus, Cladosporium oxysporum* and *Candida albicans*) activities by the minimum inhibitory concentration (MIC) method. The DNA cleavage studies of all the complexes were studied by agarose gel electrophoresis method. The results indicate that the biological activity increases on complexation.

- P.Jayaseelan*et al.*,**(2016)** studied a new tetradentate binucleating ligand [H2L] has been synthesized by condensation between 3, 3′ -diaminobenzidine and

o-hydroxyacetophenone in the molar ratio 1:4. The reaction of the ligand with metal chelation leads to bimolecular complexes of the general formula [M2(L)]. In conductivity experiments, all metal chelates showed to be non-electrolytic in nature. The bonding sites are the nitrogen atoms of the azomethine and the oxygen atoms of the phenolic groups. The anti-microbial activities were screened against one Gram-positive bacterium (*Streptococcus pyogenes*) and one Gram-negative bacterium (*Klebsella pneumoniae*). The anti-fungal activity was screened against *Asperigillus flavus*. All complexes showed significant anti-bacterial and anti-fungal activities. The DNA binding studies were performed by electronic spectroscopy, cyclic voltammetry studies and viscosity measurements. The cleavage studies of these complexes are investigated by gel electrophoresis method in the presence of peroxide. All complexes cleaved efficiently and the complex interacts with DNA through an intercalating way.

- A novel Schiff base ligand has been prepared by the condensation between butanedione monoxime with 3,3′-diaminobenzidine. The ligand and metal complexes have been characterized by Poomalai Jayaseelan*et al.,* (**2016**). The molar conductance studies of Cu(II), Ni(II), Co(II) and Mn(II) complexes showed non-electrolyte in nature. The ligand acts as dibasic with two N4-tetradentate sites and can coordinate with two metal ions to form binuclear complexes. The spectroscopic data of metal complexes indicated that the metal ions are complexed with azomethine nitrogen and oxyimino nitrogen atoms. The binuclear metal complexes exhibit octahedral arrangements. DNA binding properties of copper(II) metal complex have been investigated by electronic absorption spectroscopy. Results suggest that the copper(II) complex bind to DNA via an intercalation binding mode. The nucleolytic cleavage activities of the ligand and their complexes were assayed on CT-DNA using gel electrophoresis in the presence and absence of H2O2. The ligand showed increased nuclease activity when administered as copper complex and copper(II) complex behave as efficient chemical nucleases with hydrogen peroxide activation. The anti-microbial activities and thermal studies have also been studied. In anti-microbial activity all complexes showed good

anti-microbial activity higher than ligand against gram positive, gram negative bacteria and fungi.

- The new symmetrical Schiff base *N*,*N* ′ bis(pyrrole-2-carbaldehyde)ethylenediamine and its Mn(II), Co(II), Ni(II) and Cu(II) complexes were synthesized and characterized by spectral, magnetic and electrochemical studies. This work was carried out by Bibhesh K.Singha*et al.*,(**2017**).The spectral studies of the complexes reveal that the ligand has coordination through the azomethine nitrogen atoms, pyrrole nitrogen atoms and anions, supported by octahedral geometry. Mass spectrum explains the successive degradation of the molecular species in solution and justifies ML complexes. The electrochemical study indicates that the pyrrole ring stabilizes the metal ion, makes the complex more positively charged, and causes it to be more easily reduced. The molecular structure of the complexes has been optimized by MM2 calculations and suggests an octahedral geometry. Powder X-ray diffraction allows us to determine the cell parameters of the complexes. The bio-efficacy of the ligand and their complexes has been examined against the growth of bacteria in vitro to evaluate their anti-microbial potential.

- The stability constants for complexes of metal ions (M2+) such as Co^{2+}, Mn^{2+}, Cd^{2+}, Pb^{2+}, and Zn^{2+} with iodoquinol (IQ) at the ionic strength of 0.1 (using NaNO3) have been determined at 25 °C. This study has been done in the binary mixed solvents N,N-dimethyl formamide/Methanol (DMF/MeOH) by a spectrophotometry method. The stoichiometry for M2+/IQ complexes was calculated by applying the “Job” and “molar ratio” methods. A 1:1 complex is generated between each M2+ and the IQ. It was found that the stability constants of the complexes were increased with increasing amount of MeOH in the binary mixtures. The results show that the stability constants decrease in the order Zn2+ > Co2+ > Pb2+ > Mn2+ > Cd2+. The biggest stability constant was found for the Zn2+/IQ system.(Hasan AliHosseinia*et al.*, (**2017**))

- S.Kanchia*et al.,* **(2017)** was studiedthe separation and identification of selenium(IV) and cobalt(II) in *Macrobrachium lamarrei*, fresh water prawn samples and their feeding materials after pre-capillary complexation with ammonium piperidine-1-carbodithioate (APC) by using capillary electrophoresis. Microwave assisted procedure was adapted to analyze selenium(IV) and cobalt(II) in prawn samples which was eco-friendly to environment. Various parameters such as effect of pH, effect of complexing agent concentration, buffer nature, applied voltage and interferences by other metal ions were also investigated to enhance the sensitivity and detection limits of the present method. The obtained results were in good agreement and correlated with AAS method in terms of Student's "*t*"-test and Variance ratio "*f*"-test. The method was applied for the analysis of selenium(IV) and cobalt(II) in various *M. lamarrei*, fresh water prawn samples and their feeding materials.

- Mohammad Reza Jamali*et al.,* **(2017)** enumerate a simple in situ solvent formation microextraction (ISFME) methodology based on the application of ionic liquid (IL) as an extractant solvent and sodium hexafluorophosphate (NaPF6) as an ion-pairing agent was proposed for the preconcentration of the trace levels of cobalt ions. In this method cobalt was complexed with 2-(5-bromo-2-pyridylazo)-5-diethylaminophenol (5-Br-PADAP) and extracted into an ionic liquid phase. After phase separation, the enriched analyte in the final solution is determined by flame atomic absorption spectrometry (FAAS). Some effective factors that influence the microextraction efficiency were investigated and optimized. Under the optimum experimental conditions, the limit of detection and the enrichment factor were 0.97 μg L^{-1} and 50, respectively. The relative standard deviation (R.S.D.) was obtained as 2.4%. The proposed method was assessed through the analysis of certified reference water and recovery experiments.

Chapter IV

Materials and Methods

4.1. Materials used

4.1.1. Solvents

Water: Double distilled water and distilled over alkaline KMnO4, was used for all the experiments.

Acetone: An L.R. grade sample of acetone supplied by S.D. fine chem., Ltd, was used as the solvent for the preparation of the complexes.

Ethanol: An L.R. grade sample of ethanol supplied by Shakthi Sugars Lab, Coimbatore.

Ether: Solvent ether supplied by S.D.Fine Chem., Ltd, Hyderabad was used as such for washing the complexes.

4.1.2. Chemicals used

Cobalt(II) chloride: Crystalline sample of A.R. $CoCl_2.6H_2O$ obtained from LOBA Chemie, was used as such for the preparation of the complexes.

Cobalt(II) bromide: Green colored powered sample obtained from Sigma-Aldrich, used for preparation of the bromo complexes.

Pyrazine: White crystalline solid obtained from Avra synthesis Pvt Ltd was used for the preparation of the complexes.

Pyrazine carboxylic acid: White amorphous powder obtained from Avra synthesis Pvt Ltd was used for the preparation of the complexes.

2- Methyl pyrazine: Pale brown liquid obtained from Avra synthesis Pvt Ltd was used for the preparation of the complexes.

Pyrazine Carbonitrile: Pale brown colour liquid obtained from Avra synthesis Pvt Ltd was used for the preparation of the complexes.

