UNIVERSITÉ DE YAOUNDÉ 1
FACULTÉ DES SCIENCES

CENTRE DE RECHERCHE ET FORMATION DOCTORALE EN SCIENCES, TECHNOLOGIES ET GÉOSCIENCES

UNITÉ DE RECHERCHE ET FORMATION DOCTORALE EN CHIMIE ET APPLICATIONS

UNIVERSITY OF YAOUNDE I
FACULTY OF SCIENCE

POSTGRADUATE SCHOOL OF SCIENCE, TECHNOLOGY AND GEOSCIENCE

RESEARCH AND POSTGRADUATE TRAINING UNIT IN CHEMISTRY AND APPLICATIONS

DÉPARTEMENT DE CHIMIE INORGANIQUE
INORGANIC CHEMISTRY DEPARTMENT

LABORATOIRE DE CHIMIE INORGANIQUE APPLIQUÉE
APPLIED INORGANIC CHEMISTRY LABORATORY

SYNTHESIS, CHARACTERIZATION, AND ANTIMICROBIAL STUDY OF MIXED IONIC COMPLEXES OF COBALT(II) AND ZINC(II) DIPICOLINATES WITH N,N-DONOR LIGANDS

Mémoire présenté en vue de l'obtention du diplôme de Master en Chimie
A dissertation presented in fulfillment as partial requirements for obtaining a Master's degree in Chemistry

Spécialité / *Speciality* : Chimie Inorganique/ *Inorganic Chemistry*
Option : Chimie de Coordination/ *Coordination Chemistry*

Par/*by*

JOSIAH FONDZEVEI

(Matricule/*registration number* 21T2032)
Licencié en Chimie Général (UY1)/*First dergree holder in General Chemistry (UY1)*

Sous la Direction de /*Under the supervision of* :
NEBAH née NDOSIRI BRIDGET NDOYE
Maître de Conférences (UY1) /*Associate professor*(**UY1**)

Année/*year* 2024

UNIVERSITÉ DE YAOUNDÉ 1
FACULTÉ DES SCIENCES

CENTRE DE RECHERCHE ET FORMATION DOCTORALE EN SCIENCES, TECHNOLOGIES ET GÉOSCIENCES

UNITÉ DE RECHERCHE ET FORMATION DOCTORALE EN CHIMIE ET APPLICATIONS

UNIVERSITY OF YAOUNDE I
FACULTY OF SCIENCE

POSTGRADUATE SCHOOL OF SCIENCE, TECHNOLOGY AND GEOSCIENCE

RESEARCH AND POSTGRADUATE TRAINING UNIT IN CHEMISTRY AND APPLICATIONS

DÉPARTEMENT DE CHIMIE INORGANIQUE
INORGANIC CHEMISTRY DEPARTMENT

LABORATOIRE DE CHIMIE INORGANIQUE APPLIQUÉE
APPLIED INORGANIC CHEMISTRY LABORATORY

SYNTHESIS, CHARACTERIZATION, AND ANTIMICROBIAL STUDY OF MIXED IONIC COMPLEXES OF COBALT(II) AND ZINC(II) DIPICOLINATES WITH N,N-DONOR LIGANDS

Mémoire présenté en vue de l'obtention du diplôme de Master en Chimie
A dissertation presented in fulfillment as partial requirements for obtaining a Master's degree in Chemistry

Spécialité / *Speciality* : Chimie Inorganique/ *Inorganic Chemistry*
Option: Chimie de Coordination/ *Coordination Chemistry*

Par/*by*

JOSIAH FONDZEVEI

(*Matricule/Registration number:* 21T2032)
Licencié en Chimie Général (UY1)/*First dergree holder in General Chemistry (UY1)*

Sous la Direction de /Under the supervision of :
NEBAH née NDOSIRI BRIDGET NDOYE
Maître de Conférences(UY1)/*Associate Professor (UY1)*

Année/*year* 2024

DEDICATION

I dedicate this piece of work to my mother

Ma Vivian Birgha

ACKNOWLEGEMENTS

This research work was carried out in the Laboratory of Applied Inorganic Chemistry within the Coordination Chemistry research team at the Department of Inorganic Chemistry of the Faculty of Science, University of Yaounde I.

I thank Pr. Ndi Julius Nsami, the Head of Department of Inorganic Chemistry, for the interest he shows in the upbringing of young undergraduate Cameroonians.

I would like to express my deepest gratitude to Pr. Nebah Ndosiri Bridget Ndoye for supervising this work, for her advice given both scientifically and personally, her availability, and her patience during the completion of this work.

I warmly thank Pr. NENWA Justin, a library of knowledge for the valuable advice and follow up throughout this work.

I equally want to thank all the lecturers within the Department of Inorganic Chemistry, University of Yaounde I, especially Pr. Ndifon Peter, Pr. Paboudam Awawou, Pr. Nyamen Dyoriss, Pr. Djoufack Woumfo and Dr. Nchimi Katia, for the knowledge they have imparted to me.

My thanks also go to my senior laboratory mates, particularly Dr. Pouamo Ledoux, Dr. Nde Colince, Dr. Njiki Line, Mr Nguifo Ghislain, Mrs Kuisseu Michelle, Mrs Lumnui Gildas, Mr Lactouo Rocky, Mr Ndiffo Anselme, Mrs Tchougong Ornela, Mrs Tandja Marie, Mrs Maimboudne Delphine, Mrs Wandji Nerisse, Mr Ndibi Edwin, Mrs Domjang Christelle and Mr Njiki Rene for their suggestions and advice that have contributed to the success of this work.

I also wish to thank the coordinators of the following laboratories of the University of Yaounde 1, where some physico-chemical analyses were carried out:

- The Analytical Chemistry research group for the infrared spectroscopic analysis,
- The Analytical Chemistry research group for measurement of conductivity,
- The Microbiology research group for the analysis of the antimicrobial activities.

I will equally want to thank all my classmates, especially Mrs Djamou Ingrid for her collaboration and valuable advice which were of great help towards the accomplishment of this work.

I extend my gratitude to my wife Emaculate Ngwenyi and to my sisters for their support both physically and spiritually. I also wish to extend my heartfelt and fervent gratitude to madam Modest Berinyuy for her unwavering support throughout this work.

More thanks go to all my friends and acquaintances, for their support in one way or the other

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AIDS:	Acquired Immuno Deficiency Syndrome
Amp:	Aminopyridine
Ampho:	Amphotericin
A. baumannii:	*Acinetobacter baumannii*
AN:	*Aspergillus niger*
CA:	*Candida albicans*
Cipro:	Ciprofloxacin
CT:	*Candida tropicalis*
Dipic:	dipicolinic acid or pyridine-2,6-dicarboxylic acid
4-DMAP :	4-(dimethyl)aminopyridine
DNA :	Deoxyribonucleic acid
E. coli:	*Escherichia coli*
Eqn:	Equation
HIV:	Human Immunodeficiency Virus
HPV:	Human Papillomavirus
IR:	Infrared
P. aeruginosa :	*Pseudomonas aeruginosa*
Phen :	1,10-Phenanthroline
S. aureus :	*Staphylococcus aureus*
S. epidermidis	*Staphylococcus epidermidis*
S. flexineri	*Shigella flexineri*
UV- Visible:	Ultraviolet-visible

LIST OF TABLES

LIST OF FIGURES/IMAGES

ABSTRACT

Within the framework of this study, two mixed ionic complex salts of cobalt(II) and zinc(II) dipicolinates with 1,10-phenanthroline and 4-(dimethyl)aminopyridine as N,N-donor ligands were synthesized in aqueous solutions. The two salts $\mathbf{[Co(DMAP)_6]^{2+}[Zn(dipic)_2]^{2-}\cdot XH_2O}$ (compound **A**) and $\mathbf{[Co(phen)_3]^{2+}[Zn(dipic)_2]^{2-}\cdot XH_2O}$ (compound **B**) which appeared as crystals of red and orange colouration respectively were characterized using various physico-chemical analytical techniques such as melting point determination, solubility tests, conductimetry, powdered X-ray diffraction, IR, UV-Visible and photoluminescence spectroscopies. Their ability to inhibit microbial growth was also assessed on some bacterial and fungal strains. The molar conductivities of compounds **A** (121.2 $S.cm^{2}.mol^{-1)}$ and **B** (118.5 $S.cm^{2}.mol^{-1}$) showed that each of the synthesized compounds is made up of two ions in aqueous solution. Both compounds did not melt up to a temperature of 330 $^{\circ}C$, which is the threshold temperature of the instrument used. This further confirmed the strong nature of the forces holding the constituent particles. The solubility test results suggests that both compounds are ionic with **A** soluble in both polar protic and polar aprotic solvents while **B** on its part was only soluble in polar aprotic solvents. The IR spectra revealed that each of the synthesized materials contained water molecules of crystallization as indicated by broad bands at (3400 cm^{-1}) for compounds **A** and (3173 cm^{-1}) for compounds **B**. Shifts in vibration bands in both compounds **A** and **B** with respect to the ligands used could be attributed to complexation while vibration bands that fall in the lower region (900-400 cm^{-1}) corresponding to metal to oxygen or nitrogen bonds in the synthesized compounds further confirm the formation of new bonds. The UV-Visible and photoluminescence spectra of both compounds indicated the presence of *d-d* electronic transitions within the d^7 orbitals of Co^{2+} which are responsible for the colouration of the synthesized compounds, which equally supposes an octahedral geometry in the coordination spheres of the central metal ions. The antimicrobial activities of the target materials **A** and **B** were evaluated against five bacterial strains (*Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Acinetobacter baumannii and Shigella flexineri*) and two fungal strains (*Candida tropicalis and Candida albicans*) by microdilution in liquid medium. Compounds **A** and **B** both showed antimicrobial activities on some bacterial strains and no activity against any of the fungal strains. Compound **A** has a good antibacterial activity against *Staphylococcus aureus* while compound **B** shows a weak activity against *Escherichia coli*.

Keywords: **Mixed ionic complexes, dipicolinates, 1,10-phenanthroline, 4-(dimethyl)aminopyridine, antimicrobial activity.**

RÉSUMÉ

Dans le cadre de cette étude, deux sels complexes ioniques mixtes de dipicolinates de cobalt(II) et de zinc(II) avec Les ligands 1,10-phénanthroline et 4-(diméthyl)aminopyridine comme les ligands N,N-donneurs ont été synthétisés en solutions aqueuses. Les deux sels $[Co(DMAP)_6]^{2+}[Zn(dipic)_2]^{2-}\cdot XH_2O$ (composé **A**) et $[Co(phen)_3]^{2+}[Zn(dipic)_2]^{2-}\cdot XH_2O$ (composé **B**) qui se présentaient sous forme de cristaux de coloration rouge et orange respectivement ont été caractérisés à l'aide de diverses techniques d'analyse physico-chimique telles que la détermination du point de fusion, les tests de solubilité, la conductimétrie, la diffraction des rayons X sur poudre, les spectroscopies IR, UV-Visible et de photoluminescence. Leur capacité à inhiber la croissance microbienne a également été évaluée sur certaines souches bactériennes et fongiques. Les conductivités molaires des composés **A** (121,2 $S.cm^2.mol^{-1}$) et **B** (118,5 $S.cm^2.mol^{-1}$) ont montré que chacun des composés synthétisés était constitué de deux ions en solution aqueuse. Les deux composés n'ont pas fondu jusqu'à une température de 330 ºC, qui est la température seuil de l'instrument utilisé. Cela a confirmé la nature forte des forces qui maintiennent les particules constitutives. Les résultats du test de solubilité suggèrent que les deux composés sont ioniques, **A** étant soluble dans les solvants polaires protiques et aprotiques tandis que **B**, de son côté, n'était soluble que dans les solvants polaires aprotiques. Les spectres IR ont révélé que chacun des matériaux synthétisés contenait des molécules d'eau de cristallisation comme l'indiquent les larges bandes à ($3400\ cm^{-1}$) pour les composés **A** et ($3173\ cm^{-1}$) pour les composés **B**. Les décalages dans les bandes de vibration des composés **A** et **B** par rapport aux ligands utilisés pourraient être attribués à la complexation tandis que les bandes de vibration qui tombent dans la région inférieure ($900\text{-}400\ cm^{-1}$) correspondant aux liaisons métal-oxygène ou azote dans les composés synthétisés confirment davantage la formation de nouvelles liaisons. Les spectres UV-Visible et de photoluminescence des deux composés ont indiqué la présence de transitions électroniques d-d dans les orbitales d^7 de Co^{2+} qui sont responsables de la coloration des composés synthétisés, ce qui suppose également une géométrie octaédrique dans les sphères de coordination des ions métalliques centraux. Les activités antimicrobiennes des matériaux cibles **A** et **B** ont été évaluées contre cinq souches bactériennes (*Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Acinetobacter baumannii* et *Shigella flexineri*) et deux souches fongiques (*Candida tropicalis* et *Candida albicans*) par microdilution en milieu liquide. Les composés **A** et **B** ont tous deux montré des activités antimicrobienne sur certaines souches bacteriennes utiliseés et aucune activite contre des souches fongiques. Cependant, le composé **A** a une bonne activité antibactérienne contre *SA* et **B** une activité appréciable contre EC.

Mots clés: **Complexes ioniques mixtes, dipicolinates, 1,10-phénanthroline, 4-(diméthyl)aminopyridine, Activité antimicrobienne. .**

GENERAL INTRODUCTION

In recent times, an expansion on the synthesis and applications of mixed ionic complexes of transition metals have gained steam, due to the applications of transition metals complexes in medical field, catalysis, luminescence, coordination polymerization, magnetism, and in optical devices [1, 2]. Therefore, the syntheses of new materials capable of combining several properties or multifunctional materials occupy a special place [3]. Such is the case with mixed ionic complexes. Their properties will depend to an extent on the separate properties of the different transition metal cations that make up the anionic and cationic parts, on the ligands associated to the transition metal ions and on the geometries of the oppositely charged complexes. Mixed ionic complexes of cobalt(II) and zinc(II) with N,N-donor ligands will of no doubt possess hyper combined properties that will go a long way to provide solutions to many societal problems in various fields such as: electronics, catalysis especially in biological systems, magnetism, information storage and medicine [3,4]. One of such very useful ligands in mixed ionic complexes is dipicolinic acid which is a chelating ligand. Its transition metal complexes are of capital importance in the analysis of DNA due to their important physico-chemical properties and their possible applications as new therapeutic agents [5]. They can inhibit the growth of some pathogens such as *mycobacterium tuberculosis* and *staphylococcus aureus* [6,7]. Other ligands implicated in this work of prime importance are: 1,10-phenanthroline and 4-(dimethyl)aminopyridine. These two ligands have significant catalytic properties [8], antimicrobial properties [9-12], magnetic and optical properties [10].

Antimicrobial resistance is an increasingly serious threat to global public health that requires innovative solutions to counteract new resistance mechanisms emerging and spreading globally in infectious pathogens. Classic organic antibiotics are rapidly exhausting the structural variations available for an effective antimicrobial drug and new compounds emerging from the industrial pharmaceutical pipeline will likely have a short-term and limited impact before the pathogens can adapt. Inorganic and organometallic complexes offer the opportunity to discover and develop new active antimicrobial agents by exploiting their wide range of three-dimensional geometries and virtually infinite design possibilities that can affect their substitution kinetics, charge, lipophilicity, biological targets and modes of action [13]. Several attempts have been made in the field of research to manufacture new drugs which are more effective to resistant microbes. Complexes of cobalt, zinc, dipicolinic acid, phenanthroline and aminoderivatives of pyridine have shown antimicrobial properties. Hence synthesizing compounds that combine to a larger extent, these compounds will of no doubt provide greater antimicrobial activity, as a partial solution to antimicrobial resistance.

PROBLEM STATEMENT

Antimicrobial resistance has become a global concern ultimately affecting humans' ability to prevent and treat an increasing number of infections caused by bacteria, parasites, viruses and fungi and the success of surgery and cancer chemotherapy [13]. One of the causes for the emergence of the problem is the overuse and misuse of existing antibiotics, which fueled the evolution of pathogens resistant to the current library of antimicrobial agents. As a result, available medicines become ineffective, infections persist in the body, increasing the risk to patients' health, spreading and health care costs [13].