Pyrimidine: Pale yellow colour liquid obtained from Avra synthesis Pvt Ltd was used for the preparation of the complexes.

4.2. Preparation of the cobalt (II) complexes

The heterocyclic moieties of the Pyrazine derivatives [Pyrazine(Pz), Pyrazine Carboxylic acid(PzCA), Methyl Pyrazine(MPz), Pyrazine Carbonitrile(PzCN), Pyrimidine(Pym)] were used for the synthesis of cobalt(II) complexes. Cobaltous salts ($CoCl_2$ or $CoBr_2$) were mixed with heterocyclic body of the pyrazine derivatives in 1:4 ratio in an aqueous solution of methanol or acetone and refluxed for an hour. The blue colour slowly turned pink or violate which ensured the formation of the complexes of the type $[Co(L)_4(H_2O)_2]\ X_2$.

$$\mathbf{[Co(B)_4(H_2O)_2]X_2}$$

Where, $\mathbf{X^-}$= Cl^- or Br^-

B = Pyrazine(Pz), Pyrazine Carboxylic acid(PzCA),
Methyl Pyrazine(MPz), Pyrazine Carbonitrile(PzCN), Pyrimidine(Pym).

4.3. Spectral Characterizations

4.3.1. Infrared Spectra

IR spectra of the complexes were obtained using Shimadzu IR spectrophotometer in KBr disc. The IR spectra are given in { Fig-5.2.1.(a) to 5.2.1.(e)}

4.3.2. Electronic Spectra

The UV-Visible spectra of the complexes {Fig- 5.2.2.(a) to 5.2.2.(c)} of suitable concentrations in aqueous ethanol were obtained from Double Beam spectrophotometer using 1 cm matched quartz cells.

4.3.3. Thermal analysis

The TGA curves **{Figs- 5.2.3.}** of the complexes were obtained using SII TG-DTA 6300 Exstar at Avinashilingam University, Coimbatore.

4.4. Antimicrobial Studies

For the antimicrobial study, anti bacterial and antifungal study were used. Cultures of *Staphylococcus aureus*, *Escherichia coli*, and *klebsiellapneumoniae* were used for antibacterial.

The bacterial cultures were stocked at 4^0C after subculturing incubation of 24hrs at 37^0C in incubator. Mueller Hinton Agar were prepared and sterilized at 121^0C for 15minutes. The antibacterial assays were carried out by the agar well-diffusion method (Jesteena et al 2017). Mueller Hinton agar plate were prepared and after solidification 60 µl of culturewere poured and spreaded with sterile cotton swab and kept for drying for 2-3 minutes. Wells were made with cork borer in the diameter of 5mm and added the sample (8 samples) separately around 50µl in each well. Ampicillin (AMP 2mcg) antibiotic disc used as a positive control. All the plates were incubated at 37^0c for 24 hours. The diameters of inhibition zone produced by the extract were measured in mm after the incubation period.(**Jesteena Johney *et al*.,2017**). The zone of inhibition of the complexes are shown in Fig- 5.2.4(a) and 5.2.4.(b)

Chapter V

Results and Discussions

5.1. Preparation of the Complexes

The complexes of the type $[Co(B)_4(H_2O)_2]X_2$where $\mathbf{X^-}$ = Cl^- or Br^- and **B**= Pyrazine based ligands like Pyrazine carboxylic acid (PyzC), 2- Methyl pyrazine (MPyz), Pyrazine (Pyz), Pyrazine Carbonitrile(PzCN) and Pyrimidine(Pym) wereprepared as mentioned in the chapter III. The paragrammatic representation of cobalt (II) complexes are shown in the **Fig- 5.1(a)**

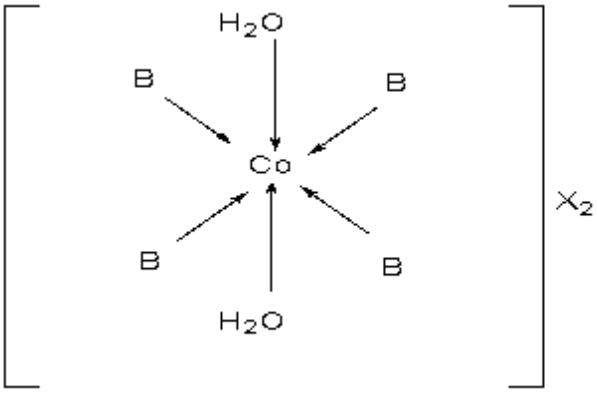


Fig :5.1(a) Schematic representation of $[Co(B)_4(H_2O)_2]X_2$

5.2. Characterization of the Complexes

The prepared cobalt(II) complexes were subjected to various spectral studies to characterize their structures. The antimicrobial studies reveal the biological activities of the complexes.

5.2.1. IR spectra of complexes of the type $[Co(B)_4(H_2O)_2]X_2$

The IR data of cobalt(II) complexes are given in **Table-5.2.1.** Some sample IR spectra of complexes are given in **Fig-5.2.1.(a) toFig-5.2.1.(e)**.The C-N stretching of the complexes was observed around 1260 cm^{-1}. C-N stretching of the heterocyclic bases were found to be much higher in the case of cobalt(II) complexes.A band at 3160 cm^{-1} in the spectrum of the complex can be attributed to the stretching vibration of NH2 moiety.Co-N stretching around 540 cm^{-1} ensured the ligation of heterocyclic base to thecobalt**(Baker Jr, W. A, *et al.*,1966)**. This peak indicates the formation of

the complex. The C=N stretching in the cobalt(II) complexes was observed around 2200 cm^{-1} In cobalt(II) complexes, the O-H stretching due to the axial water molecule was shifted (around 3100 cm^{-1})to higher frequency compared to the other cobalt(II) complexes.

Table: 5.2.1. IR Spectral data of complexes of the type $[Co(B)_4(H_2O)_2]X_2$

Complexes	**Co-N**	**Axial ligands**				
	V(Co-N)	**V(-N-H)**	**V(C-N)**	**C=O**	**O-H**	**C=N**
$[Co(Pz)_4(H_2O)_2]Cl_2$	547	3178	1616	1330	3113	2206
$[Co(PzCA)_4(H_2O)_2]Cl_2$	543	3402	1257	1627	3062	2191
$[Co(MPz)_4(H_2O)_2]Cl_2$	540	3406	1273	1639	3113	2299
$[Co(PzCN)_4(H_2O)_2]Cl_2$	547	3398	1265	1647	3155	2137
$[Co(Pz)_4(H_2O)_2]Br_2$	547	3394	1261	1627	3113	2156
$[Co(PzCA)_4(H_2O)_2]Br_2$	547	3375	1280	1639	3113	2202
$[Co(Pym)_4(H_2O)_2]Br_2$	547	3251	1249	1614	3109	2198

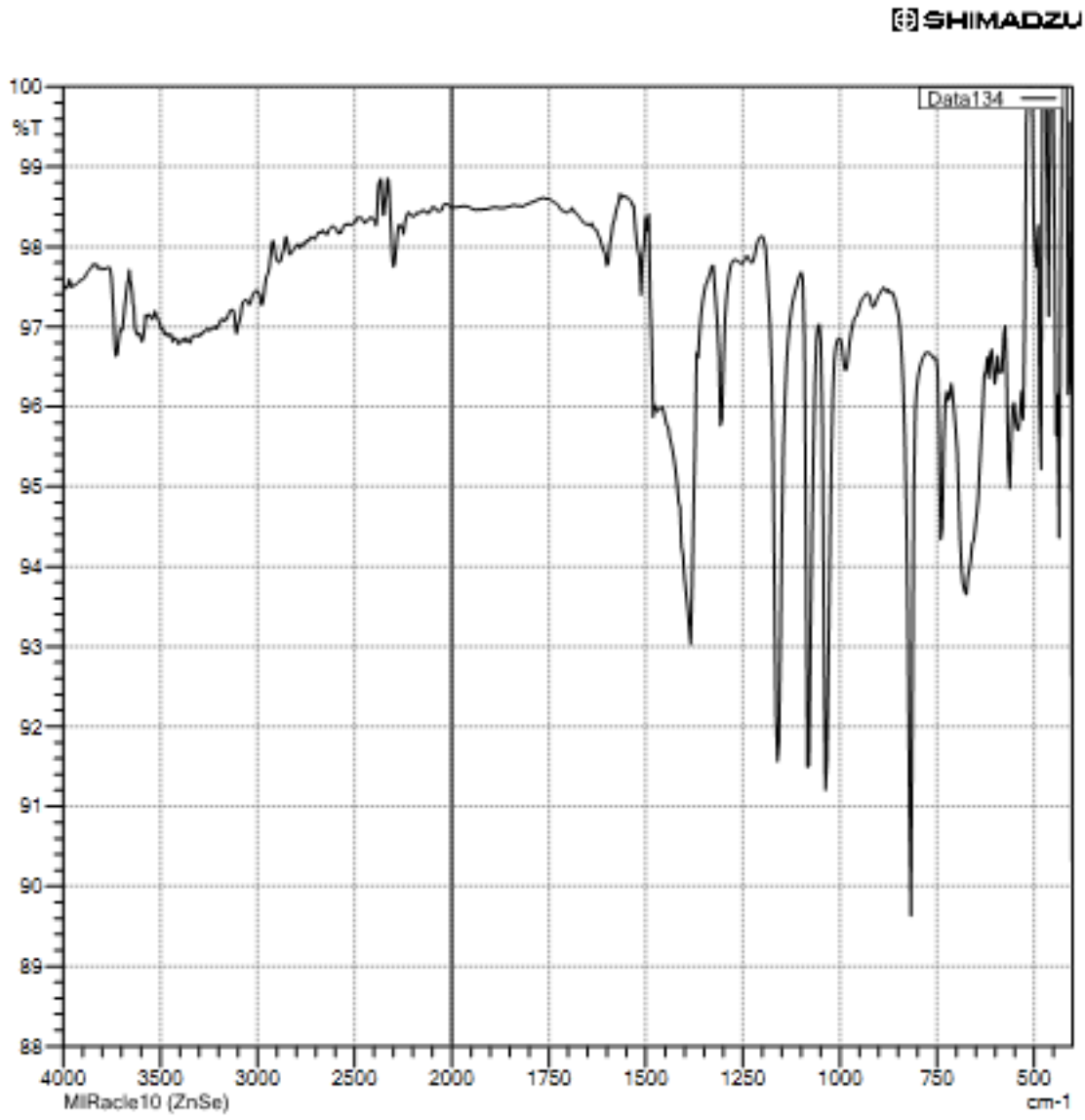


Fig:5.2.1(a) IR spectrum of $[Co(MPz)_4(H_2O)_2]Cl_2$

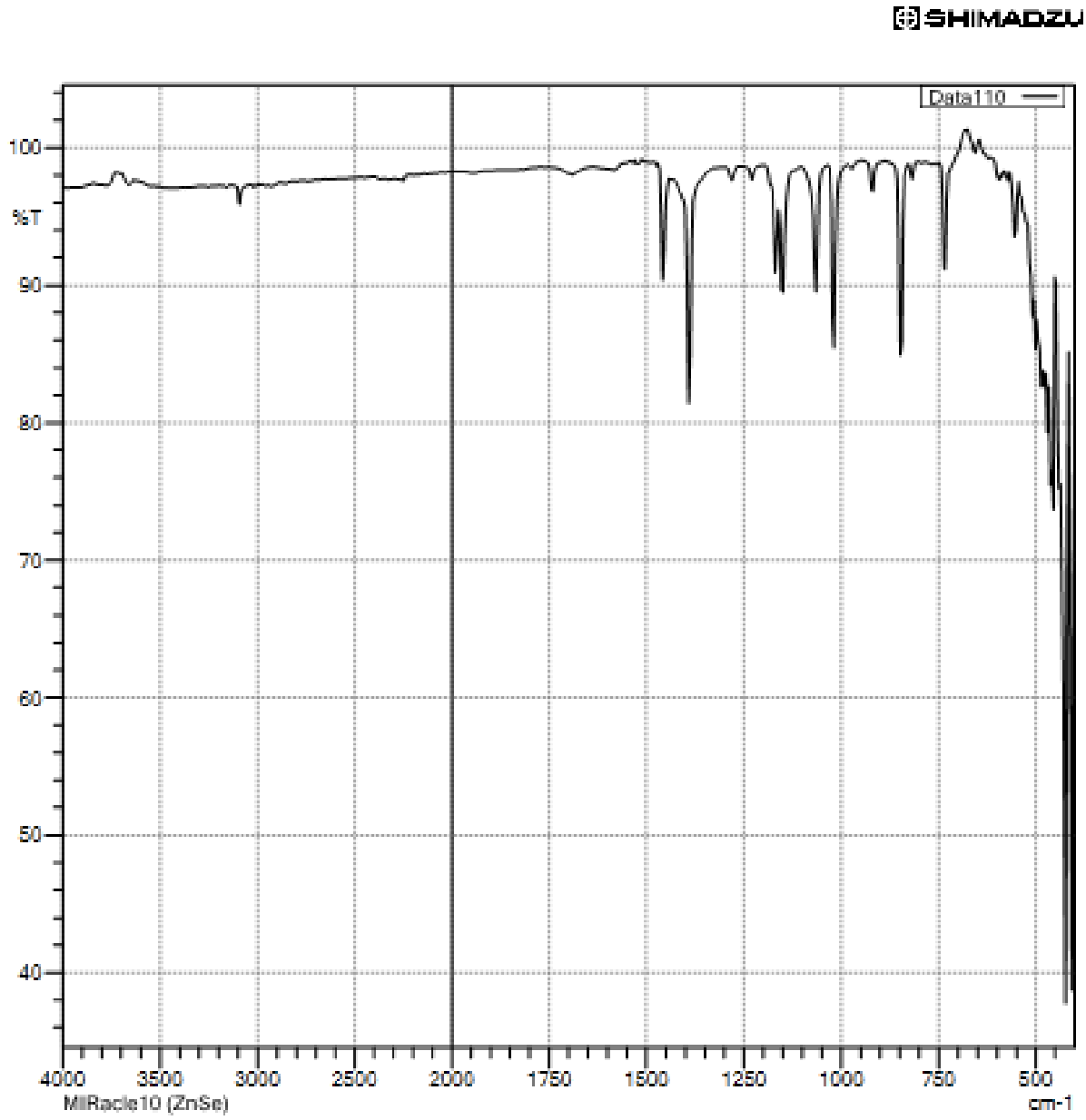


Fig: 5.2.1(b) IR spectrum of $[Co(PzCN)_4(H_2O)_2]Cl_2$

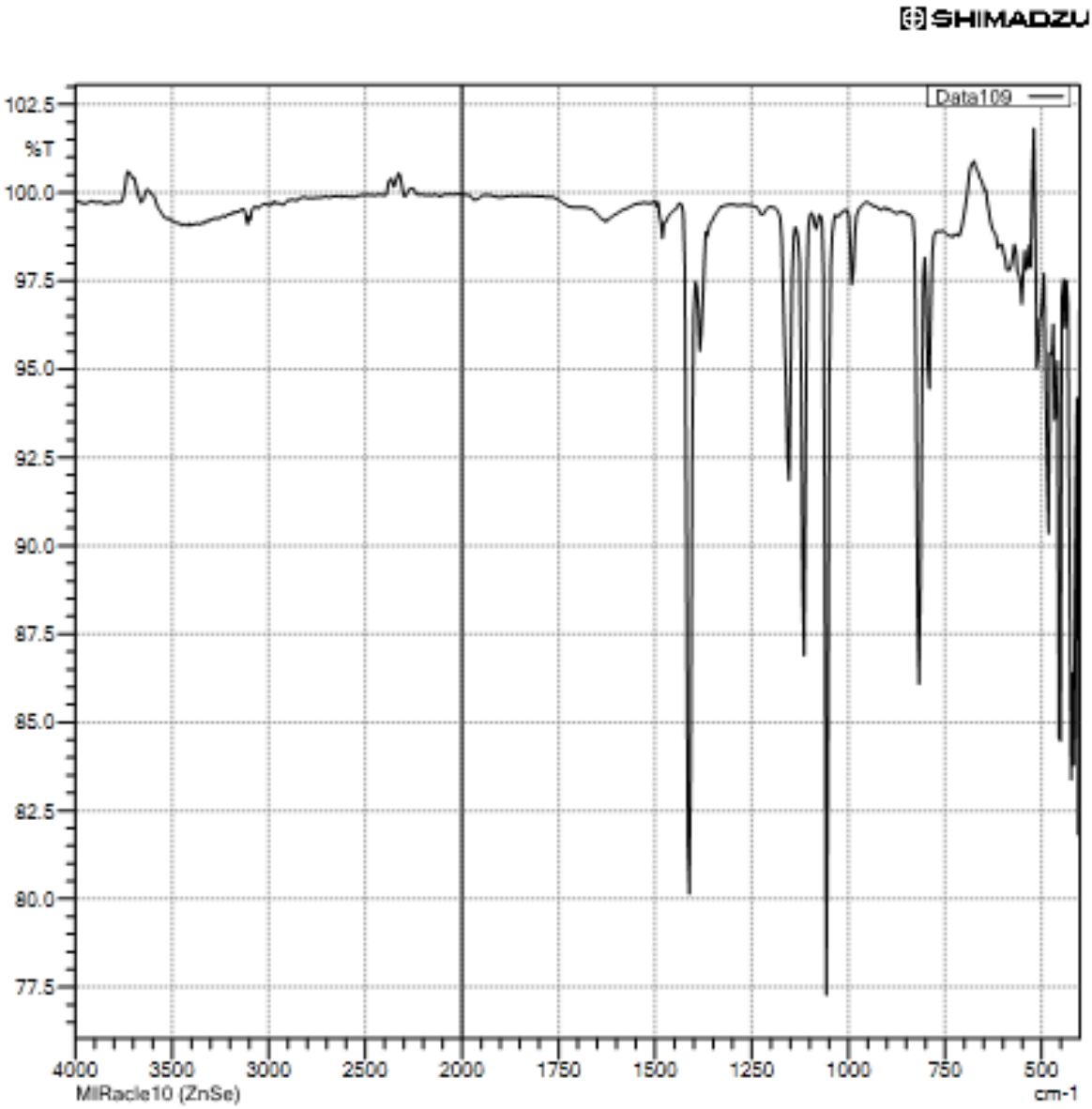


Fig: 5.2.1(c) IR spectrum of $[Co(Pz)_4(H_2O)_2]Cl_2$

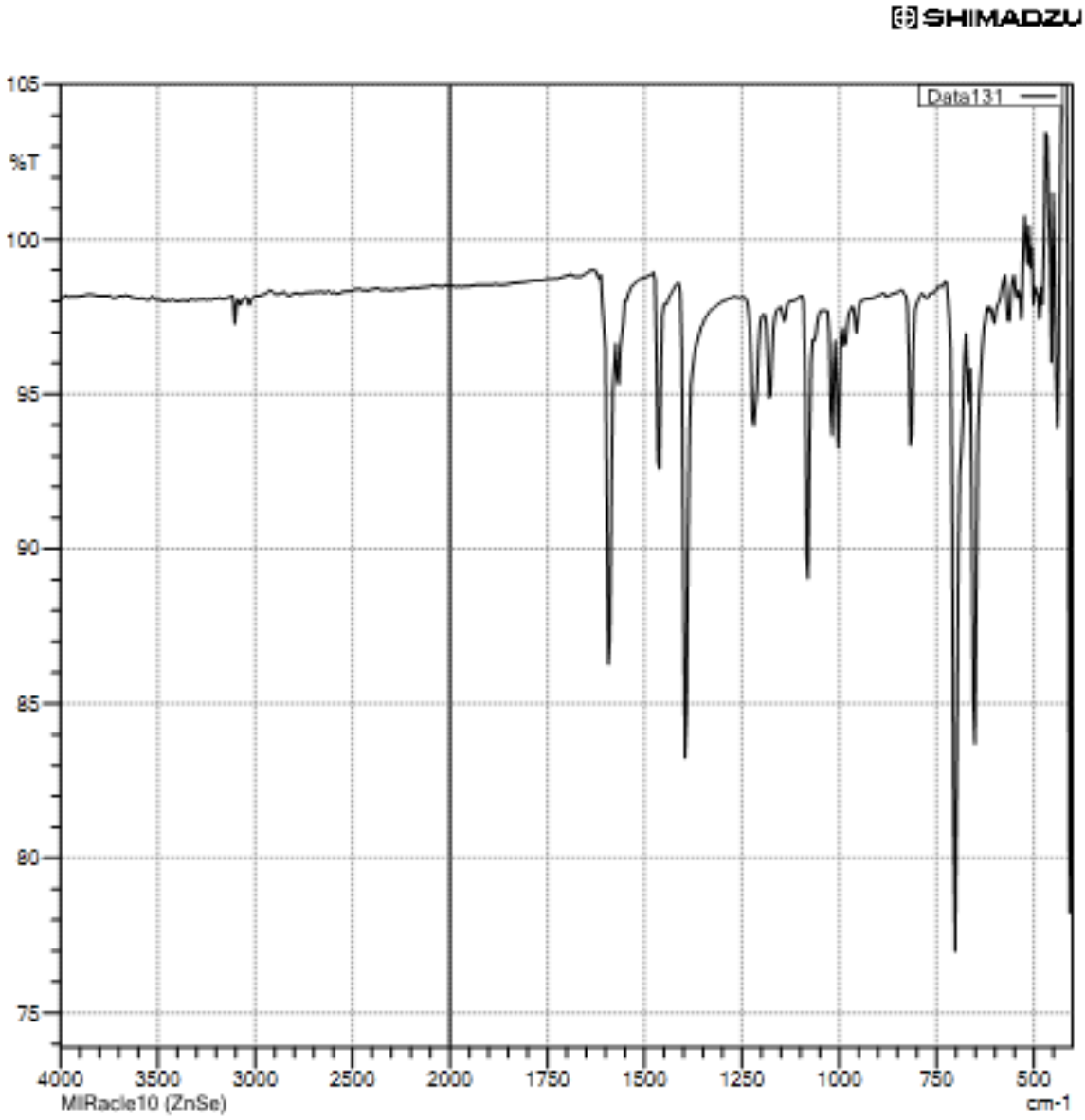


Fig: 5.2.1(d) IR spectrum of $[Co(Pym)_4(H_2O)_2]Br_2$

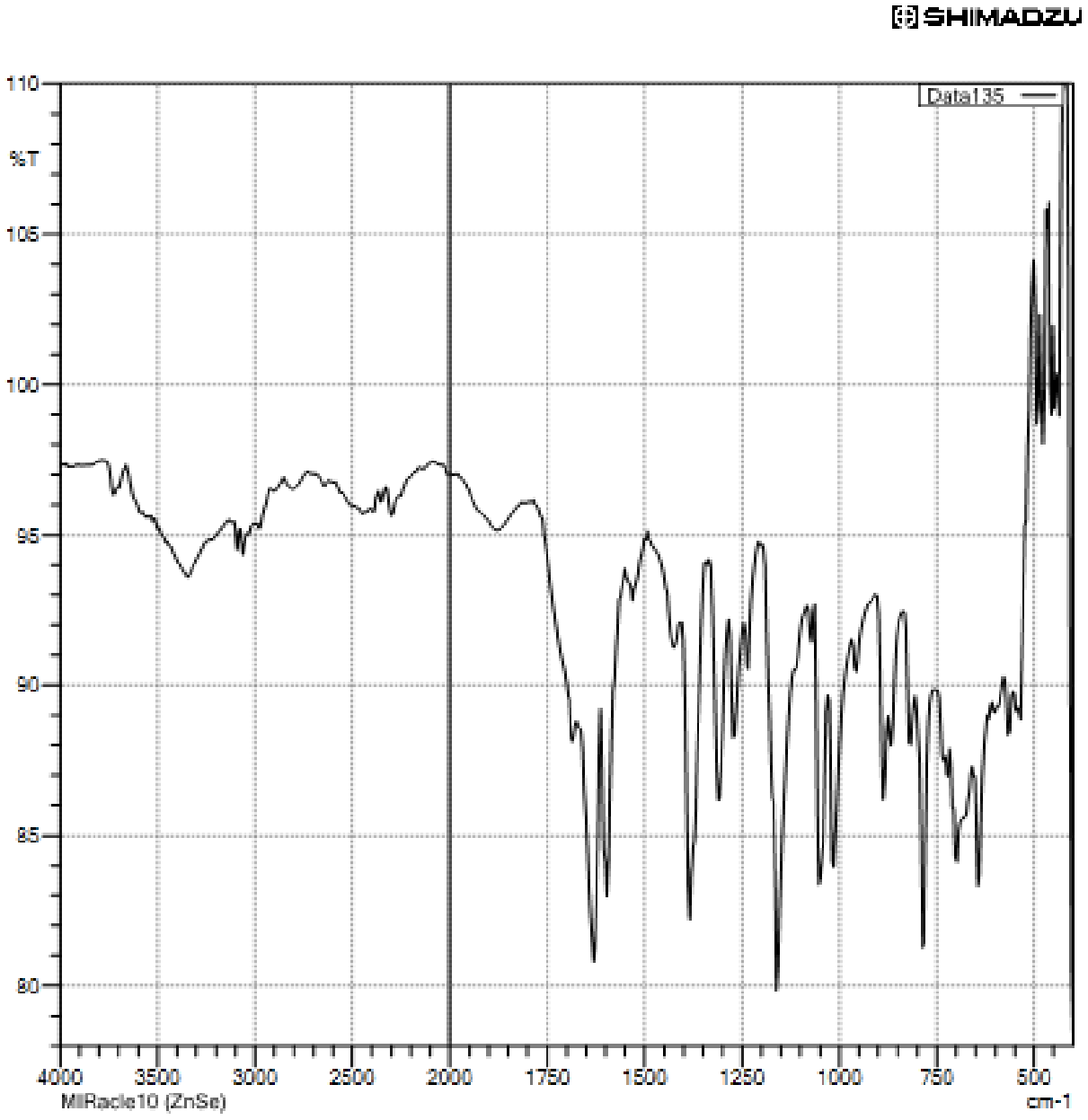


Fig: 5.2.1(e) IR spectrum of $[Co(PzCA)_4(H_2O)_2]Br_2$

5.2.2. ELECTRONIC SPECTRA