In previous works, complexes of cobalt(II), zinc(II), dipicolinic acid, 4-(dimethyl)aminopyridine, phenanthroline, have been synthesized and characterized by our research team. Dipicolinic acid being a polydentate ligand forms various complexes with transition metal ions or atoms. Classical synthetic methods make it possible to generate various complexes with various structures and geometries [7]. Nevertheless, it should be noted that, very few research works are reported in literature where dipicolinate ligand is associated to 1,10-phenanthroline and or 4-dimethylaminopyridine. Hence the concern of this work will be to synthesize novel mixed ionic complexes of dipicolinates with 1,10-phenanthroline and 4-(dimethyl)aminopyridine with cobalt(II) and zinc(II) and to study the potential antimicrobial properties of these novel compounds as a partial solution to antimicrobial resistance.

RESEARCH QUESTION

Will the association of appropriate proportions of cobalt(II) and zinc(II) salts with Dipicolinic acid and 1,10-phenanthroline or Dipicolinic acid and 4-(dimethyl)aminopyridine in aqueous or alcoholic medium lead to the formation of novel mixed ionic complex compounds with antimicrobial applications?

HYPOTHESIS

Literature review shows that, complexes of dipicolinic acid with other ligands show antimicrobial properties, previous works on cobalt(II) and zinc(II) equally have shown antimicrobial properties [11,12]. However, there is little or nothing in literature showing the antimicrobial properties of dipicolinic acid associated with 1,10-phenanthroline or with 4-(dimethyl)aminopyridine in complexes. Nevertheless, complexes of each of these ligands in literature show antimicrobial properties. Our research team therefore supposes that, mixed ionic complexes of cobalt(II) and zinc(II) with these ligands will have more potent antimicrobial properties than the complexes of the separate ligands.

GENERAL OBJECTIVE

The main objective of this work is to synthesize, characterize and study the antimicrobial properties of mixed ionic complexes of cobalt(II) and zinc(II) dipicolinates with 1,10-phenanthroline and with 4-dimethylaminopyridine.

SPECIFIC OBJECTIVES

This work encompasses several specific objectives which include:

- To synthesize a series of mixed ionic complexes of cobalt(II) and zinc(II) dipicolinates with 1,10-phenanthroline and 4-dimethylaminopyridine;
- To characterize the synthesized complexes using some physico-chemical analytical techniques such as melting point determination, conductivity measurements, solubility tests, powder XRD and UV-visible, IR and photoluminescence spectroscopies,
- To investigate the antimicrobial properties of the synthesized complexes.

MOTIVATION

The motivation towards carrying out this work, is to contribute our quota to the antimicrobial activity of complexes as a partial solution to drug resistance.

PLAN OF THE WORK

This work is structured into three main chapters as follows**:**

Chapter I presents generalities on transition metals, the coordination chemistry and biological activities of cobalt, zinc, dipicolinic acid, 1,10 Phenanthroline, 4-(dimethyl)aminopyridine and mixed ionic complexes . The chapter equally presents important points about microorganisms with case studies and antimicrobial resistance of microbes to drugs.

Chapter II describes the materials, equipment and reagents used during the various laboratory manipulations, the experimental procedures used for synthesis and characterization of the different chemical compounds.

Chapter III presents the results and a thorough analysis of these results obtained from our findings.

The last part of this work is the general conclusion which relates the obtained results and their resulting perspectives.

CHAPTER I: LITERATURE REVIEW

This chapter presents generalities on transition metals, the coordination chemistry and biological activities of cobalt, zinc, dipicolinic acid, 1,10 Phenanthroline, 4-(dimethyl)aminopyridine and mixed ionic complexes . The chapter equally highlights important points about microorganisms with case studies and antimicrobial resistance of microbes to drugs.

I.1: TRANSITION METALS

These are chemical elements in the d and f-blocks of the periodic table in which their highest energy electrons are filing into an inner d or f subshells respectively and which can form cations with an incompletely filled d or f subshell. The d-block series involves the elements from group 3A to group 12A in periods 4, 5 and 6 while the f-block transition series include the lanthanides and the actinides. Generally, the transition metals except mercury which is a liquid, are solids at room temperature and pressure. They form coloured compounds, coordination compounds or complexes, compounds with either paramagnetic or diamagnetic properties.

Transition metals are known to be involved in several biological processes in bodies of living organisms. They occur in all living organisms ranging from unicellular to multicellular. Nevertheless, in some cases, they may just occur as traces. They have very important and essential properties in the human body [14, 15]. In this work, we shall focus on two ions of d-block elements, namely, zinc(II) and cobalt(II) ions.

I.1.1: CHEMISTRY OF COBALT

I.1.1.1: Generalities

Cobalt is a chemical element with symbol Co, atomic number 27 and electronic configuration $[Ar]3d^7 4s^2$. It is a d-block element in the first transition series. The occurrence of cobalt in the earth's surface varies greatly. This element does not exist in its native form and is encountered only in meteorites. Cobalt is most often found in the form of arsenides and sulphides. The most important cobalt minerals are cobaltite (CoAsS), linnaeite (Co_3S_4), smaltyn ($CoAs_2$) and karrolit ($CuCo_2S_4$) [16].

Cobalt occurs usually as a double-valenced cation, Co^{2+} (cobalt(II) compounds). In erosive environments, it easily undergoes oxidation from Co^{2+} to Co^{3+} and creates the complex anion $[Co(OH)_6]^{3-}$. It relatively easily becomes mobile in acidic oxidizing environments, but does not undergo extensive aqueous migration, since it combines with the hydroxides of iron and manganese as well as silty minerals [17].

I.1.1.2: Physico-chemical properties of cobalt

Metallic cobalt occurs in two crystallographic structures: Face centred cubic (fcc) and hexagonal close packed (hcp). Non alloyed cobalt is a hard ferromagnetic material solid, with a silver-white appearance. It has a relative density of 7.874, a melting point of 1495 °C and a boiling point of 2927 °C [18].

Cobalt is a moderately reactive metal. It combines with oxygen in the air when heated but does not burn in air except in the powder form. It combines with most dilute acids to liberate hydrogen gas. However, cobalt does not react with water at room temperature and with nitrogen gas. Equations (**Eqn (1))** and (**Eqn(2)**) show the reaction of native cobalt with oxygen and dilute nitric acid respectively

$3Co_{(s)} + 2O_{2(g)} \rightarrow Co_3O_{4(s)}$ **Eqn (1)**

$Co_{(s)} + 2HNO_{3(aq)} \rightarrow Co(NO_3)_{2(aq)} + H_{2(g)}$ **Eqn (2)**

I.1.1.3: Ores of cobalt

There is lack of fundamental knowledge on cobalt minerals and their processability. The bulk of world cobalt output usually arises as a by-product of extracting other metals, mostly nickel (Ni) and copper (Cu), from a wide variety of deposit types mostly Cu-Co sediment-hosted deposits, but also Ni-Co laterites, Ni-Cu-Co sulphides or hydrothermal and volcanogenic deposits [16]. Cobalt can also be found in varying amounts in plants, soils and animals and is a vital element for many organisms. With mammals, cobalt is an active component of vitamin B12 (cobalamin), a substance which catalyzes the regeneration of red blood cells, and plays a role in the normal functioning of the brain and nervous system [19]. Cobalt mineralization is typically found in Cu-Co sulphide or oxide ores, Ni-Cu magmatic sulphide ores or Ni-Co laterites. Some ores of cobalt include: Cobaltite, Smaltite, erythrite, glaucodot and Linnaeite [16].

I.1.1.4: Coordination chemistry

Cobalt forms compounds in several oxidation states but the most common are +2 and the +3 oxidation states [20]. Cobalt in the +2 oxidation state has electronic configuration $[Ar]3d^7$ while Cobalt in the +3 oxidation state has electronic configuration $[Ar]3d^6$.

Cobalt in both oxidation states forms paramagnetic compounds in weak ligand fields. However, with strong field ligands, cobalt(III) compounds or complexes are diamagnetic while cobalt(II) ions/complexes are paramagnetic [21]. Cobalt complexes generally have octahedral, square planar (rare) and tetrahedral shapes with coordination numbers of 6, 4, 4 respectively. The common coordination numbers in literature are 4 and 6.

Figure 1 shows the distribution of d electrons in Co^{2+} ions ($[Ar]3d^7$) in an octahedral and in a square planar complex with strong field ligands.

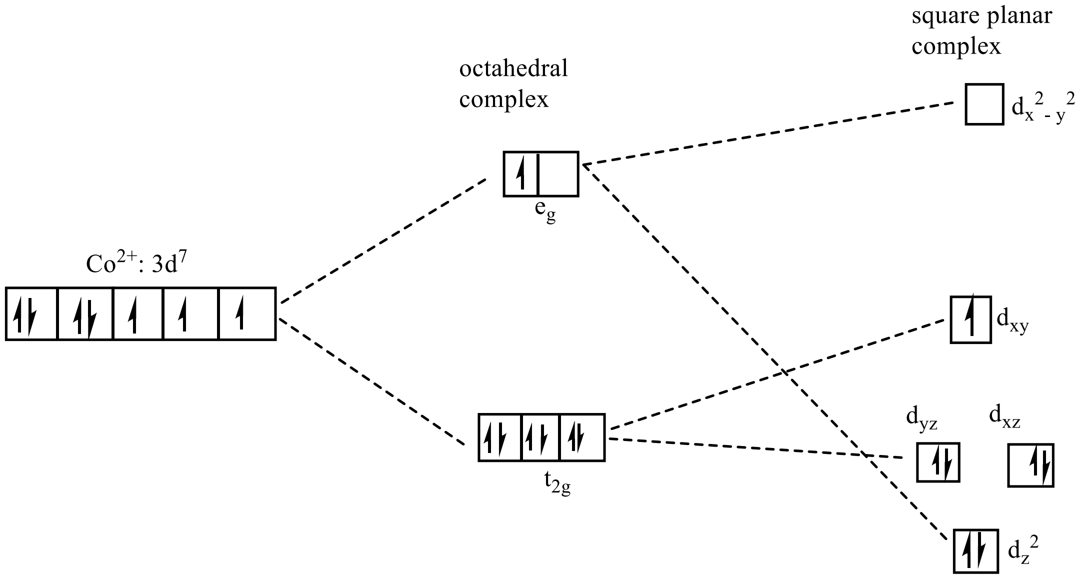
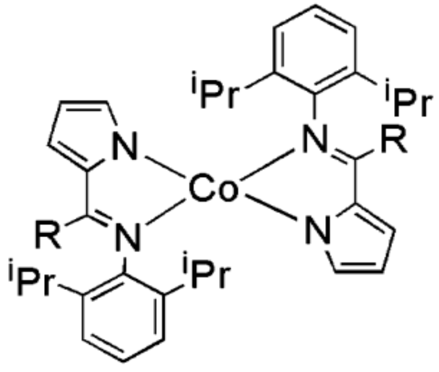


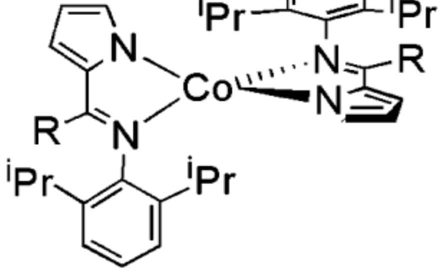
Figure 1: The distribution of d electrons in Co^{2+} ions (d^7) in a strong ligand field

Cobalt(III) [d^6], forms mainly octahedral complexes.

- Complexes of cobalt with a coordination number of 4 usually show either tetrahedral or square planar geometries e.g $[CoCl_4]^{2-}$, tetrachlorocobaltate(II) ion has a tetrahedral geometry while $[Co(CN)_4]^{2-}$, tetracyanocobaltate(II) ion has a square planar shape [22]. Figure 2 shows an example of a tetrahedral and a square planar complex of cobalt(II) [23].



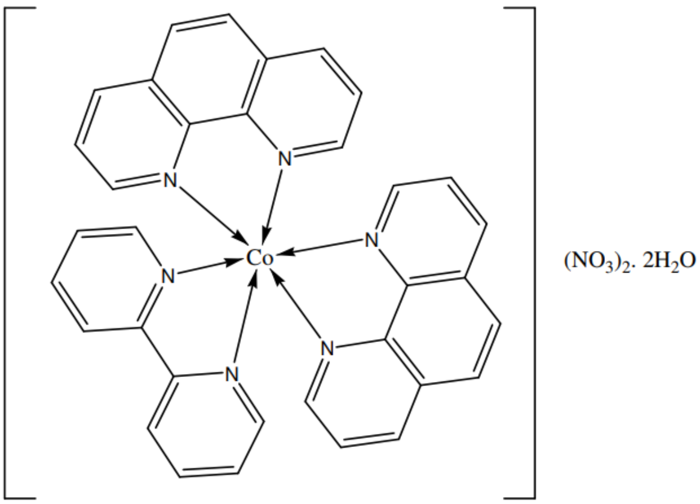
square planar



tetrahedral

Figure 2: A tetrahedral [23] and a square planar complex of cobalt(II) [23]

Cobalt(II) complexes with a coordination number of 6 have octahedral shapes [23]. An example of a cobalt(II) complex in the octahedral geometry is $[Co(bpy)(phen)_2](NO_3)_2{\cdot}2H_2O$ [24], whose structured is displayed in Figure 3.



$[Co(bpy)(phen)_2](NO_3)_2.2H_2O$

Figure 3: An octahedral complex of cobalt (II) [24]

I.1.1.5: Biological activities

Cobalt is a very important element for metabolism in all animals, especially for the production of cobalamin or Vitamin B12. Cobalt and cobalt oxide nanoparticles have biological applications because of their distinctive antioxidant, antimicrobial, antifungal, anticancer, larvicidal, antileishmanial, anticholinergic, wound healing and antidiabetic properties [24, 25]. Cobalt has a significant role in protein; there are at least 8 cobalt dependent proteins [24]. Cobalt complexes with their parent nitrogen donor ligands “1,10-phenanthroline and 2,9-dimephenanthroline” synthesized by Shalash et al., (2017) showed high activity against $Gram^-$ or $Gram^+$ bacteria except against *E. coli and S. epidermidis* [24].

In medicine: some cobalt compounds can acts as antimicrobial agents in biological systems [11, 12]. Cobalt ferrite ($CoFe_2O_4$) has a great physical and chemical stability and large anisotropy, making it suitable for biomedical applications. This compound is equally applicable in pathogen detection, drug delivery and tissue repairs [26].

Cobalt-60 is a radioactive isotope of cobalt used for sterilizing medical equipment and consumer products, radiation therapy and for treatment of cancer [27].

I.1.2: CHEMISTRY OF ZINC

I.1.2.1: Generalities

Zinc is a chemical element with symbol Zn, atomic number 30 and electronic configuration $[Ar]3d^{10}4s^2$. It is a d-block element in the first transition series. It is a bluish-white metal of moderate strength, hardness and ductility. Zinc occurs naturally in the combined state as zinc sulphide in sphalerite, and as zinc oxide ores. Zinc oxide ores contain various types of carbonates and/or silicates, such as smithsonite ($ZnCO_3$), hydrozincite [$Zn_5(CO_3)_2(OH)_6$], zincite (ZnO) and willemite (Zn_2SiO_4) [28]. Zinc forms only one ion (Zn^{2+}) with a completely filled d-subshell and hence its compounds are usually not coloured. However, it forms several complexes.

I.1.2.2: Physico-chemical properties of zinc

Zinc is a bluish - white metal. It adopts a hexagonal closed packed crystal structure at room temperature. It occurs in 5 isotopic forms with masses ranging from 64 to 70. Zinc metal has a relative density of 7.13, a melting point of 420 °C and a boiling point of 906 °C [29].

In ordinary conditions, zinc reacts rapidly with air, moderately with halogens, acids and alkalis. Zinc reacts with dilute sodium hydroxide to form sodium zincate and with dilute acids to form salts liberating hydrogen gas as shown in **Eqn (3)** and **Eqn (4)**. Hence zinc is an amphoteric metal.