Electronic spectra of complexes of the type $[Co(B)_4(H_2O)_2]X_2$

The electronic spectra of some typical complexes are given in **Fig- 5.2.2.(a) to 5.2.2.(c)** with their correspondingλ_{max} values in **Table-5.2.2.** The cobalt(II) complexes show an high intense absorption band in the range **220-240** nm andmoderately intense band around **240-260** nm, which may be attributed to $\pi \rightarrow \pi^*$ transition of the equatorial heterocyclic moieties or the pyrazine based ligands. A shoulder around **300-350** may be due to the ligand to metal charge transfer (**LMCT**) transition(**Carol C *et al.*,2006**& **Davar M. B *et al.*,2008**).

Table-5.2.2. Electronic Spectra of complexes of the type $[Co(B)_4(H_2O)_2]X_2$; λ_{max}, nm

Complexes	λ_{max} n- π^*	λ_{max} π-π^*	λ_{max} dπ- π^*	λ_{max} LMCT
$[Co(Pz)_4(H_2O)_2]Cl_2$	238	266	375	458
$[Co(PzCA)_4(H_2O)_2]Cl_2$	210	237	285	315
$[Co(MPz)_4(H_2O)_2]Cl_2$	238	264	532	-
$[Co(PzCN)_4(H_2O)_2]Cl_2$	236	264	377	395
$[Co(Pz)_4(H_2O)_2]Br_2$	215	240	265	308
$[Co(PzCA)_4(H_2O)_2]Br_2$	240	268	-	-

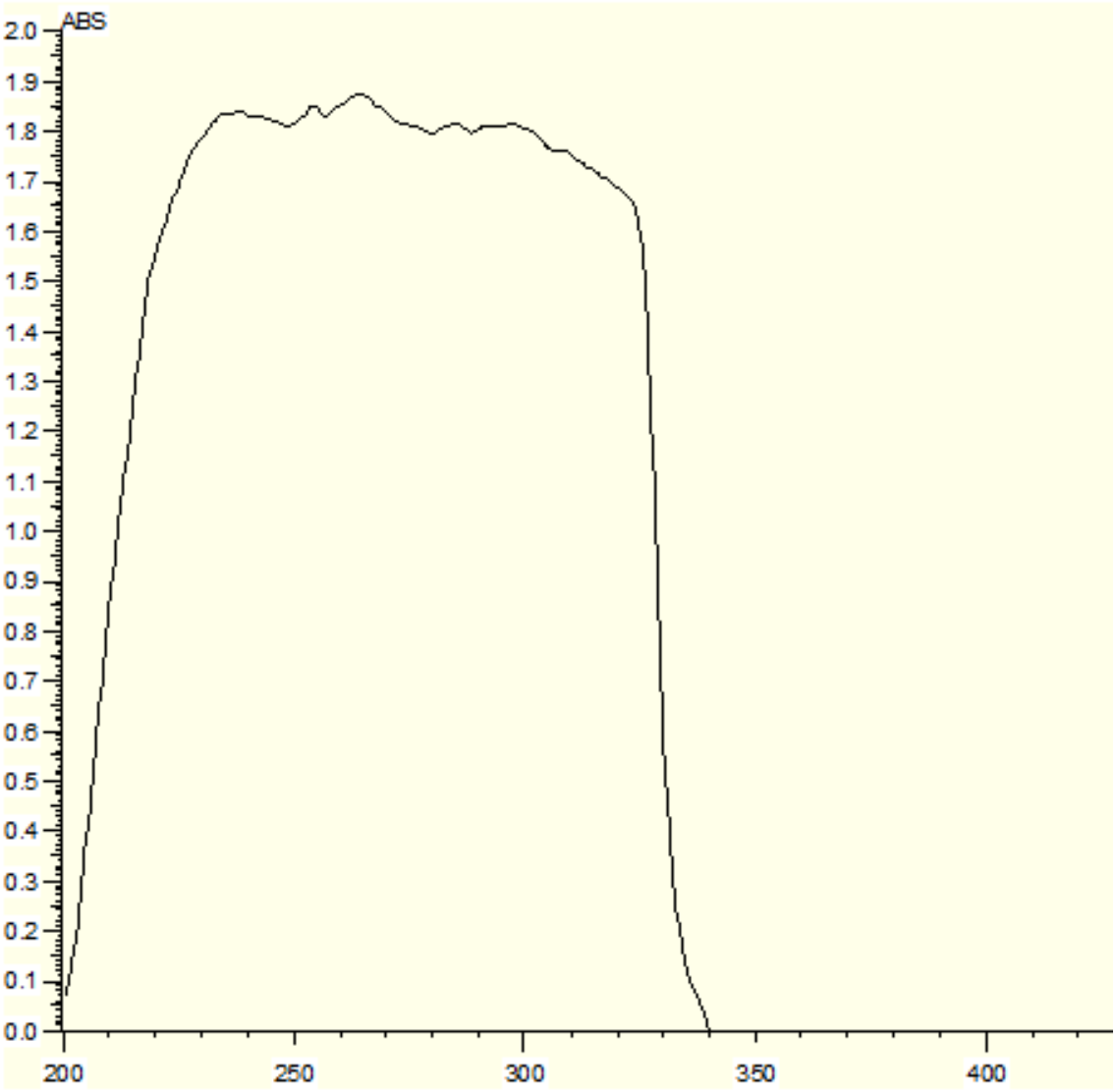


Fig: 5.2.2.(a) Electronic spectrum of $[Co(MPz)_4(H_2O)_2]Cl_2$

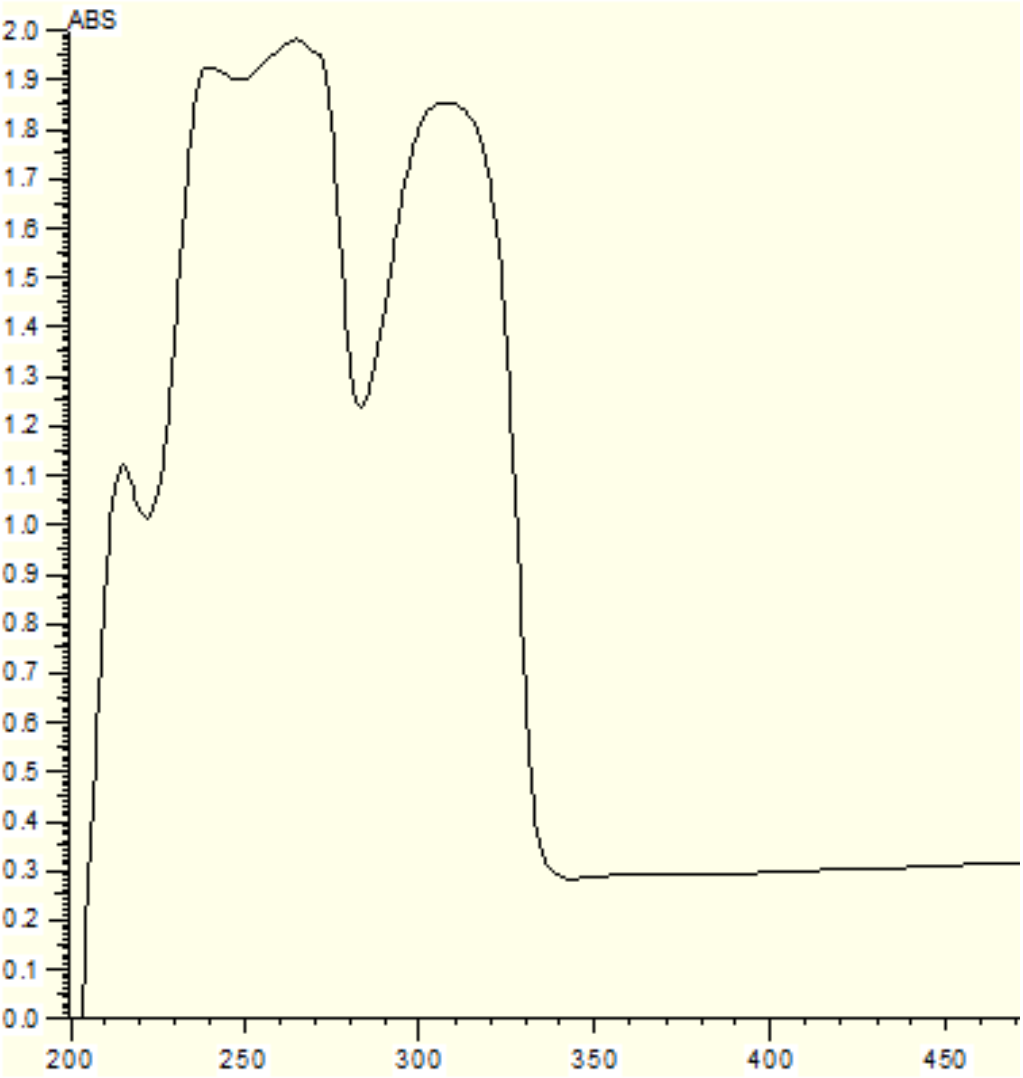


Fig: 5.2.2.(b) Electronic spectrum of $[Co(Pz)_4(H_2O)_2]Br_2$

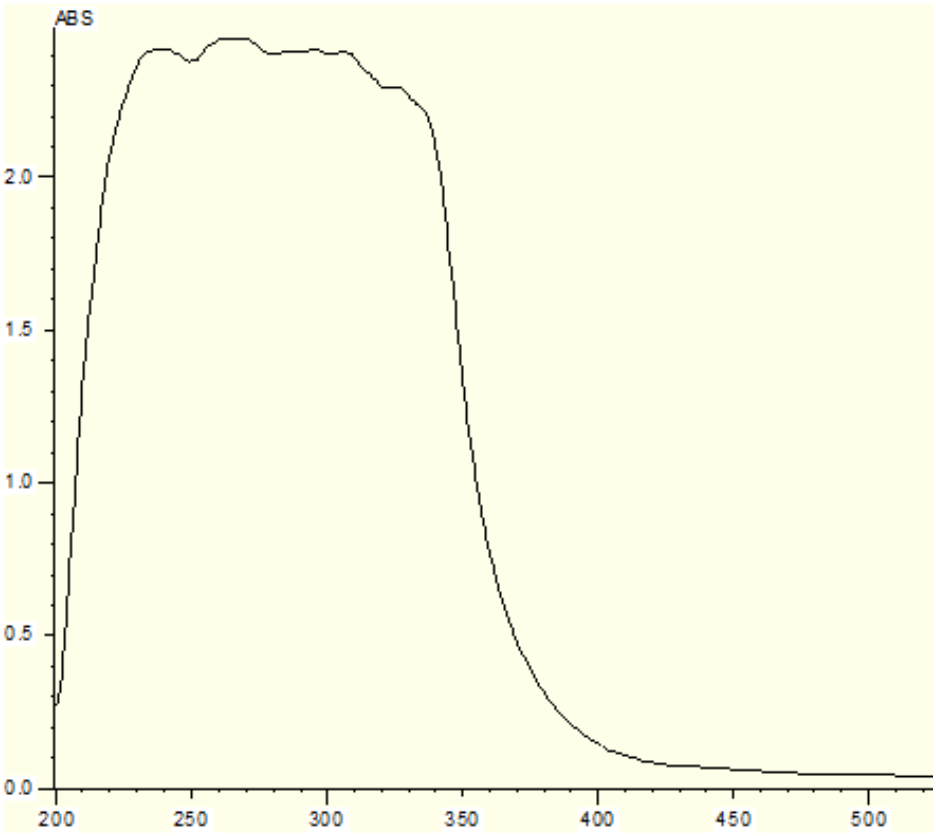


Fig: 5.2.2.(c) Electronic spectrum of $[Co(PzCA)_4(H_2O)_2]Br_2$

5.2.3. THERMAL ANALYSIS

The thermal decomposition of the complexes was found to be a multi stage process where the subsequent detachment of the ligands was observed with Co_3O_4 as the final product of decomposition. The TG/DTA curve indicates that the complexes are thermally stable up to 200°C.