$2NaOH(aq) + Zn(s) \rightarrow Na_2ZnO_2(s) + H_2(g)$ **Eqn (3)**

$H_2SO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + H_2(g)$ **Eqn (4)**

I.1.2.3: The ores of zinc

Zinc(II) is found as numerous, named minerals of widely different types, including sulfides (ZnS, sphalerite and wurtzite), sulfates ($ZnSO_4$, zincosite; $ZnSO_4.2H_2O$, goslarite), oxides (ZnO, zincite; $ZnFe_2O_4$ franklinite; $ZnAl_2O_4$, gahnite), carbonates (smithsonite, $ZnCO_3$), phosphates ($Zn_3(PO_4)_2.4H_2O$), hopeite) and silicates (Zn_2SiO_4, willemite; $Zn_4Si_2O_7(OH)_2.H_2O$, hemimorphite). The principal zinc ores of commerce are sphalerite, smithsonite, and hemimorphite [29, 30].

I.1.2.4: Coordination chemistry of zinc metal

Zinc forms only one ion (Zn^{2+}) with a completely filled d-subshell (d^{10}). Therefore, zinc coordinated compounds or complexes are diamagnetic, and often colourless. Nevertheless, Zinc metal still forms complexes with various geometries ranging from tetrahedral and square planar (coordination number 4), trigonal bipyramidal or pentagonal bipyramidal (coordination number 5) [31], to octahedral (coordination number 6). In aqueous solution, zinc forms the octahedral complex $[Zn(H_2O)_6]^{2+}$, hexaaquazinc(II) ion. Zinc forms predominantly complexes with a coordination number of 4. E.g $[ZnCl_2(Hpz)_2]$ and $[ZnCl_2(Bpzm)]$ [32] as shown in Figure 4. These complexes adopt a tetrahedral geometry.

Figure 4: Tetrahedral complexes of zinc [32]

Some zinc complexes with coordination number six (octahedral) are given given in Figure 5. [33].

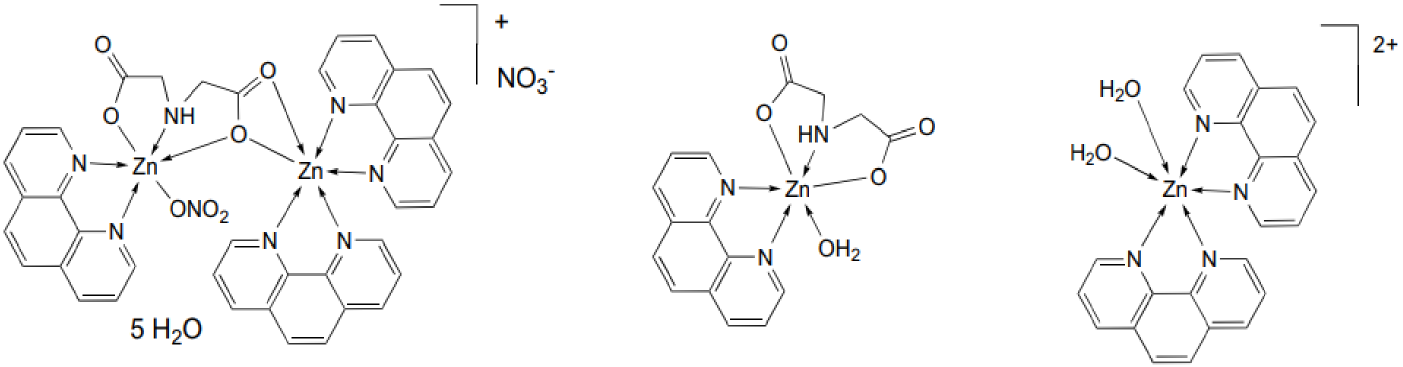


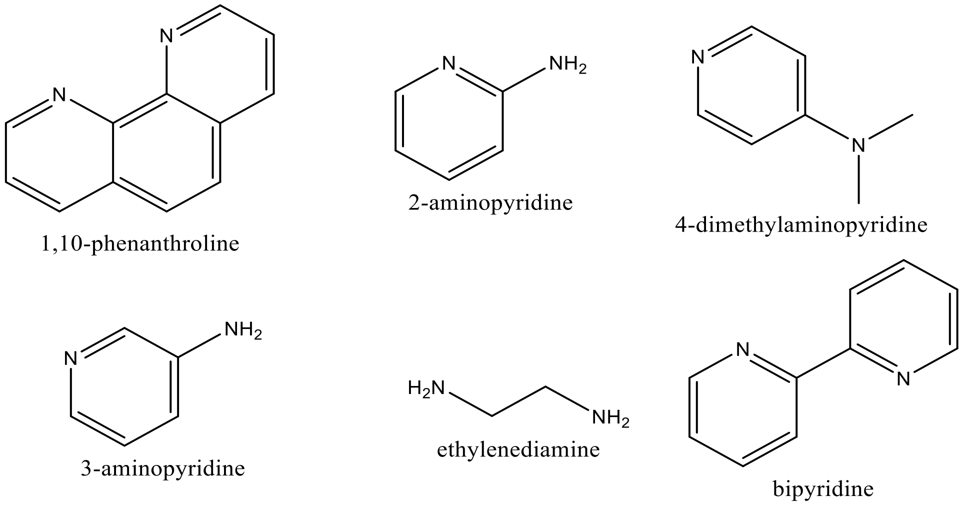
Figure 5: Octahedral complexes of zinc [33]

I.1.2.5: biological activity of zinc metal and its complexes

The average human body contains 3g of zinc which makes it the second most abundant trace element in the body after Iron [34]. Zinc is the only metal that appears in all classes of enzymes. It is mainly distributed in blood, kidney, liver and bone. Studies have shown that zinc(II) has important antibacterial and antiviral effects [11, 12]. Zinc deficiency in the human body can lead to retarded growth. In medicine, it has both antifungal and antibacterial properties, promotes tissue regeneration and reduces inflammation. Zinc is equally involved in DNA synthesis, cell division and gene expression. Some Zinc complexes have been proven to have anticancer properties [29, 31, 33, 34].

I.2: REVIEW OF LIGANDS USED

A ligand is a neutral molecule or negatively charged specie that contains at least a lone pair of electrons that it can donate to a central metal atom or ion to form a dative bond or coordinate bond. N,N donor ligands are nitrogen containing ligands with two lone pairs of electrons from two nitrogen atoms. Most of these ligands are amine or imine derivatives. They are typically chelating agents and are polydentate ligands. Examples of N,N-donor ligands include: bipyridine, 2-aminopyridine, ethylenediamine, 4-dimethylaminopyridine, 1,10-phenanthroline. [35]. Figure 6 shows some examples.



1,10-phenanthroline

2-aminopyridine

4-dimethylaminopyridine

3-aminopyridine

ethylenediamine

bipyridine

Figure 6: Examples of N,N donor ligands [35]

The ligands used in the course of this work are: dipicolinic acid, 1,10-phenanthroline and 4-(dimethylamino)pyridine.

I.2.1: DIPICOLINIC ACID

I.2.1.1: Structure

Pyridine-2,6-dicarboxylic acid, also known as dipicolinic acid, abbreviated as Dipic is a versatile multidentate ligand that forms very stable complexes of a limited steric hindrance with various metals ions via two carboxyl oxygen atoms situated at 120° angle and pyridine ring nitrogen atom, providing interesting topologies and physical properties, such as the photoluminescence, gas adsorption, catalysis, multifunctional materials and nonlinear optics under the appropriate conditions [36]. It is a dibasic acid and hence produces two hydrogen ions in aqueous solution. Salts of dipicolinic acids are called dipicolinates. The structure of Dipic is given in Figure 7.

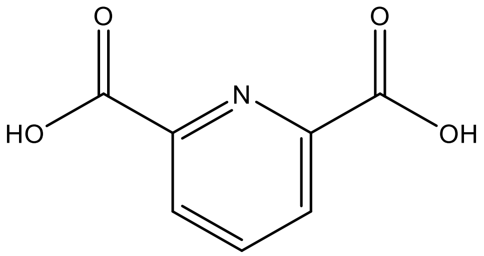


Figure 7: Structure of Dipic

Figure 8 presents the coordination modes of Dipic [37].

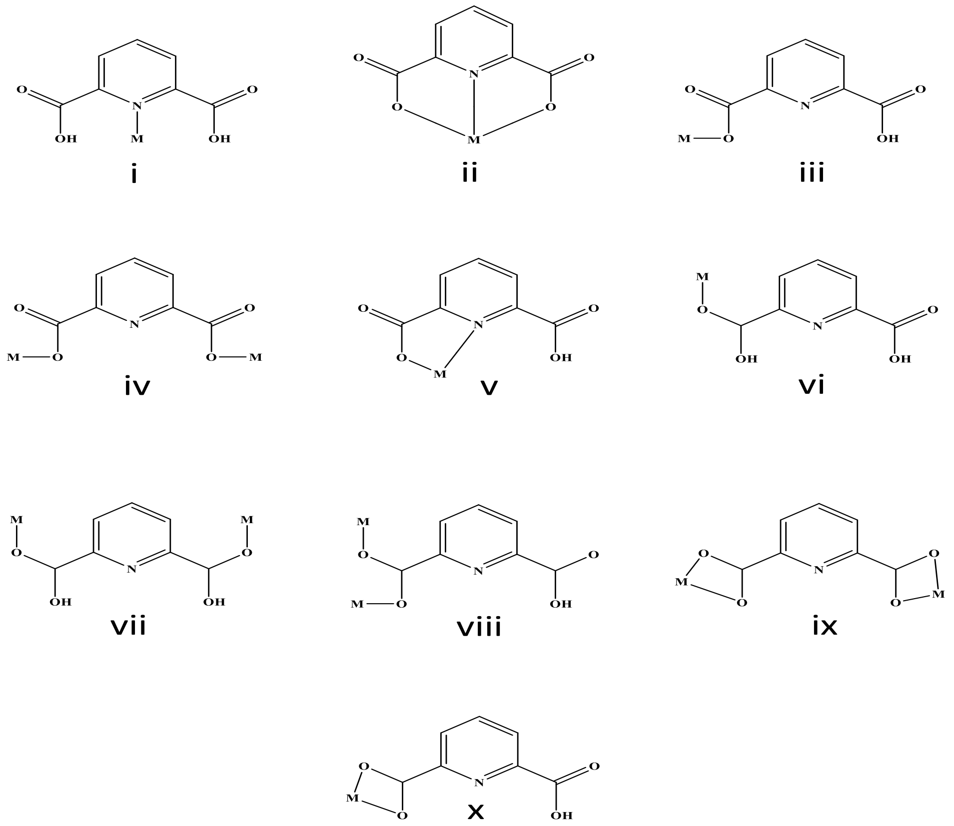


Figure 8: Coordination modes of Dipic [37]

I.2.1.2: Physico-chemical properties of DIPIC

Dipic, with general molecular formula $C_7H_5NO_4$ is a white crystalline solid with a molar mass of 167.12 g/mol. It has a melting point of 253 $^{\circ}$C and a boiling point of 463.7 $^{\circ}$C. It is soluble in water and has a density of 1.6 g/cm^3.

I.2.1.3: Biological activity

Pyridine-2,6-dicarboxylic acid has been proven to have a broad range of biological uses in medicine and pharmaceuticals, as well as a significant function in coordination chemistry and catalysis [36]. Dipic exhibits significant antimicrobial effects [36-39]. It can inhibit the growth of various microorganisms making it valuable in combating various infections. Dipicolinates are promising candidates for developing new antimicrobial agents, especially against drug resistant microbes. However, more studies are needed to understand their mechanism of action, toxicity, and pharmacokinetics.

Dipic has shown *antifungal properties*. It inhibits the growth of *Vibrio pyri* at concentrations below 5mM (pH=5.6). *Vibrio pyri* is a fatal canker pathogen that causes significant reduction of crop yield in pear orchards. Dipic in the presence of divalent metals such as zinc, cobalt and copper have greater antifungal activities [40].

Some dipicolinate-based vanadium complexes have shown potent *anticancer effects* against different types of tumors, such as leukemia, breast, prostate, and colon cancer. They can induce cell death through apoptosis and autophagy, generate reactive oxygen species, and inhibit cell migration and angiogenesis [41].

Some dipicolinate-based vanadium complexes have shown insulin-mimetic properties, meaning they can lower blood glucose levels and improve glucose metabolism in diabetic animals. They can also modulate the expression of genes involved in insulin signaling and glucose transport [42].

Some dipicolinate-based lanthanum complexes have shown *antibacterial activity* against Gram-positive and Gram-negative bacteria, such as *Staphylococcus aureus, Escherichia coli*, and *Pseudomonas aeruginosa*. They can disrupt the bacterial cell membrane and interfere with the bacterial DNA replication [42].

Dipicolinates are versatile ligands that can modify the biological activity of metal ions. They can also interact with biomolecules, such as proteins and DNA, and affect their structure and function. However, more research is needed to understand the mechanisms, safety, and efficacy of these compounds in humans.

1.2.2: 1,10-PHENANTHROLINE

I.2.2.1: Structure:

1,10-phenanthroline abbreviated as Phen, is a bidentate heterocyclic chelating ligand with its structure composed of three cyclic benzylic rings containing two nitrogen donor atoms [68]. It has a rigid structure and possesses a high capacity to chelate with a number of metallic ions through its two nitrogen donor atoms, forming sigma bonds with metal ions. Its structure is given in Figure 9.

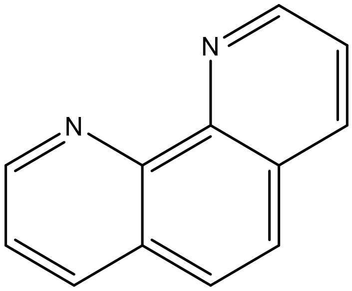
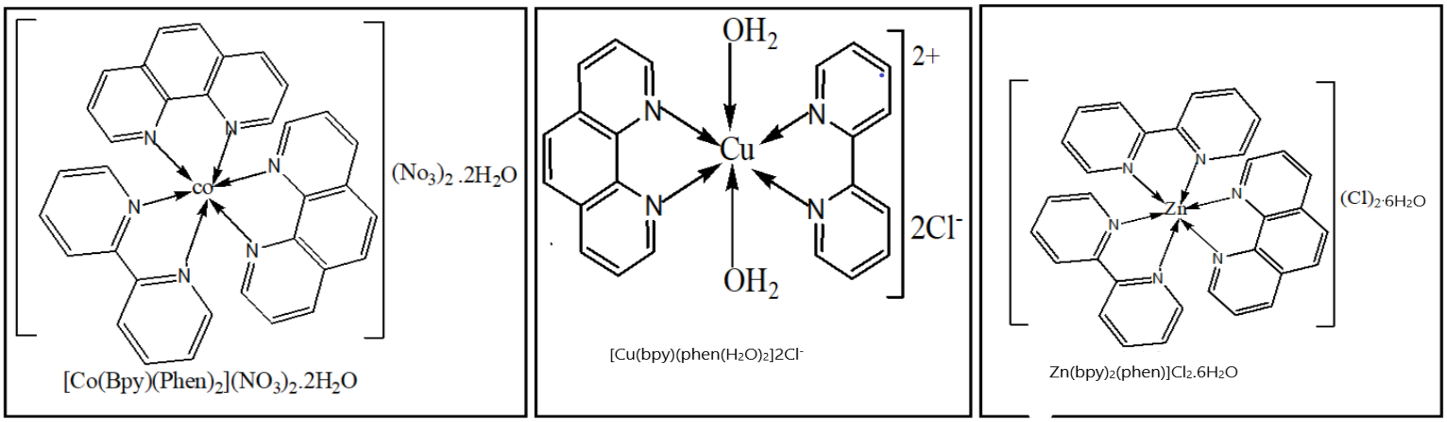


Figure 9: Structure of Phen

Many transition metal complexes of phen have been synthesized. Some of these complexes include:
$[Co(Bpy)(Phen)_2].(NO_3)_2.2H_2O$, $[Cu(phen)(bpy)(H_2O)_2]Cl_2$, $[Zn(bpy)_2(phen)]Cl_2.6H_2O$ [43]. The structures of these complexes are shown in Figure 10.