Thermal analysis of complexes of the type $[Co(B)_4(H_2O)_2]X_2$

The TG, DTA and DSC analysis for the $[Co(B)_4(H_2O)_2]X_2$ showed three TG curves corresponding to three major weight losses. The thermal study of the cobalt (II) complexes reveals that the axial water molecules dissociate first followed by the dissociation of the heterocyclic moiety of the pyrazine derivatives. The axial water molecules leave in the temperature range of 200-250^{0}C. The complexes are stable upto 500^{0}C, thereafter they decompose to leave Co_2O_3 as the final residue(**Adhikari, N, *et al*.,2006 & Adhikari, N,2008**)**(Fig-5.2.3.)**.

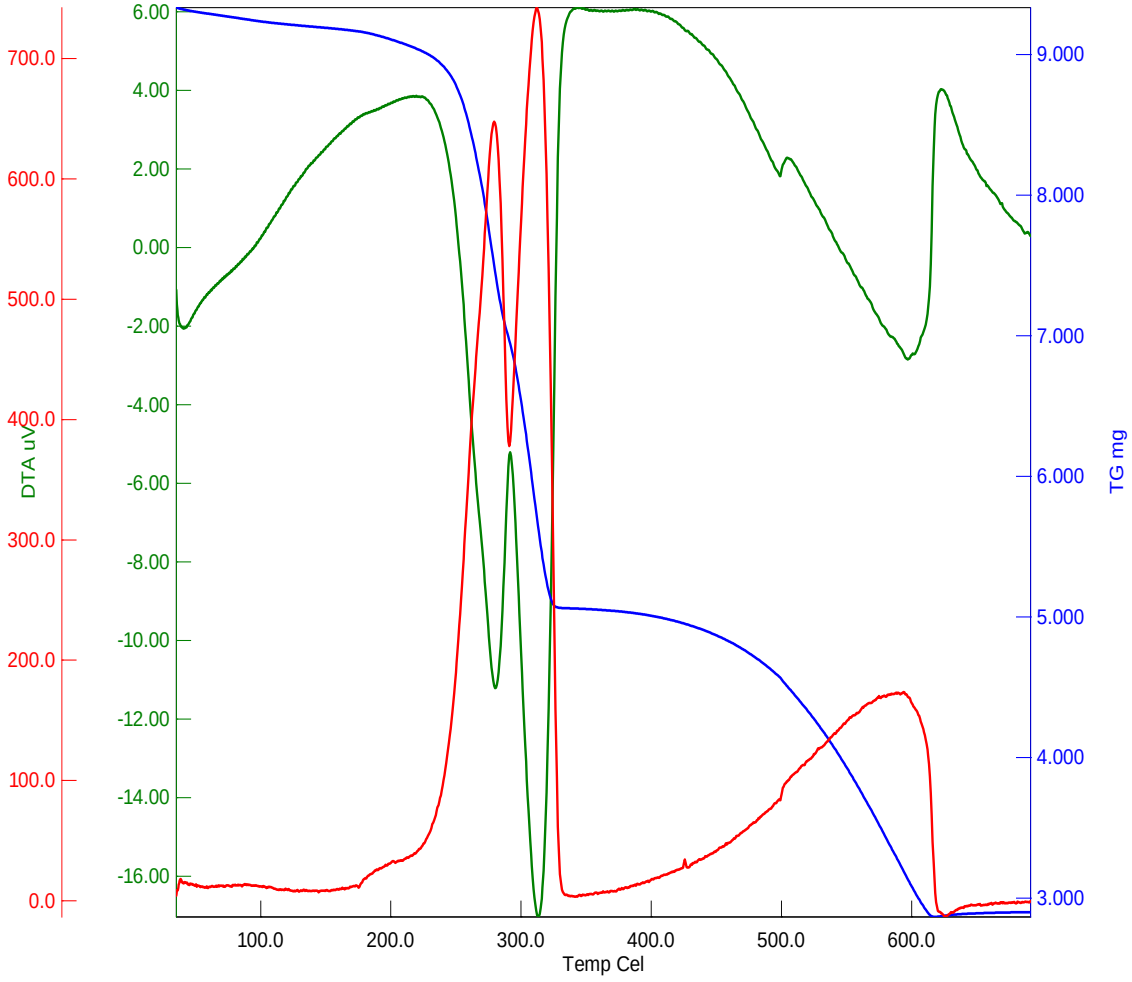


Fig: 5.2.3. Thermogram of the complex $[Co(MPz)_4(H_2O)_2]Cl_2$

5.2.4. ANTIBACTERIAL ACTIVITY

Antibacterial activity is one of the most important tools to explore the medicinal value of the ligands and the complexes. The activity of the complexes generally varies depending on the metal and the ligand environment around it. The zone of inhibition of the complexes of cobalt is given in **Tables 5.2.4.(a) and Tables 5.2.4.(b).** The corresponding figures in **Fig: 5.2.4.(a) and Fig: 5.2.4.(b)**

4.13.1. Antibacterial activity of complexes of the type $[Co(B)_4(H_2O)_2]X_2$

Complexes of cobalt(II) containing the hetero cyclic base showed better activity at almost all the levels of concentration.(**Zahid H *et al.*,2006**) Complexes of cobalt(II) showed a very good zone of inhibition against all the microbes. The Co(II) complexes containing Methylpyrazine as ligand showed moderate activity comparably with other ligands containing complexes.(**Renu S, *et al.*,2009**) The complex containing Pyrazinecarboxlyic acid as ligand showed least activity among them. When compare to bromo complexes choloro complexes showed good activity against all tested microbes. Among the tested microbes *Staphylococcus aureus* showed slight activity towards all complexes.

Tables 5.2.4.(a) Antibacterial activity of $[Co(B)_4(H_2O)_2]Cl_2$

Organisms	Zone of Inhibition(nm) Concentration: µg/disc					
	2MP 2	**CPA 1**	**2PC 3**	**PCA 1**	**DISC**	**DMSO**
Klebsiella pneumonia	11	8	8	3	Nil	Nil
Escherichia coli	12	9	8	4	Nil	Nil
Staphylococcus aureus	10	6	5	3	3	Nil

B={2MP2=$[Co(MPz)_4(H_2O)_2]Cl_2$; CPA1= $[Co(Pz)_4(H_2O)_2]Cl_2$;

2PC3= $[Co(PzCN)_4(H_2O)_2]Cl_2$; PCA1 = $[Co(PzCA)_4(H_2O)_2]Cl_2$}

Tables 5.2.4.(b): Antibacterial activity of $[Co(B)_4(H_2O)_2]Br_2$

Organism	Zone of Inhibition(nm) Concentration: µg/disc				
	CPMO	PCAB	CPM	DMSO	Disc- Ampicillin
S.aureus	8	3	7	Nil	3
K.pneumoniae	10	2	7	Nil	4
E.coli	9	3	6	Nil	Nil

B={CPMO = $[Co(Pym)_4(H_2O)_2]Br_2$; PCAB = $[Co(PzCA)_4(H_2O)_2]Br_2$; CPM = $[Co(Pz)_4(H_2O)_2]Br_2$}