1=1,10-Phenanthroline (phen); 2=2,2'-bipyridine (bpy); 3=$Co(NO_3)_3.6H_2O$; 4=$[Co(bpy)(phen)_2](NO_3)_2.2H_2O$; 5=$CuCl_2.2H_2O$; 6=$[Cu(bpy)(phen)]Cl_2.\ 2H_2O$; 7=$ZnCl_2$; 8=$[Zn(bpy)_2(phen)]Cl_2.\ 6H_2O$;



$[Co(Bpy)(Phen)_2](NO_3)_2.2H_2O$

$[Cu(bpy)(phen(H_2O)_2]2Cl^-$

$Zn(bpy)_2(phen)]Cl_2.6H_2O$

Figure 10: Some complexes of phen [43]

I.2.2.2: Physico-chemical properties of Phen

Phen with general molecular formula $C_{12}H_8N_2$ is a white crystalline solid with a molar mass of 180.2 g/mol. It has a melting point of 118.56 °C and boils at approximately 409.2 °C. It is very soluble in water and in organic solvents such as acetone and ethanol. It has a density of 1.31 g/cm^3.

I.2.2.3: Biological activity

Phen is a molecule with a wide variety of chemical and biological activities. The vast applications of phen and its metallic complexes for the development of potential metallodrugs in this era of increasing drug resistance cannot be over emphasized. [44]. Phenanthroline complexes have shown antibacterial properties in the past against (*S. aureus*, *E. coli* and *P. aeruginosa*) [12, 45].

Phenanthroline has equally shown effective antifungal activities especially against *candida albicans*, an opportunistic yeast that is a common member of the human gut flora [12, 46]. Some Phenanthroline complexes have equally shown resistance to some pathogens evaluated using in vitro assays [47].

1.2.3: 4-(DIMETHYL)AMINOPYRIDINE

I.2.3.1: Structure:

4-dimethyaminolpyridine abbreviated as 4-DMAP is a pyridine derivative. It is a tertiary amine-pyridine derivative with two methyl groups on a nitrogen atom bonded to atom four of the ring. It belongs to a family of aminopyridines. Pyridines are basic heterocyclic organic compounds, similar to the aromatic compounds but with a carbon atom of the ring substituted by a nitrogen atom. The structure of 4-DMAP is shown on Figure 11. It is principally a monodentate ligand due to stearic hindrance on the dimethyl-nitrogen atom.

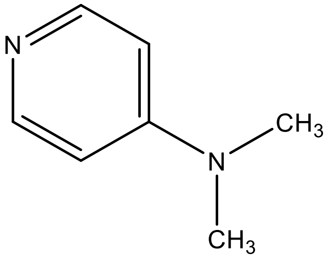
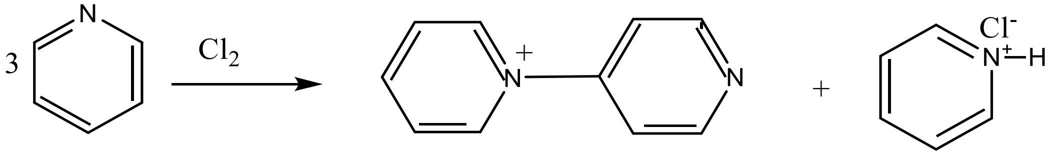


Figure 11: Structure of 4-DMAP

It is prepared from pyridine in two steps as shown in **Eqn (5)** and **Eqn (6)**

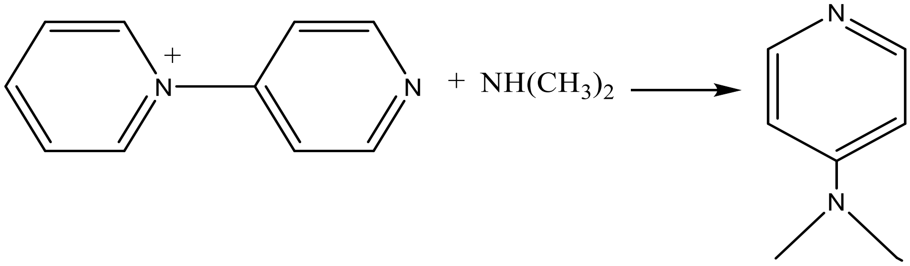
- Oxidation of pyridine to form the 4-pyridylpyridinium cation



Eqn (5)

4-pyridinium cation

- The cation then reacts with dimethylamine to yield DMAP



Eqn (6)

I.2.3.2: Physico-chemical properties

4-DMAP with general molecular formula $C_7H_{10}N_2$ has a molar weight of 122.17 g/mol. It is a white solid with a melting point of 110 °C and a boiling point of 162 °C. 4-DMAP is soluble in methanol, benzene and chloroform but less soluble in water. It has a Density of 0.906 g/cm^3.

I.2.3.3: Biological activity

4-DMAP is not naturally occurring in the human body. Due to its toxicity, it is not commonly applicable in biomedical fields. It is preliminarily known for its catalytic properties in organic synthesis [48]. 4-DMAP and its complexes may have potential applications in medicine that are yet to be fully explored.

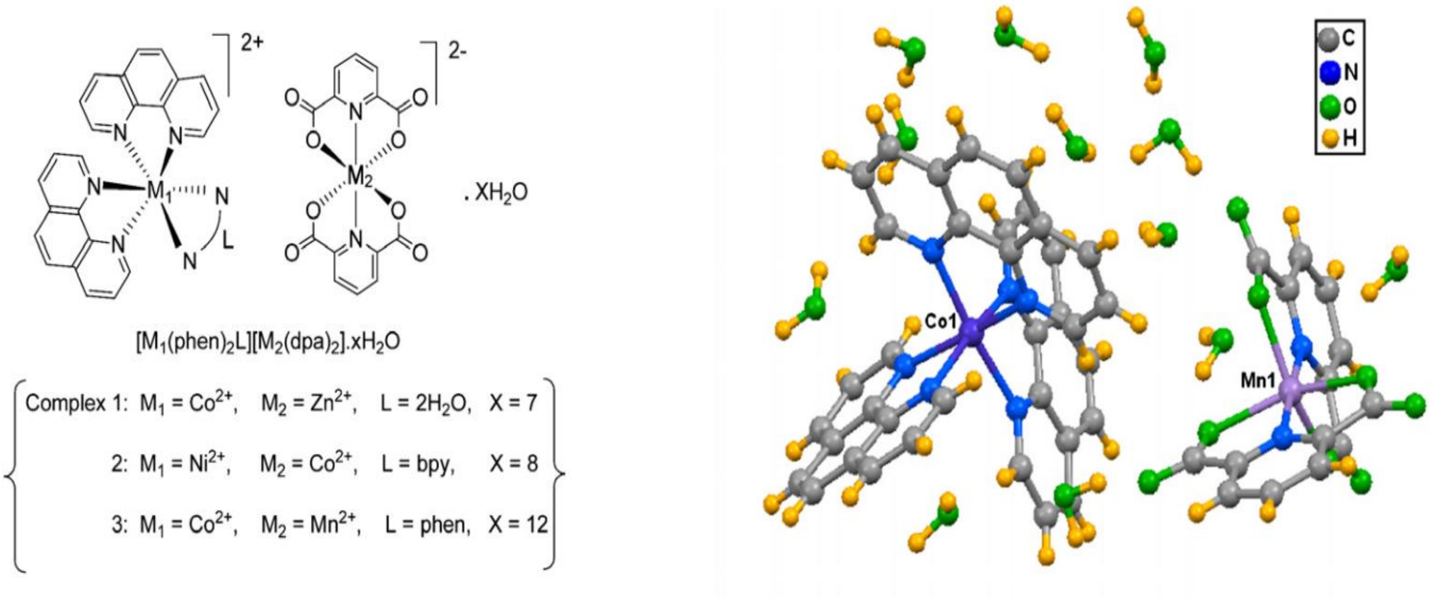
In synthetic chemistry, 4-DMAP is known for its catalytic efficiency due to its nucleophilic properties and ability to stabilize pyridinium ions [48]. This makes it a valuable catalyst for the synthesis of biologically active compounds; such derivatives have shown inhibitory effects on human cancer cell lines and possess lower toxicity in normal cells compared to other treatments. Studies have shown that 4-DMAP can form host-guest complexes with certain molecules, which have demonstrated significant antioxidant and antibacterial properties. These complexes have been tested and shown to have high free radical scavenging rates and the ability to inhibit bacterial growth, indicating potential for medical and pharmaceutical applications [49, 50].

1.3: MIXED IONIC COMPLEXES

1.3.1: GENERALITIES:

Coordination compounds that contain both anionic and cationic parts made up of transition metal complexes are a unique and less common class of coordination compounds. They are known as mixed-metal, mixed ionic, bimetallic, heteronuclear complexes or double complex salts. In these complexes, different metal ions serve as the central metal atom/ion for the cationic and anionic parts, and they are linked together through bridging ligands or kept together through strong columbic attractive forces between the anionic and the cationic spheres. The combinations of these complexes can lead to a variety of structures with unique properties [51].

For example, a heterometallic complex may have a structure like ($[Cr(2\text{-}amp)_2(H_2O)_2][Zn(dpa)_2]^{2-}$), where $[Cr(2\text{-}amp)_2(H_2O)_2]^{2+}$) is the cationic part with chromium(II) as the central metal ion , and $[Zn(dpa)_2]^{2-}$), is the anionic part with zinc(II) as the central metal ion. The entire complex is neutral, but it contains two different metal ions, each in its own coordination sphere. Some other examples of mixed ionic complexes that have been synthesized in literature include : $[Co(phen)_3][Mn(dpa)_2]\cdot 8H_2O$, $[Ni(Phen)_2dpy][Mn(dpa)_2]\cdot 12H_2O$, $[Co(phen)_2(H_2O)_2][Zn(dpa)_2]\cdot 7H_2O$ [52-55]. Figure 12 shows the structure of these complexes.



(1) (2)

Figure 12: Structure of $[M_1(phen)_2(L)][M_2(dpa)_2]\cdot xH_2O$ (1), Asymmetric unit of $[Co(phen)_2(H_2O)_2][Zn(dpa)_2]\cdot 7H_2O$ (2) [52].

These types of compounds can exhibit interesting properties and are studied for their potential applications in areas such as catalysis, magnetism, antimicrobial properties and molecular electronics [51, 52].

I.3.2: ANTIMICROBIAL ACTIVITY OF MIXED IONIC COMPLEXES

Heterometallic coordination compounds, which feature both anionic and cationic parts composed of transition metals, have garnered interest for their potential antimicrobial activities [51, 56]. There is a dire need for new antimicrobial compounds to combat the growing threat of widespread antibiotic resistance. With a currently very scarce drug pipeline, consisting mostly of derivatives of known antibiotics, new classes of antibiotics are urgently required. Metal complexes are currently in clinical development for the treatment of cancer, malaria and neurodegenerative diseases [54]. However, not enough attention has been paid to their application as potential antimicrobial compounds. Research indicates that metal complexes can be a significant source of new antibiotics, especially in the face of increasing antibiotic resistance. These compounds often exhibit a higher hit-rate for antimicrobial activity compared to purely organic molecules, with some showing promising results against strains like *methicillin-resistant Staphylococcus aureus* (MRSA) [58].

For example, studies have highlighted metal complexes containing transition metals like Mn, Co, Zn, Ru, Ag, Eu, Ir, and Pt, which have shown activities down to the Nano molar range against MRSA. [56, 51-57].

The antimicrobial activity of these complexes is typically assessed using methods like disc diffusion or agar diffusion, microdilution and their effectiveness can vary based on the metal ions, ligands involved, and the structural arrangement of the complex. The exploration of these heterometallic complexes for antimicrobial purposes is an active area of research, aiming to design truly novel antibiotics to combat antimicrobial resistance [58].

In the course of this work, cobalt(II) and zinc(II) ions will be used. Zinc, cobalt metals and their ions have shown antimicrobial properties in their previous compounds [19-27, 31, 33, 34]. In addition, the ligands used in this work, 4-DMAP, Dipic, and phen have all shown antimicrobial properties in previous works [12, 36-42, 44-47, 49, 50]. These mixed ionic complexes when synthesized will therefore be expected to exhibit hyper antimicrobial properties thereby contributing a partial solution to antimicrobial resistance.

I.4: MICROORGANISMS

I.4.1: DEFINITION

Microorganisms are very tiny living things that can only be viewed with the aid of a microscope. They include bacteria, algae, fungi, protozoa and viruses [59].

I.4.2: GENERALITIES ON MICROORGANISMS

- **Bacteria,** are single-celled, prokaryotic (no nucleus) microorganisms. They are typically a few micrometers in length and are among the first life forms to appear on earth. They differ in their shapes and walls. Frequently encountered pathogenic species include:

Staphylococcus aureus: It is a Gram-positive spherically shaped bacterium (has a thick cell wall). It is an opportunistic pathogen in humans, causing diseases such as abscesses, respiratory infections like sinusitis, food poisoning and skin exfoliation [59]. *Staphylococcus aureus* is one of the leading pathogens for deaths associated with antimicrobial resistance.

Escherichia Coli: It is a Gram-negative, facultative anaerobic, rod-shaped coliform bacterium of Genus Escherichia that is commonly found in the lower intestine of warm blooded organisms. Most E. *coli* are harmless but some serotypes are pathogenic and can cause serious food poisoning in their host, release a potent toxin and cause pathogenic effects on intestinal, gastrointestinal, and urinary infections [59, 60].

Pseudomonas aeruginosa: is a Gram-negative, aerobic-facultatively anaerobic rod-form bacterium. It is pathogenic to both plants and animals including humans. It is responsible for hospital acquired infections such as ventilator associated pneumonia and various sepsis syndromes. It is able to selectively inhibit various antibiotics from penetrating its outer membrane and hence poses a serious drug resistant issue to public health [61].

Klebsiella pneumoniae: It is a Gram-negative non-motile encapsulated, lactose-fermenting, facultative anaerobic rod-shaped bacterium, it appears in rod form. Although found in the normal flora of the mouth, skin and intestines, it can cause destructive changes to humans and animal lungs if inhaled [59].

- **Fungi:** These are eukaryotic microorganisms (with a nucleus). They include yeast and molds. There are several categories of fungi that are potentially pathogenic for living beings. Pathogenic fungi are microscopic. Candida species are pathogens responsible for most fungal infections in our environment, such as:

  Candida albicans: It is an opportunist pathogenic yeast which is a common member of the human gut flora. It is a commensal organism in animals but can be pathogenic in immunocompromised individuals under a variety of conditions [62]. It causes the human infection Candidiasis which results from an overgrowth of the fungus [59, 62].

- **Virus**: A virus is a microscopic pathogen that replicates only in living cells of organisms. They cause diseases in all life forms ranging from microorganisms to multicellular organisms. They are the most numerous types of biological entities. Some viral infections in humans include HIV/AIDS, HPV infections, Hepatitis, Influenza and COVID 19. Viral multiplication is so rapid [63].

I.5: ANTIMICROBIAL RESISTANCE

The discovery of penicillin in 1928 by Sir Alexander Fleming marked the beginning of the antibiotic revolution [64]. However, the massive use of antibiotics has led to resistance limiting the effectiveness of treatments. Antimicrobial resistance happens when germs like bacteria and fungi develop the ability to defeat the drugs designed to kill them. That means the germs are not killed and continue to grow when the patient takes the prescribed dose.

Microorganisms have the ability to adapt to changes in their environment by developing various forms of mechanisms to protect themselves from attacks. This is called antimicrobial resistance. Several resistance mechanisms have been developed by bacteria: These include: Natural and artificial resistance [65, 66]. Antimicrobial resistance usually result from: limiting uptake of a drug, modification of a drug structure, inactivation of a drug or from active efflux of a drug. However, it is more important to detect it because it can progress to higher levels subsequently making the microbes inaccessible to therapy; this aspect was developed regarding the resistance of pneumococcus to penicillin [65]. The wide use of antifungals has equally lead to emergence of antifungal resistance [67].

CHAPTER II: EXPERIMENTAL SECTION

This chapter describes the materials, equipment and reagents used during the various laboratory manipulations, the experimental procedures used for synthesis and characterization of the different chemical compounds.

II.1: REAGENTS AND MATERIALS

All reagents used in this work are commercially available and were used as such without further purification.

II.1.1 REAGENTS

The names and characteristics of the reagents used in this work are given in Table I.

Table I :Names and characteristics of reagents used

Reagents	Molar mass (g/mol)	Chemical Formula	Physical aspect	Firm and/or purity
Zinc(II) acetate	183	$Zn(CH_3COO)_2$	White solid	Riedel-de Haën 97%
Cobalt(II) acetate tetrahydrate	249.08	$Co(CH_3COO)_2.4H_2O$	Pink	Sigma Aldrich 98%
Dipicolinic acid dihydrate	167.12	$C_7H_5O_4\cdot 2H_2O$	White crystals	Prolabo 99.8%
4-(dimethyl)aminopyridine	122.17	$C_7H_{10}N_2$	White solid	Riedel-de Haën 98%
1,10-phenanthroline	180.21	$C_{12}H_8N_2$	Colourless crystals	Sinochembt 99.5%
Ethanol	46	C_2H_6O	Colourless liquid	NODISCAM 98%
Distilled water	18	H_2O	Colourless liquid	Physical chemistry laboratory (UY1)

II.1.2 MATERIALS

An electronic balance of 0.01 g precision, compact electric heater/magnetic stirrer, filter funnels, magnetic bars, wash bottles, spatula, filter papers, beakers of 100 mL, 150 mL and 250 mL, crystallizer of 250 mL, clamp and stands, hood, glass watch, mortar, thermometer, a reflux set up.

II.2: SYNTHESES

The compounds obtained in this work were synthesised in an aqueous medium. The objective was to obtain mixed ionic complex salts of formulae $[Co(DMAP)_6]^{2+}[Zn(Dipic)_2]^{2-}\cdot xH_2O$ **(A)** and $[Co(phen)_3]^{2+}[Zn(Dipic)_2]^{2-}\cdot xH_2O$ **(B)** respectively by the method of direct synthesis.

II.2.1 SYNTHESIS OF COMPOUND A

The cationic and anionic bricks were synthesized in aqueous medium at room temperature.

(a) Synthesis of the cationic brick: $[Co(DMAP)_6]^{2+}$

Procedure:

20 mL of distilled water were measured into a clean 150 mL glass beaker and a magnetic bar inserted. The beaker was placed on an electric heating plate/magnetic stirrer. 0.73 g (6 mmol) of 4-DMAP were weighed and dissolved in the distilled water under magnetic stirring for 5 minutes at room temperature. 0.25 g (1 mmol) of cobalt(II) acetate were weighed and added into the mixture and allowed under magnetic agitation for 1hour. **Eqn (7)** shows the chemical reaction that occurred leading to the formation of a pink solution (solution 1)

$$Co(CH_3COO)_2\cdot 4H_2O + H_2O + 6DMAP \longrightarrow [Co(DMAP)_6]^{2+}(CH_3COO^-)_2 + 5H_2O \quad \textbf{Eqn (7)}$$

(b) Synthesis of the anionic brick:$[Zn(Dipic)_2]^{2-}$

Procedure:

20 mL of distilled water were measured into a clean 150 mL glass beaker and a magnetic bar inserted. The beaker was placed on an electric heating plate/magnetic stirrer. 0.34 g (2 mmol) of Dipic were weighed and dissolved in the distilled water under magnetic stirring for 5 minutes at room temperature. 0.18 g (1 mmol) of zinc(II) acetate were then weighed and added into the mixture and allowed under magnetic agitation for 1 hour. **Eqn (8)** shows the chemical reaction that occurred leading to the formation of a white sticky solution (solution 2)

$$Zn(CH_3COO)_2\cdot 4H_2O + H_2O + 2Dipic \longrightarrow [Zn(Dipic)_2]^{2-} + 2CH_3COOH + 2H_3O^+ \quad \textbf{Eqn (8)}$$

(c) Synthesis of $[Co(DMAP)_6]^{2+}[Zn(Dipic)_2]^{2-}\cdot XH_2O$

Procedure:

Solution 1 was poured drop wise to solution 2 while under magnetic agitation. 5 mL of ethanol were added to the mixture and the mixture refluxed at 50°C for two hours. A light blue solution was obtained that turned reddish brown at the end. After 2hours, the mixture was cooled, filtered and kept. **Eqn (9)** shows the reaction that occurred.

Shiny red crystals were obtained after 48hours.

$$[Co(DMAP)_6]^{2+}(CH_3COO)_2 + [Zn(dipic)_2]^{2-} + 2H_3O^+ \longrightarrow [Co(DMAP)_6]^{2+}[Zn(dipic)_2]^{2-} + 2H_2O + 2CH_3COOH \quad \textbf{Eqn (9)}$$

II.2.2 SYNTHESIS OF COMPOUND B

The cationic and anionic bricks were synthesized in aqueous medium at room temperature

(a) Synthesis of the cationic brick: $[Co(phen)_6]^{2+}$

Procedure:

20 mL of distilled water were measured into a clean 150 mL glass beaker and a magnetic bar inserted. The beaker was placed on an electric heating plate/magnetic stirrer. 0.37 g (3 mmol) of phen were weighed and dissolved in the distilled water under magnetic stirring for 5 minutes at room temperature. 0.25 g (1 mmol) of cobalt(II) acetate were weighed and added into the mixture and allowed under magnetic agitation for 1hour. **Eqn (10)** shows the chemical reaction that occurred leading to the formation of a pink solution (solution 3)

$$Co(CH_3COO)_2\cdot 4H_2O + H_2O + 3Phen \longrightarrow [Co(Phen)_3]^{2+}(CH_3COO^-)_2 + 5H_2O \quad \textbf{Eqn (10)}$$

(b) **Synthesis of the anionic brick:$[Zn(Dipic)_2]^{2-}$**

Procedure:

20 mL of distilled water were measured into a clean 150 mL glass beaker and a magnetic bar inserted. The beaker was placed on an electric heating plate/magnetic stirrer. 0.34 g (2 mmol) of Dipic were weighed and dissolved in the distilled water under magnetic stirring for 5 minutes at room temperature. 0.18 g (1 mmol) of zinc(II) acetate were then weighed and added into the mixture and allowed under magnetic agitation for 1 hour. **Eqn (11)** shows the chemical reaction that occurred leading to the formation of a white sticky solution (solution 4)

$$Zn(CH_3COO)_2\cdot 4H_2O + H_2O + 2Dipic \longrightarrow [Zn(Dipic)_2]^{2-} + 2CH_3COOH + 2H_3O^+ \quad \textbf{Eqn (11)}$$

(c) Synthesis of $[Co(phen)_3]^{2+}[Zn(Dipic)_2]^{2-}\cdot XH_2O$

Procedure:

Solution 3 was poured drop wise to solution 4 while under magnetic agitation. The mixture was allowed under magnetic agitation for two hours giving a brown solution that turned orange at the end. **Eqn (12)** shows the reaction that occurred. After 2 hours, the mixture was filtered and kept. Bright orange crystals were obtained after 24hours.

$$[Co(Phen)_3]^{2+}(CH_3COO)_2^- + [Zn(dipic)_2]^{2-} + 2H_3O^+ \longrightarrow [Co(phen)_3]^{2+}[Zn(dipic)_2]^{2-} + H_2O + 2CH_3COOH$$

Eqn (12)

II.3: CHARACTERISATION TECHNIQUES

II.3.1: SOLUBILITY TEST

This test is carried out to determine in which solvent the target or synthesized materials are more soluble, fairly soluble or insoluble. For each solvent, 0.01 g of a sample of the synthesized compounds **A** and **B** were introduced into two separate 100 mL clean glass beakers. 5 mL of the desired solvent was introduced and the solution stirred for few minutes.

II.3.2: MELTING POINT DETERMINATION

The melting point of a body (or the point of fusion) represents the temperature at a given pressure, at which a pure element or chemical compound changes from the solid phase to the liquid phase. The melting point of the compounds synthesised were obtained using a melting point apparatus of mark STUART SCIENTIFIC and of heating rate 10 ºC/min with a maximum temperature of the thermometer equal to 330 ºC in the laboratory of Applied Inorganic and Analytical Chemistry of the University of Yaounde 1.

II.3.3: CONDUCTIMETRIC MEASUREMENT

Conductimetry is a technique used to measure the ability of a material to conduct electricity in aqueous solution. It tells if the substance is ionic in nature or molecular. Conductimetric measurements were carried out in Applied Physical and Analytical Chemistry Laboratory of the University of Yaounde I using a Multifunction water quality tester of mark HANNA H19811-5 pH/°C/EC/TDS. The molar conductance Λ_m of the aqueous solutions of the synthesized compounds were calculated using the mathematical equation, **Eqn (13)**.

$$\Lambda \mathrm{m} = \frac{\mathrm{K}}{\mathrm{M}} \qquad \boldsymbol{Eqn} \quad (\mathbf{13})$$

K: Electrical conductivity (S. cm^{-1})
M: Concentration of the solution (mol. cm^{-1})
Λ_m: Molar conductivity (S. cm^2. mol^{-1})

II.3.4: INFRARED SPECTROSCOPY

Infrared spectroscopy is a technique used in determining the functional groups and bond types found in organic or inorganic molecules. It makes use of the fact that molecules absorb specific frequencies of IR radiations characteristic of particular bonds in their structures, likewise, it allows us to know whether there is complexation or not, by comparing the spectrum of the free ligand with that of the complex obtained. The IR spectra of the ligands were obtained by simulation while those of the cobalt(II) and zinc(II) complexes were recorded in the Applied Physical and Analytical Chemistry Laboratory of the University of Yaounde I. These recordings were obtained using a Bruker ALPHA-P IRTF spectrophotometer with a scanning range of 4000 to 400 cm^{-1}. The IR spectra were recorded from solid samples at approximately 1% by mass deposited on a KBr pellet previously cleaned with ethanol and were processed by the ATR method.

II.3.5: UV-VISIBLE SPECTROSCOPY

This is a characterization technique whose principle is based on the interaction between radiation in the UV-visible domain and ions, molecules or a material. It tells us the possible electronic transitions in the material analyzed, thus making it possible to justify the coloring of the latter and at the same time, to predict the geometry around the central metal in the complexes. The UV (200-400 nm) and visible (400-800 nm) spectra of the compounds synthesised were recorded using a HACH DR 3900 UV-visible spectrometer of the mark Brucker. This analysis was done in the Laboratory of Applied Inorganic and Analytical Chemistry of the University of Yaounde I.

II.3.6: PHOTOLUMINESCENCE TEST

This is a powerful analytical technique used to study the optical properties of materials such as crystals and semi-conductors. Photoluminescence is the emission of light from a material when it absorbs photons (UV-visible). A solution of each material **(A, B)** was prepared by dissolving 0.01 g of the sample in 20 mL of distilled water [68]. Photons or light waves were passed through a solution of the material. The photoluminescence spectra of the compounds synthesised were recorded using a HACH DR 3900 UV-visible spectrometer of the mark Brucker. This analysis was done in the Laboratory of Applied Inorganic and Analytical Chemistry of the University of Yaounde I.

II.3.7: POWDER X-RAY DIFFRACTION

Powdered X-ray diffractometry is a qualitative and quantitative physico-chemical analytical technique. It is used to determine the nature of each crystalline phase within a sample, the arrangement of atoms, crystalline size and purity to name these. The principle behind powdered X-ray diffraction is known as Bragg's law. For a family of planes (hkl), there is therefore always among these crystallites a certain number which present to the incident monochromatic X-ray beam an angle $\boldsymbol{\theta}$ compatible with the Bragg's relation (**Eqn (14))**.

$$2d_{hkl}\sin\theta_{hkl} = n\lambda \qquad \textbf{Eqn (14)}$$

Where

d = interreticular distance

λ = wavelength of X-rays (nm),

θ = Bragg diffraction angle corresponding to the plane (hkl) considered

n = diffraction order (generally n = 1).

This analysis was carried out using a BRUKER brand powder diffractometer of the *AXS D2 PHASER A26-X1* type equipped with a copper anticathode of Kα radiation (λ = 1.5406 Angstrom, 40 kV, 40 mA) and monochromatic beam at the Laboratory of Applied Inorganic and Analytical Chemistry of the University of Yaounde I. For each sample, scanning (0.05 minutes) was performed over a 2θ angle from 20 ºC to 60 ºC at room temperature. Particle diameters at different temperatures were calculated using the Debye Scherrer formula (**Eqn (15)**).

$$D = \frac{K\lambda}{\beta Cos\theta} \qquad \textbf{Eqn (15)}$$

D = mean particle size (nm) measured in the direction perpendicular to the (hkl) plane;

K = shape factor ≈ 0.94;
λ = X-ray wavelength (nm);
β = full width at half maximum of a diffraction peak (radian);
θ = Bragg diffraction angle corresponding to the (hkl) plane considered

II.3.8: ANTIMICROBIAL PROPERTIES ASSESSMENT

The antimicrobial activity was evaluated on five (05) bacterial strains and two fungal reference strains from BEI Resources. These bacterial strains were stored at the Phytobiochemistry and Medicinal Plant Study Laboratory in tubes containing Muller Hinton agar (bacteria) and Sabouraud Dextrose (fungal) by slant culture at 4 °C.

Preparation of stock solutions of materials and reference antibiotic / antifungal

The stock solutions of materials were prepared at 50 mg /mL by dissolving 5 mg of crude extracts in 100 µL of 100% DMSO and then stored at 4 °C for later use. Amphotericin B (Sigma Aldrich) was prepared under the same conditions, at a concentration of 1 mg/mL. Ciprofloxacin, used as a reference antibiotic, was prepared under the same conditions at 1 mg/mL in water acidified with 0.05N HCl.

Preparation of bacterial inocula

The bacterial inocula were prepared according to the 0.5McF standard. A colony from 24-hour cultures on Müller Hinton (MH) agar was collected using a platinum loop and introduced into a test tube containing 10 mL of physiological water and then calibrated to 0.5 MacFarland by comparison of turbidity to obtain an inoculum with a bacterial load of 1.5×10^8 CFU/mL (McFARLAND, 1907).

Determination of Minimum Inhibitory Concentrations (MICs)

The antibacterial activity parameter (MIC) was determined by microdilution in liquid medium according to the protocol described by the Clinical and Laboratory Standards Institute (CLSI, 2012), protocol M07-A09 [69]. The microdilution method is based on the ability of a microorganism to grow in media supplemented or not with suspected antimicrobial substances. The inhibition parameter MIC was revealed by colorimetry based on the reduction of blue rezasurin to pink resorufin by the dehydrogenases of viable cells. The tests were carried out in triplicate in sterile 96-well microplates. 196 µL of MHB culture medium were introduced into the first twelve wells of column A and 100 µL into the rest of the wells of the plate. Subsequently, 4 µL of a solution of each sample were taken and introduced into the corresponding wells, followed by a series of 5 dilutions of geometrical ratio of order 2 from column A to column F. Finally, 100 µL of a bacterial suspension with a load of 1×10^6 CFU/mL (intermediate solution) were distributed in the test wells and those of the negative control. The final load of the inoculum in each well was 5×10^5 CFU/mL for a volume of 200 µL. The sterility control consisted only of the culture medium. The positive control consisted of the culture medium, the inoculum and ciprofloxacin. The microplates were covered and incubated at 37 °C for 24 hours. At the end of the incubation period, 20 µL of a freshly prepared Rezasurine solution (0.15 mg/mL) was added to all wells and the plates were once again incubated under the same conditions for 30 minutes.

Evaluation of antifungal activity

Preparation of fungal inocula

The yeast suspensions used for the sensitivity tests were prepared at 2.5 × 10^3 Cells/ml from 24-hour cultures on Sabouraud Dextrose Agar (SDA) medium. Colonies were collected with a platinum loop and introduced into a tube containing 10 ml of sterile physiological water and the suspensions were calibrated to 0.5 MacFarland by comparison of turbidity.