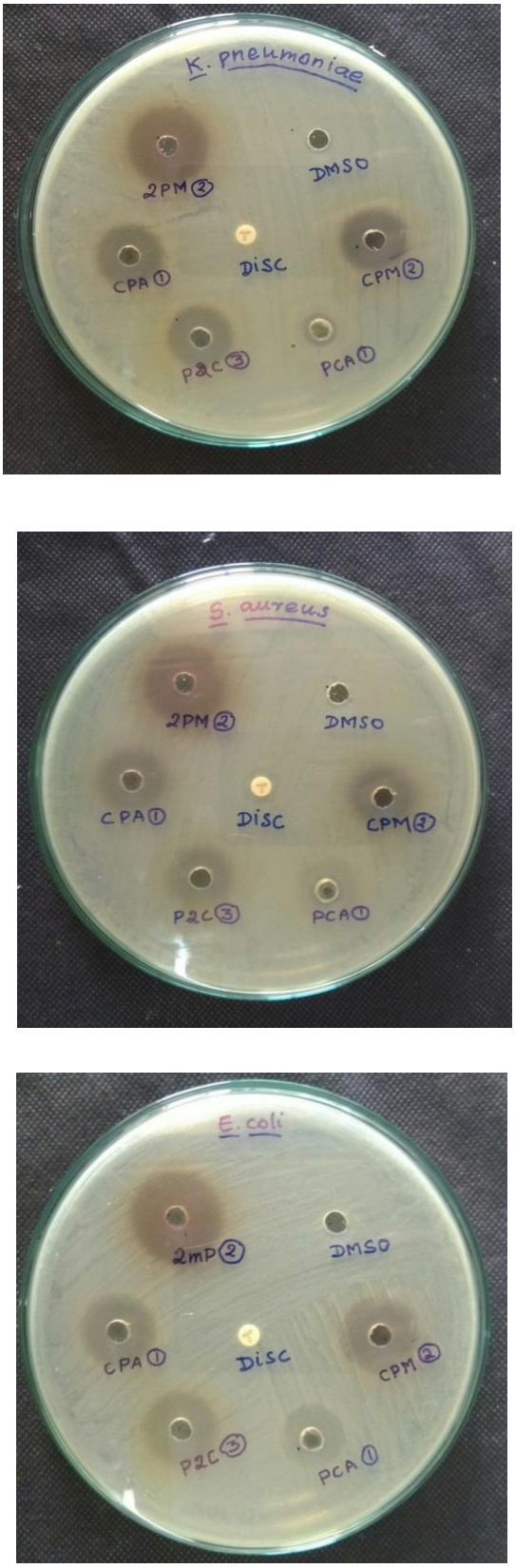
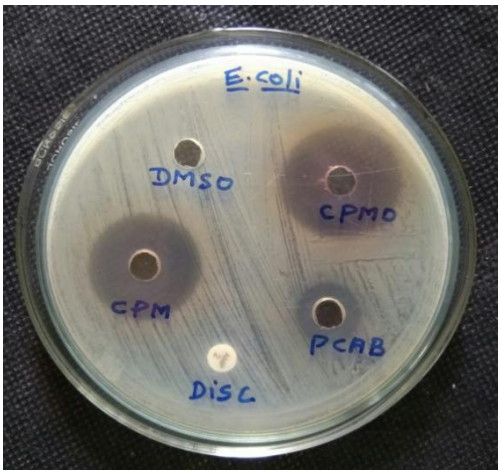
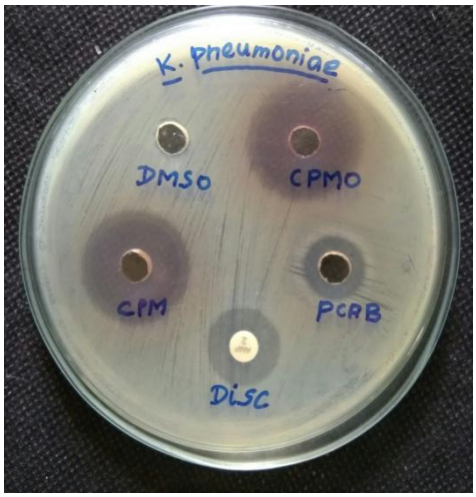


Fig: 5.2.4.(a)Zone of inhibition of $[Co(B)_4(H_2O)_2]Cl_2$





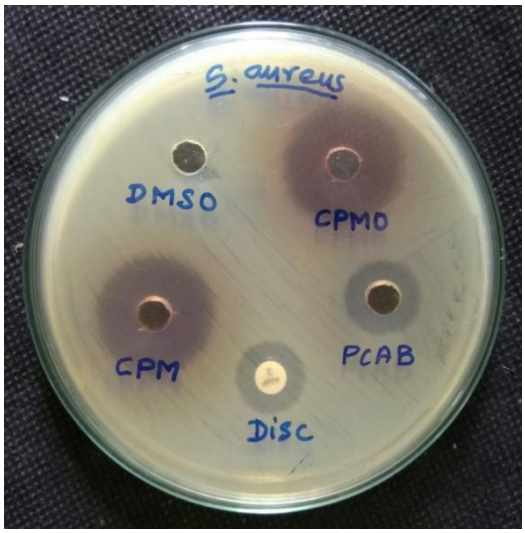


Fig: 5.2.4.(b)Zone of inhibition of $[Co(B)_4(H_2O)_2]Br_2$

Chapter-VI

Summary and Conclusion

6.1. Preparation of the complexes

Cobaltous salts ($CoCl_2$ or $CoBr_2$) were mixed with heterocyclic body of the pyrazine derivatives in 1:4 ratio in an aqueous solution of methanol or acetone and refluxed for an hour. The blue colour slowly turned pink or violate which ensured the formation of the complexes of the type $[Co(L)_4(H_2O)_2]\ X_2$.

$$\mathbf{[Co(B)_4(H_2O)_2]X_2}$$

Where, $\mathbf{X}^-$= Cl^- or Br^-

B = Pyrazine(Pz), Pyrazine Carboxylic acid(PzCA),
Methyl Pyrazine(MPz), Pyrazine Carbonitrile(PzCN), Pyrimidine(Pym)

a) All the complexes were characterized by various spectral and thermal studies.
b) The complexes were also subjected to antibacterial studies against various pathogens.

6.2. Characterization of the complexes

6.2.1. IR spectra

The C-N stretching of the complexes was observed around 1260 cm^{-1}. C-N stretching of the heterocyclic bases were found to be much higher in the case of cobalt(II) complexes.A band at 3160 cm^{-1} in the spectrum of the complex can be attributed to the stretching vibration of NH_2 moiety.Co-N stretching around 540 cm^{-1} ensured the ligation of heterocyclic base to thecobalt. The C=N stretching in the cobalt(II) complexes was observed around 2200 cm^{-1}

6.2.2. Electronic spectra

The cobalt(II) complexes show an high intense absorption band in the range **220-240** nm andmoderately intense band around **240-260** nm, which may be attributed to $\pi \rightarrow \pi^*$ transition of the equatorial heterocyclic moieties or the pyrazine

based ligands. A shoulder around **300-350** may be due to the ligand to metal charge transfer (**LMCT**) transition.

6.2.3. Thermal Analysis

The thermal study of the cobalt (II) complexes reveals that the axial water molecules dissociate first followed by the dissociation of the heterocyclic moiety of the pyrazine derivatives. The axial water molecules leave in the temperature range of 200-250^{0}C. The complexes are stable upto 500^{0}C, thereafter they decompose to leave Co_2O_3 as the final residue.

6.2.4. Antibacterial Activity

The Co(II) complexes containing Methylpyrazine as ligand showed moderate activity comparably with other ligands containing complexes. The complex containing Pyrazinecarboxlyic acid as ligand showed least activity among them. When compare to bromo complexes choloro complexes showed good activity against all tested microbes. Among the tested microbes *Staphylococcus aureus* showed slight activity towards all complexes.

Chapter VII

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