Determination of Minimal Inhibitory Concentrations (MIC)

Minimal Inhibitory Concentrations were determined by microdilution using the M27-A3 protocol [70] described by the Clinical Laboratory Standard Institute (CLSI), (2012). It consists of the visual observation of the pellet formed by the deposit of yeasts or of the turbidity in the nutrient broth at the end of the incubation. The tests were carried out in 96-well microplates. Indeed, 100 µl and 196 µl of Sabouraud Dextrose Broth (SDB) medium were introduced respectively into all the wells of the plate and into the first wells; then, 4 µl of a stock sample solution were taken and added to the 196 µl of the first wells of row 1 except those of column C and F. A series of 5 dilutions of geometric ratio 2 was carried out and 100 µl of a suspension of a single yeast, prepared at the titer 2.5 × 10^3 Cells/ml were seeded in the wells of the plate. The plates were sealed and incubated at 37 °C for 48 hours. At the end of the incubation time, the lowest concentration at which no visible growth of the germ is observed marked by the absence of turbidity corresponds to the MIC of the extract.

CHAPTER III: RESULTS AND DISCUSSION

In this chapter, the results obtained from experimental works and discussions are presented.

III.1: IDENTIFICATION OF THE TARGET MATERIAL A

III.1.1: PHYSICAL ASPECT

The target material **A** is a crystalline solid, characterised by a shiny red colouration at room temperature. Image 1 shows the physical appearance of target compound **A** synthesized.

IMAGE 1: Image of compound A

III.1.2: MELTING POINT

The melting point determination of the target compound **A** showed that it does not melt up to 330 °C, which is the threshold temperature of the measuring device used. However, at 260 °C, a change in coloration was observed; from shiny red to violet. This result suggests that the material has degraded without actually melting.

III.1.3: MOLAR CONDUCTANCE

The electrical conductivity was measured from an aqueous solution of the synthesized compound **A** of concentration 0.01897 molL^{-1}. Table II shows the electrical conductivity and the calculated molar conductance of compound **A** in aqueous solution.

Table II: Molar conductance of an aqueous solution of compound A

Sample	**Molar concentration (mol.L^{-1})**	**Electrical conductivity (µS.cm^{-1})**	**Molar conductance (S.cm^{2}.mol^{-1})**
$[Co(DMAP)_6]^{2+}[Zn(dipic)_2]^{2-}\cdot XH_2O$	**0.01897**	**2300**	**121.2**

Table III shows a set of values of molar conductance, Λ_m of aqueous solutions at 25°C with respect to the number of ions present in aqueous solution [71].

Table III: Relation between Molar conductance and number of ions present

Molar conductance ($S.cm^2.mol^{-1}$)	Number of ions
118-131	2
235-273	3
408-435	4
~560	5

From Table II, the value of the molar conductance, Λ_m of the targeted material **A** is 121.2 $S.cm^2.mol^{-1}$. This result in relation with Table III, indicates that the target compound **A** is composed of two ions: one complex cation, $[Co(DMAP)_6]^{2+}$ and one complex anion, $[Zn(dipic)_2]^{2-}$.

III.1.4: SOLUBILITY TEST RESULTS

Solubility test measurement permits us to determine in which solvent the synthesized compound is soluble helping us then to carry out other supplementary analytical tests. Table IV shows the solubility of target compound **A** in some solvents.

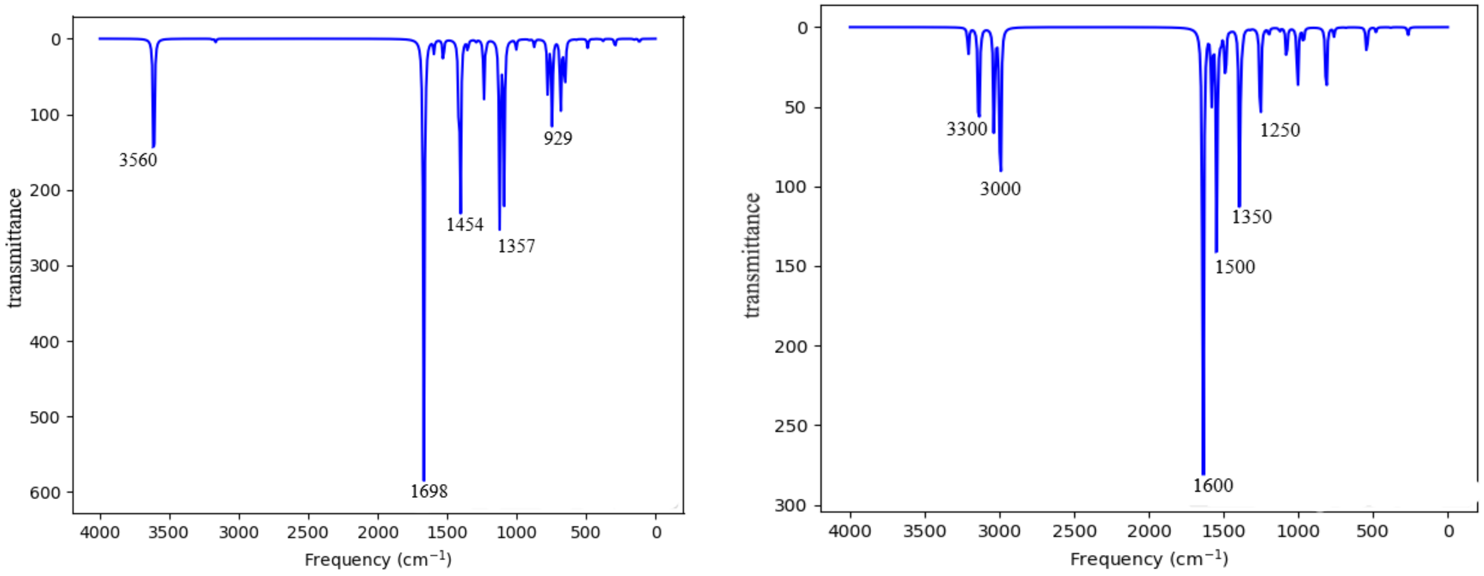
Table IV: Solubility of compounds A in some solvents at room temperature

Solvent	Solubility
Water	Soluble
Ethanol	Soluble
Acetic acid	Soluble
Methanol	Soluble
Benzene	Insoluble
Methylbenzene	Insoluble
DMSO	Soluble
DMF	Soluble

The results presented on table IV show that target compound **A** is soluble in both polar protic solvents such as water, ethanol, methanol and acetic acid and in polar aprotic solvents such as DMSO and DMF. It is insoluble in non-polar solvents such as benzene. The solubility of target compound **A** in polar solvents suggests the ionic nature of the compound.

III.1.5: INFRARED SPECTRUM

The IR spectra of the ligands used to synthesize target compound **A**, 4-DMAP and Dipic were recorded by computational simulation using Gaussview and Gaussum applications. The spectra are shown in Figure 13.



(1) (2)

Figure 13 : IR spectra of Dipic (1) and 4-DMAP (2)

The absorption bands extracted from the IR spectra of the two ligands are summarised in Table V and VI respectively.

Table V: The absorption bands of Dipic ligand

Bands (cm^{-1})	**3560**	**3100**	**1698**	**1454** **1371**	**1357**	**929**
Functional group	**v(O-H)**	**v(C-H)**	**v(C=O)**	**v(C=C)** **v(C=N)**	**v(C-O)**	**v(C-H)**

Table VI: The absorption bands of DMAP

Bands (cm^{-1})	**3300**	**3000**	**1600**	**1500**	**1350-**	**1250**	**945**
Functional group	**v(N-H)**	**v(C-H)**	**v(C=C)**	**v(C=N)**	**v(C-O)**	**v(C-N)**	**v(C-H)**

The IR spectrum of the target compound **A** was analysed using IR spectroscopy in the wave number region 4000 cm^{-1} to 400 cm^{-1}. Its IR spectrum is shown in Figure 14.

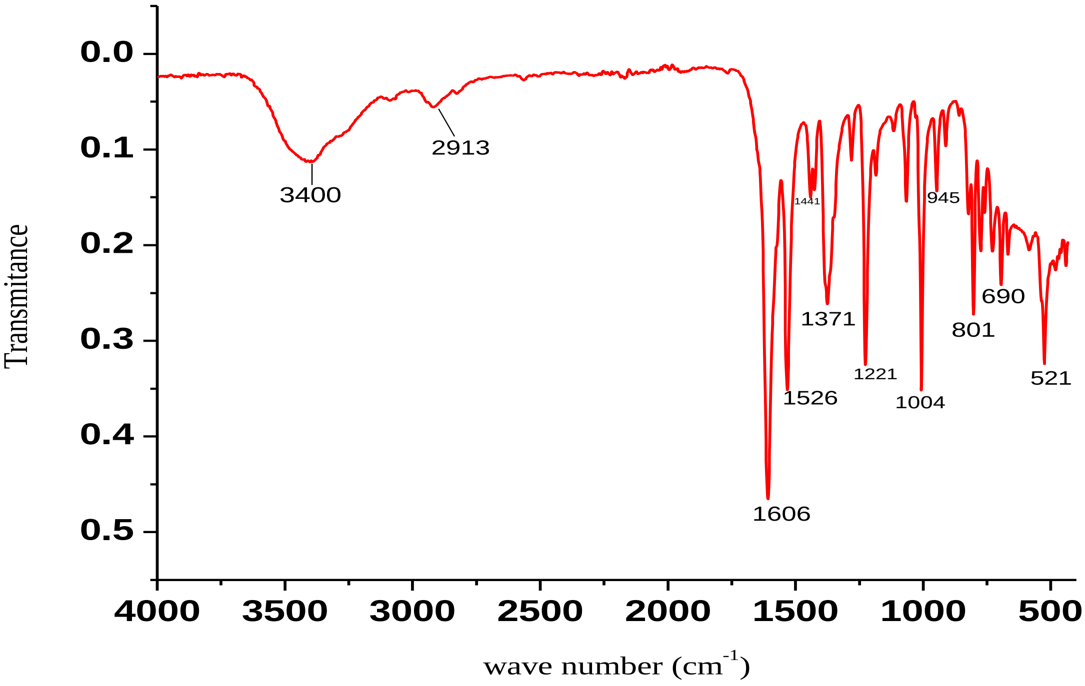


Figure 14: IR Spectrum of compound A

Observing the IR spectrum of target compound **A**, the following characteristic bands presented in table VII are present in the synthesized compound **A**.

Table VII: The absorption bands of compound A

Bands (cm^{-1})	**3400**	**2913**	**1606**	**1526**	**1441-1004**	**945**	**690** **680**	**521**
Functional group	**v(O-H)**	**v(C-H)**	**v(C=0)**	**v(C=N)**	**v(C-O),** **v(C-N)**	**v(C-H)**	**v(Zn-N)** **v(Zn-O)**	**v(Co-N),**

The IR spectrum of compound **A** shows a broad band around 3400 cm^{-1} which can be attributed to the O-H stretching vibration of water molecules of crystallisation [72, 73]. The strong bands appearing around 1606 cm^{-1}, 1528 cm^{-1}correspond to the C=O stretching vibration of the carboxylate group and the C=N groups of the dipicolinato ligand respectively. The absorption bands around 1371 cm^{-1}, 1221 and 1004 cm^{-1} can be attributed to the C-O, C-N and C-C vibration bands. Lastly, the medium and sharp absorption bands around 690 cm^{-1}, 482 cm^{-1}, and 521 cm^{-1} could be assigned to the M-O and M-N stretching vibration [74, 75]. Comparing these data to those of the ligands indicate that the complexes were actually formed since new bands are obtained. The shifts from ligand values are due to complexation.

III.1.6: UV-VIS SPECTRUM

The UV-Vis spectrum of the target compound **A** is illustrated in Figure 15.

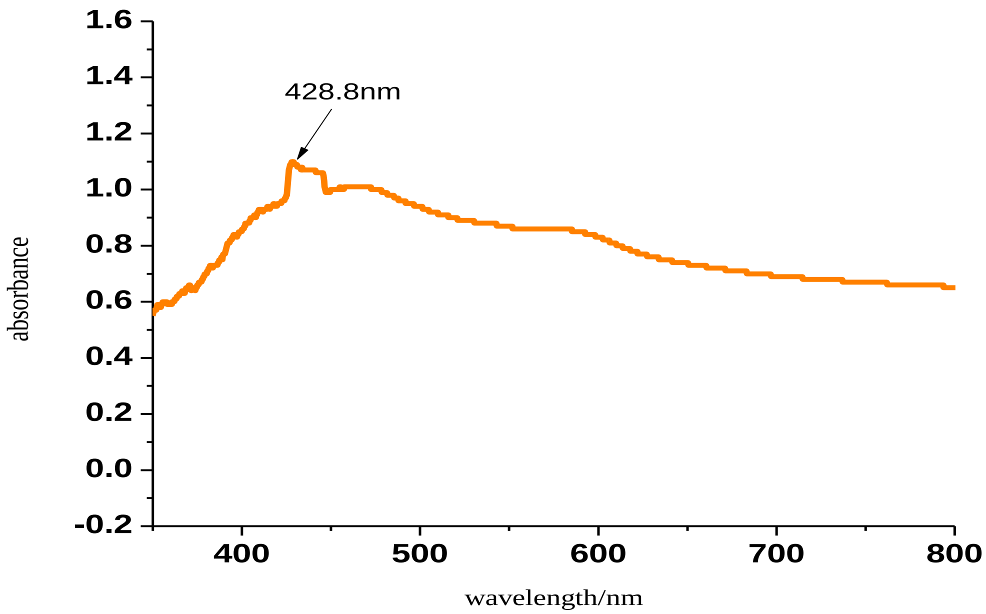


Figure 15: UV-visible Spectrum of compound A

The UV-Vis spectrum of **A** in aqueous solution shows one absorption band in the visible region (428 nm). This band can be attributed to the *d-d* transitions ($^4T_{1g} \rightarrow {}^4T_{2g}$) in a distorted octahedral geometry.

III.1.7: PHOTOLUMINESCENCE SPECTRUM

The photoluminescence spectrum of compound **A** is shown in the graph in figure 16

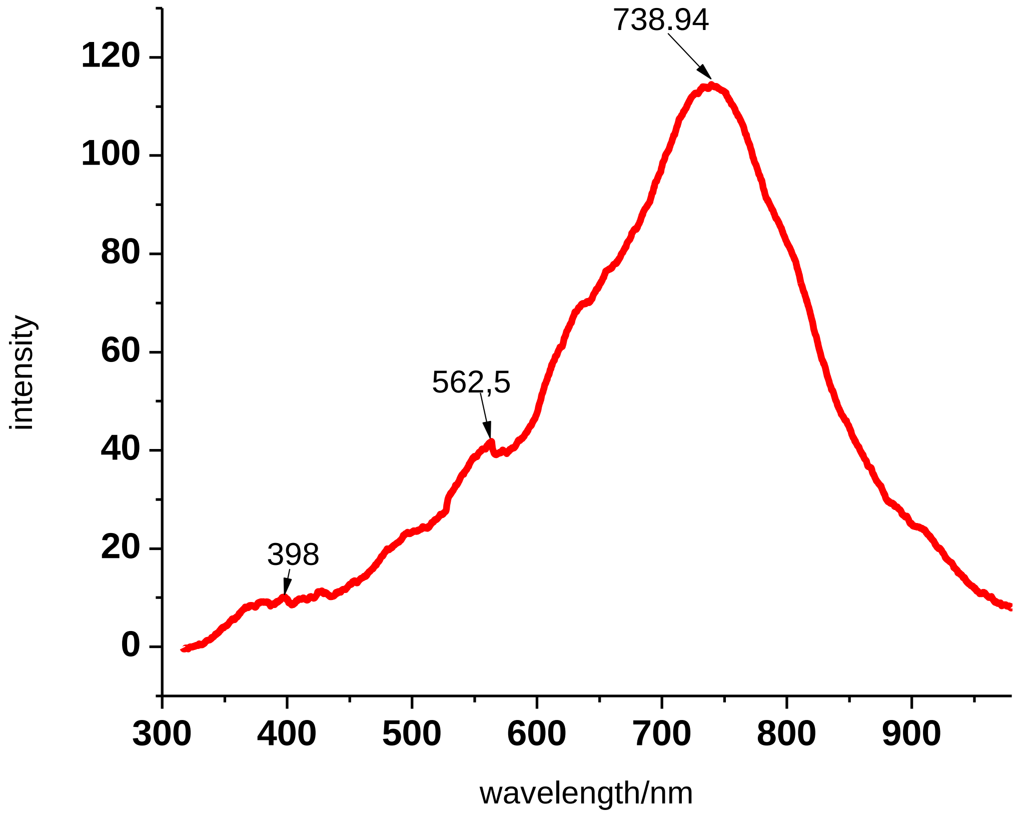


Figure 16: Photoluminescence Spectrum of compound A

The photoluminescence spectrum of target compound **A** presents three peaks at 398 nm, 562 nm and 738 nm. This indicates that the complex emits light at three wavelengths: 398 nm, 562 nm and 738 nm. The peak at 398 nm falls in the UV region of the electromagnetic spectrum suggesting *n-π** transition from DMAP to the cobalt(II) ions [79] while the peaks at 562 nm is likely due to d-d transitions within the cobalt(II) ions. The peak at 738 nm which falls in the near infrared region is likely due to ligand to metal charge transfer from the Dipic ligand to the zinc ion [80]. Hence these compounds can be used in light emitting diodes, tunable lasers and fluorescent labels.

III.1.8: THE POWDER X-RAY DIFFRACTOGRAM OF COMPOUND A

Figure 17 provides the X-ray Diffraction pattern of a plot of X-ray intensity against 2θ, where 2θ is the angle between the incident and diffracted X-ray beams. Peaks in the pattern correspond to specific crystallographic planes within the material.

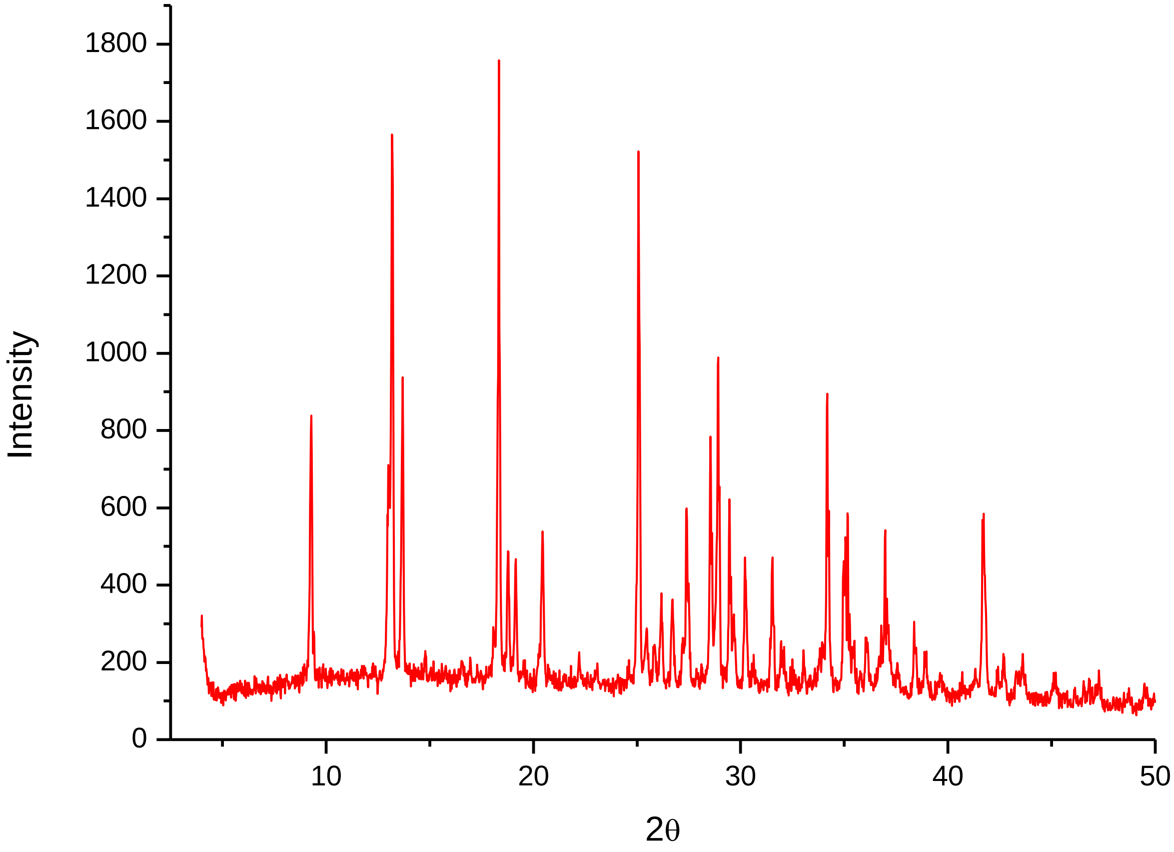


Figure 17: Powder X ray diffraction pattern of compound A

The presence of sharp peaks in the diffraction patterns of compound **A** suggests that compound **A** is crystalline. The presence of multiple peaks suggests that the structure of compound **A** is complex, likely involving multiple atoms or ions in the unit cell. The intensity of the peaks varies; with some peaks stronger than others indicating that certain crystal planes are more abundant than others [82].

III.1.9 : PROPOSED STRUCTURE OF COMPOUND A

Based on the results obtained from the analyses carried out, The IR spectroscopy shows complexation and water molecules of crystallization. . The UV spectroscopic analysis equally proposes an octahedral geometry about the various central metal ions while Solubility test results reveal the ionic natures of the compound. Conductimetric results indicate the presence of two ions in the compound. The proposed structure of **A**, pending confirmation from single-crystal X-ray diffraction is shown on Figure 18.

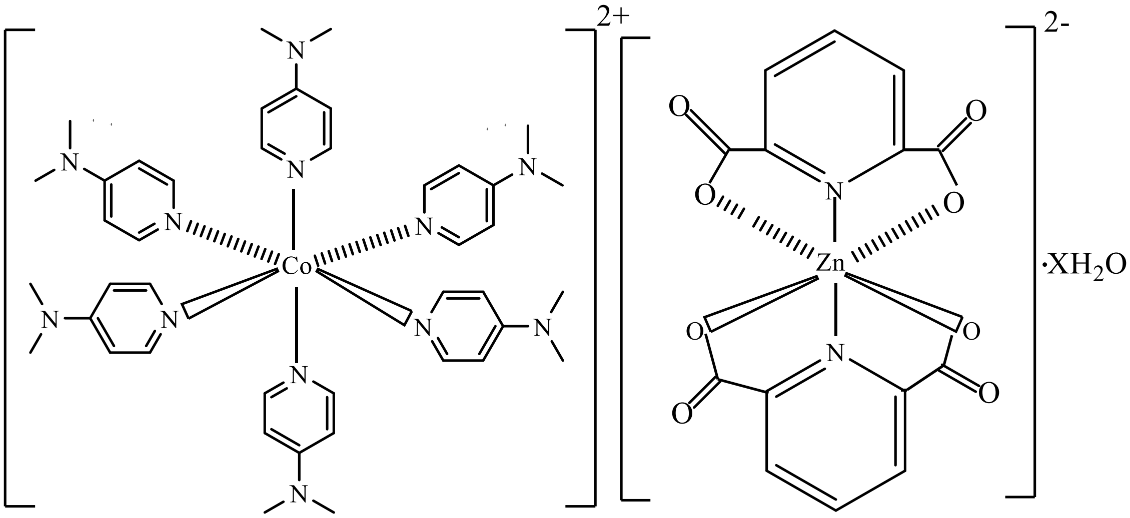


Figure 18: Proposed structure of compound A

III.2: IDENTIFICATION OF THE TARGET MATERIAL B

III.2.1: PHYSICAL ASPECT

The target material **B** is a crystalline solid, characterised by an orange colouration at room temperature. Its physical appearance is shown in image 2

IMAGE 2: Image of compound B

III.2.2: MOLAR CONDUCTANCE

The electrical conductivity was measured from an aqueous solution of the synthesized compound **B** of concentration 0.01897 mol.L^{-1}. Its molar conductivity Λ_m was calculated using the mathematical $\boldsymbol{Eqn}$ $(\mathbf{13})$ and the corresponding results are displayed in Table VIII.

Table VIII: Conductance of an aqueous solution of compound B

Sample	Molar concentration (mol.L^{-1})	Electrical conductivity (μS.cm^{-1})	Molar conductance (S.cm^{2}.mol^{-1})
$[Co(phen)_3]^{2+}[Zn(dipic)_2]^{2-}\cdot XH_2O$	0.01975	2340	118.5

From Table VIII, the value of the molar conductance, Λ_m of the targeted material **B** is 118.5 S.cm^{2}.mol^{-1}. This result in relation with Table III, indicates that the target compound **B** is composed of two ions: one complex cation, $[Co(Phen)_3]^{2+}$ and one complex anion, $[Zn(dipic)_2]^{2-}$.

III.2.3: MELTING POINT

The melting point determination of the target compound **B** showed that it does not melt up to 330 ºC, which is the threshold temperature of the measuring device used.

It equally does not degrade within this temperature limits. This suggests that the forces holding constituent parts in the synthesized compound are quite strong. These forces are probably electrovalent in nature holding the constituent cationic and anionic complex spheres in an ionic giant structure.

III.2.4: SOLUBILITY TEST RESULTS

Table IX below shows the solubility of target compound **B** in some solvents

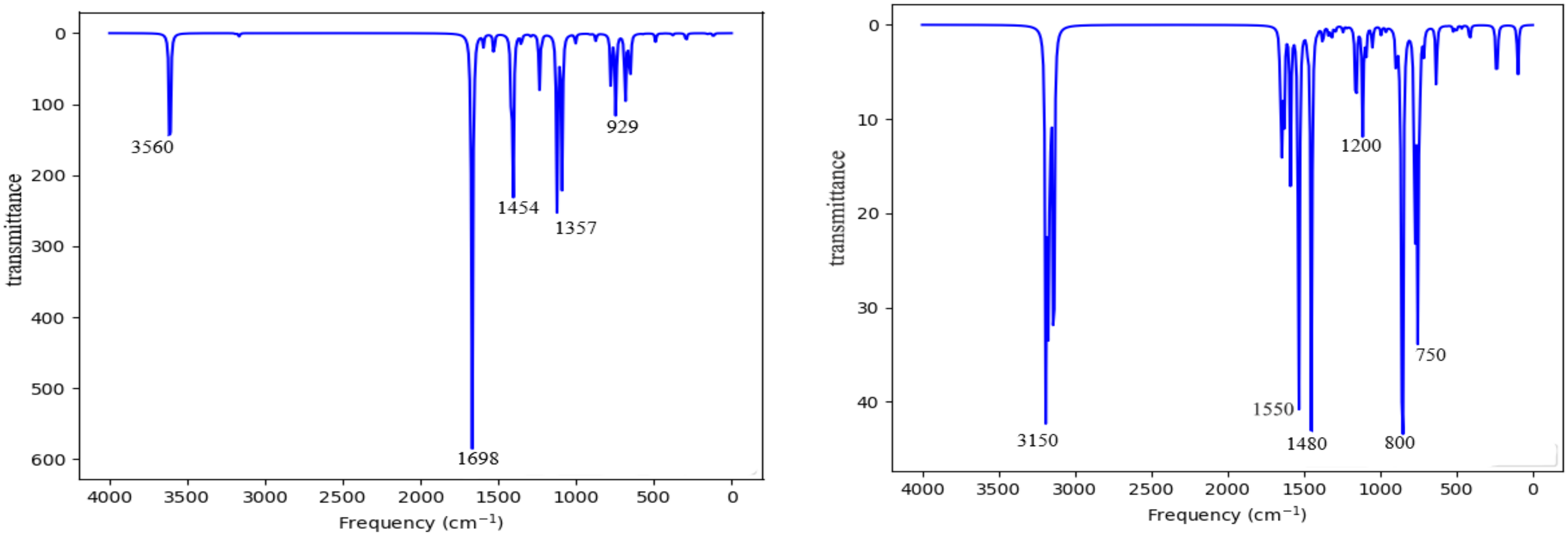
Table IX: Solubility of compound B in some solvents at room temperature

Solvent	Solubility
Distilled water	Insoluble
Ethanol	Insoluble
Acetic acid	Insoluble
Methanol	Insoluble
Benzene	Insoluble
Methylbenzene(Toluene)	Insoluble
DMSO	Soluble
DMF	Soluble

The results presented on the table IX show that target compound **B** is insoluble in polar protic solvents such as water, ethanol, methanol and acetic acid but soluble in polar aprotic solvents such as DMSO and DMF. It is insoluble in nonpolar solvents such as benzene and aniline. The solubility of target compound **B** in polar aprotic solvents suggests that it is a salt. A salt is an ionic compound and hence compound **B** is ionic.

III.2.5: INFRARED SPECTRUM

The IR spectra of the ligands used to synthesize target compound **B**, Phen and Dipic were recorded by computational simulation using Gaussview and Gaussum applications. The spectra are shown on Figure 19.



(1) (2)

Figure 19: IR spectra of Dipic (1) and Phen ligands (2)

The absorption bands extracted from the IR spectra of the two ligands are summarised in Table X and IX.

Table X: Absorption bands of Dipic ligand

Bands (cm^{-1})	**3560**	**3100**	**1698**	**1454** **1371**	**1357**	**929**
Functional group	**v(O-H)**	**v(C-H)**	**v(C=O)**	**v(C=C)** **v(C=N)**	**v(C-O)**	**v(C-H)**

Table XI: Absorption bands of Phen ligand

Bands (cm^{-1})	**3100-3000**	**1600** **1500**	**1550**	**1300**	**945**
Functional group	**v(C-H)**	**v(C=C)** **v(C=N)**	**v(C-C)**	**v(C-N)**	**v(C-H)**

The IR spectrum of the target compound **B** was analysed using IR spectroscopy in the wave number region 4000 cm^{-1} to 400 cm^{-1}. Its IR spectrum is shown in Figure 20.

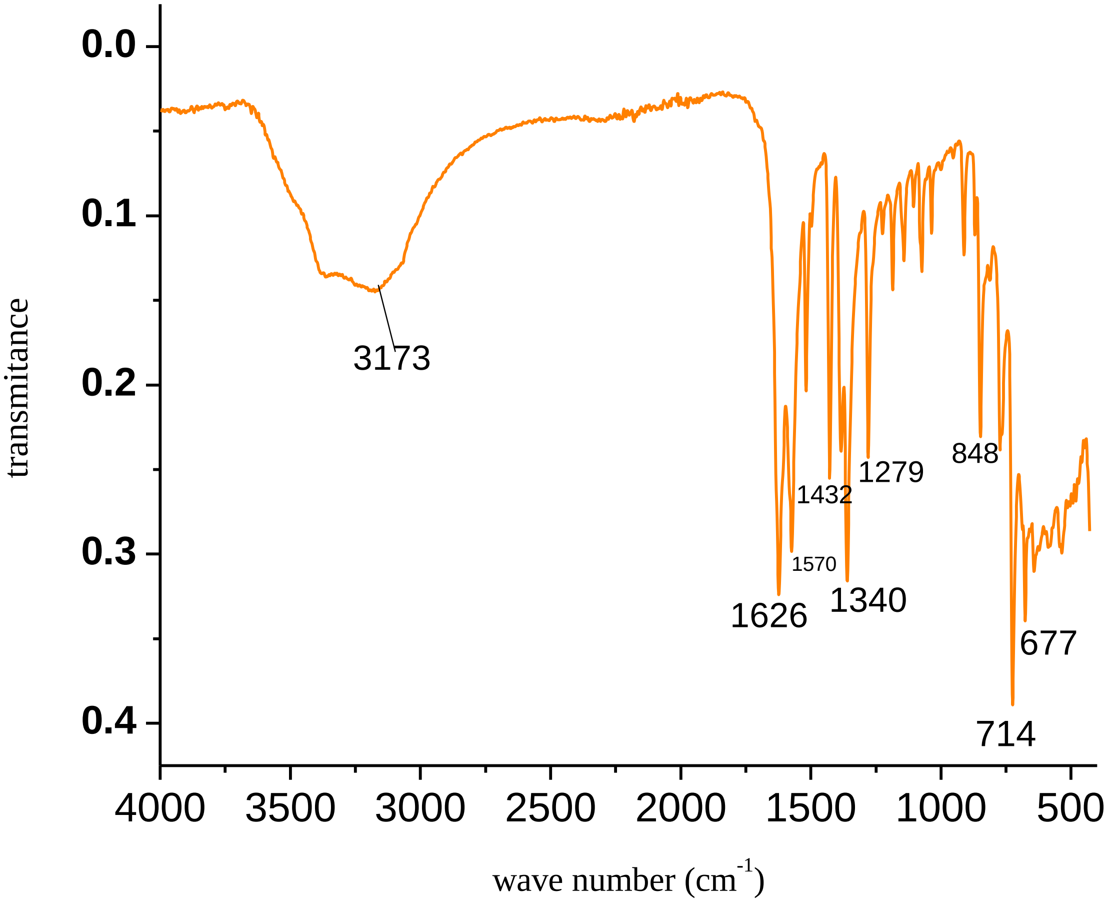


Figure 20: IR Spectrum of compound B

Observing the IR spectrum of target compound **B**, the following characteristic bands presented in table XII are present in the synthesized compound **B**.

Table XII: The absorption bands of Synthesized compound B

Bands (cm^{-1})	**3173**	**1626**	**1570**	**1432**	**1340**	**848**	**714** **662**	**677**
Functional group	**v(O-H)**	**v(C=O)**	**v(C=N)**	**v(C-C)**	**v(C-O)**	**v(C-H)**	**(Zn-O)** **(Zn-N)**	**v(Co-O)**

The IR spectrum of compound **B** shows a broad band around 3173 cm^{-1} which can be attributed to the O-H stretching vibration of water molecules of crystallisation [72, 73]. The strong bands appearing around 1626 cm^{-1}, 1570 cm^{-1}correspond to the C=O stretching vibration of the carboxylate group and the C=N groups of the dipicolinato ligand. The absorption bands around 1432 cm^{-1}, 1340 cm^{-1}, 1279 cm^{-1} can be attributed to the C-O, C-N and C-C vibrations. The band around 860 cm^{-1} corresponds to C-H stretching vibrations. Lastly, the sharp absorption bands around 715 cm^{-1} and 677 cm^{-1} could be assigned to the M - O and M - N stretching vibrations [74, 75]. Comparing these data to those of the ligands indicate that the complexes were actually formed since new bands and shifts from ligand bands are observed in the spectrum of the synthesized compound.

III.2.6: UV-VIS SPECTRUM

The UV-Vis spectrum of target compound **B** is illustrated in Figure 21.

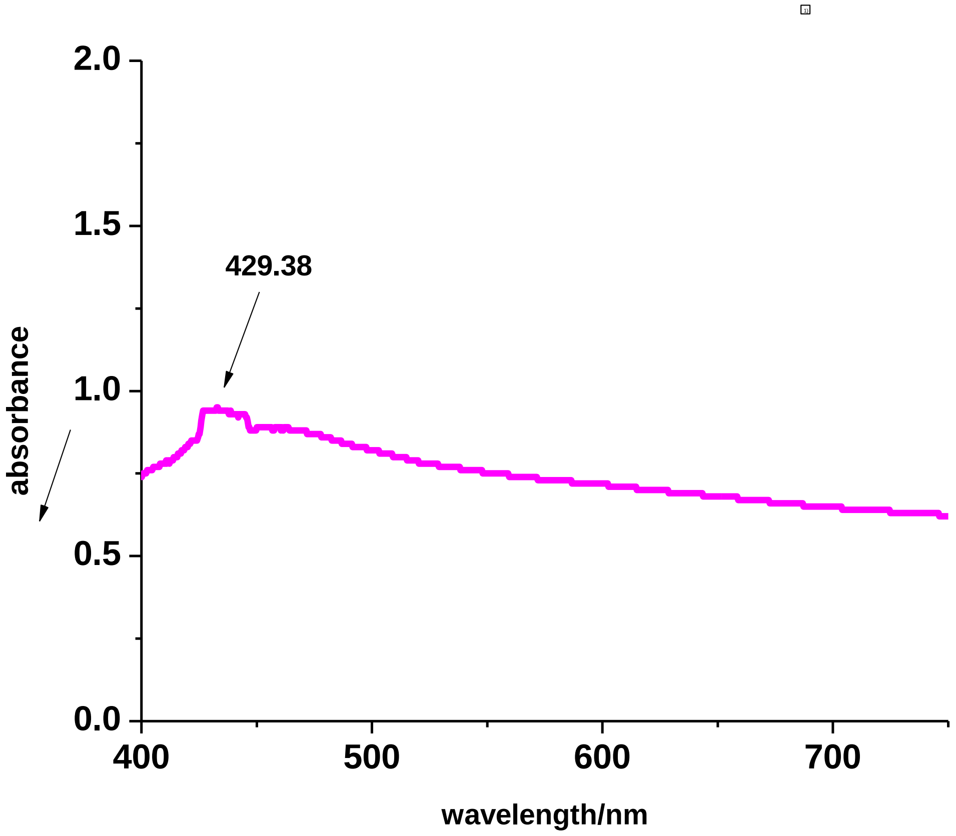


Figure 21: The UV-Visible Spectrum of compound B

The UV-Vis spectrum of **B** in aqueous solution shows one absorption bands in the visible region at 429 nm responsible for the orange colour of the complex. This transition is probably due to d-d electronic transitions attributed to ($^4A_{2g} \rightarrow {}^4T_{2g}$) suggesting an octahedral geometry.

III.1.7: PHOTOLUMINESCENCE SPECTRUM

The photoluminescence spectrum of compound **B** is shown on figure 22

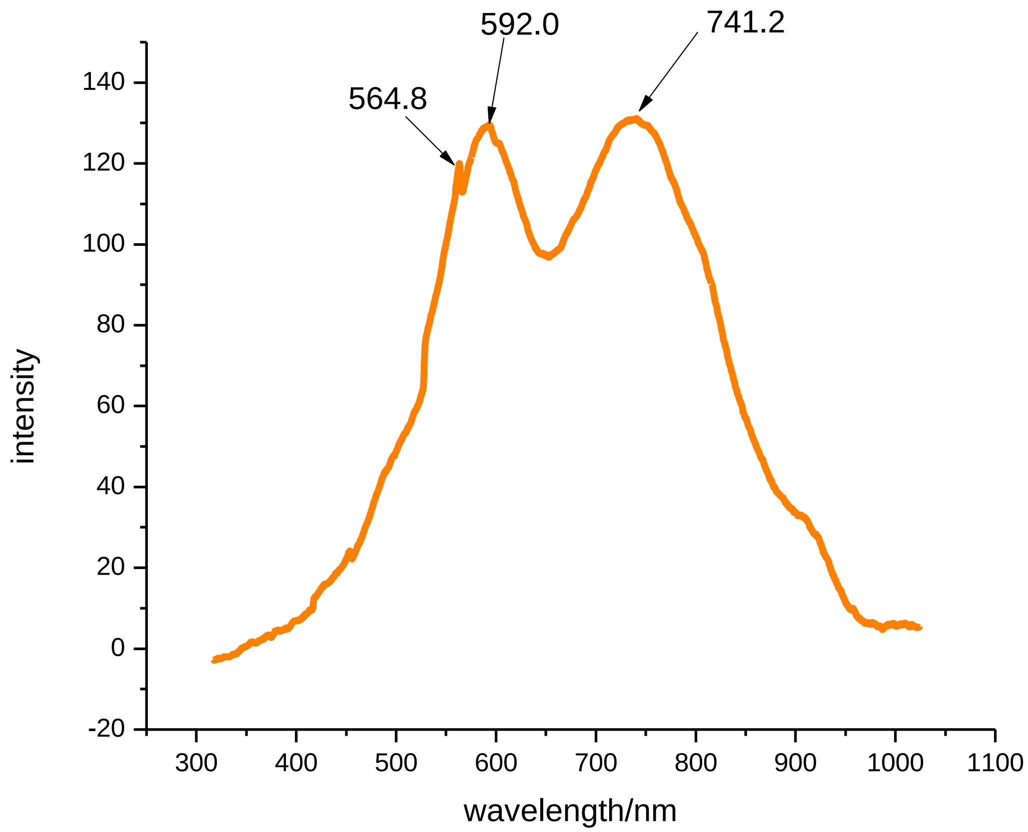


Figure 22: Photoluminescence Spectrum of compound B

The photoluminescence spectrum of target compound **B** presents three peaks at 564 nm, 592 nm and 741 nm. Hence the complex emits light at these three wavelengths. The peaks at 564 nm and 592 nm may be due to the $[Co(phen)_3]^{2+}$ because this complex cation is known to emit light at the orange-red region of the electromagnetic spectrum attributed to d-d electronic transitions within the d^7 orbitals of Co^{2+}. The peak at 741 nm is attributed to the $[Zn(Dipic)_6]^{2-}$ which emits light in the red region of the spectrum due to metal to ligand charge transfer [79-81]. Hence these compounds can be used in light emitting diodes, tunable lasers, fluorescent labels and in anti-counterfeiting devices.

III.2.8: THE POWDER X-RAYS DIFFRACTOGRAM OF COMPOUND B

Figure 23 provides X-ray Diffraction pattern of a plot of X-ray intensity against 2θ, where 2θ is the angle between the incident and diffracted X-ray beams. Peaks in the pattern correspond to specific crystallographic planes within the material.

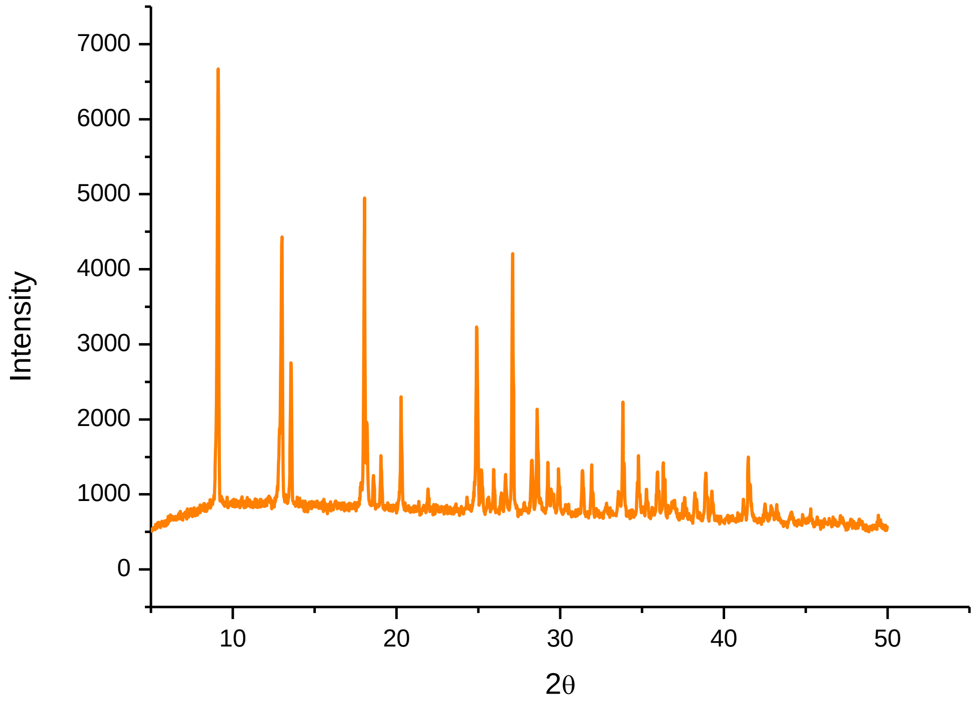


Figure 23: Powder X rays diffraction patterns of compound of B

The presence of sharp peaks in the diffraction patterns of compound **B** suggests that compound **B** is crystalline. The presence of multiple peaks suggests that the structure of compound **B** is complex, likely involving multiple atoms or ions in the unit cell. The intensity of the peaks varies; with some peaks stronger than others indicating that certain crystal planes are more abundant than others [82].

III.2.9: PROPOSED STRUCTURE OF COMPOUND B

Based on the results obtained from the analyses carried out, The IR spectroscopy shows complexation and water molecules of crystallization. The UV spectroscopic analysis equally proposes an octahedral geometry about the various central metal ions while Solubility test results reveal the ionic natures of the compound. Conductimetric results indicate the presence of two ions in the compound. The proposed structure of **B**, pending confirmation from single-crystal X-ray diffraction is shown on Figure 24.

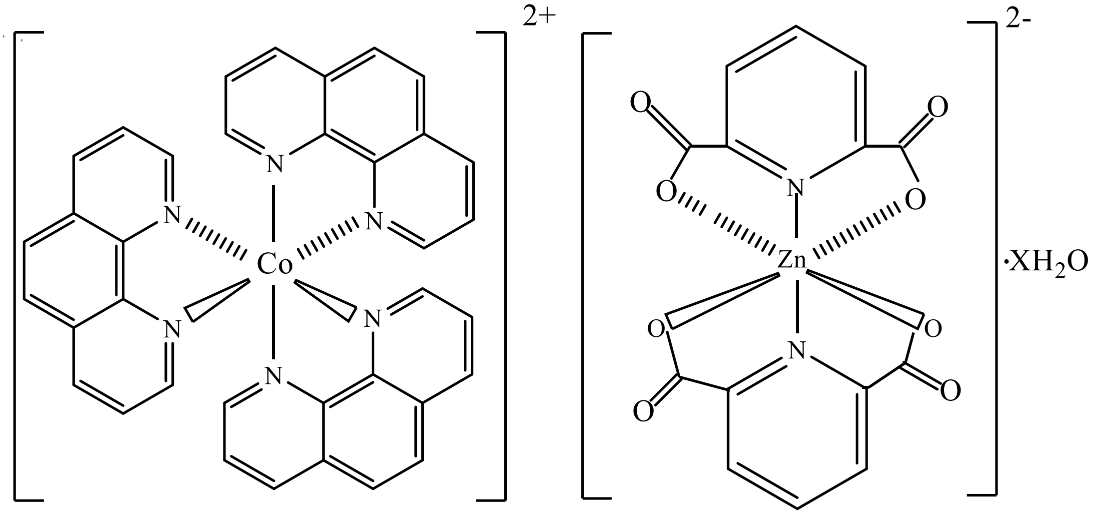


Figure 24: Proposed structure of compound B

III.2.10: ANTIMICROBIAL ACTIVITY

The antimicrobial activities of Dipic, 4-DMAP, Phen and of the target materials **A** and **B** were evaluated against five bacterial strains (*Escherichia coli* (EC), *Pseudomonas aeruginosa* (PA), *Staphylococcus aureus* (SA), *Acinetobacter baumannii* (AB) *and Shigella flexineri* (SF)) and two fungal strains (*Candida tropicalis* (CT), *Candida albicans* (CA)). SA is gram-positive while EC, PA, AB and SF are gram-negative. CA and CT are yeasts. The antibacterial activity parameter (MIC) was determined by microdilution in liquid medium and the results recorded in Table XIII.

Table XIII: Antimicrobial activity of ligands and Target compound(A and B)

Compound	**AC** NR	**PA** NR	**SA** NR	**EC** NR	**SF** NR	**CA** NR	**CT** HR
Dipic	325	450	-	-	-	450	-
4-DMAP	-	-	-	-	-	-	-
Phen	4	128	8	2	8	16	1.25
A	-	-	250	-	-	-	-
B	-	-	-	500	-	-	-
Cipro	0,125	0,0625	0,015	0,031	0,0625	//	//
Ampho B	//	//	//	//	//	1,25	2.5

Key

-:	**not active (MIC>500µg/mL)**
//	not determined
NR	non resistant
HR	**highly resistant**

According to the results in Table XIII, 4-DMAP displays no inhibition against all the bacterial and fungal strains. However, Dipic exhibits weak antimicrobial activity against some of the bacterial strains and no activity against any of the fungal strains. Phen exhibits very high antimicrobial activities against all the bacterial strains and fungal strains. Compounds **A** and **B** both showed antimicrobial activities on some bacterial strains and no activity against any of the fungal strains within the concentration limits less than 500 µg/mL against . However, compound **A** has a good antibacterial activity against SA with a MIC value of 250 µg/mL. Compound **B** on its own has a weak activity at a concentration of 500 µg/mL against EC. The low activity of these compounds against microbes is likely due to their complex structures [83], decrease in solubility, chelation which reduces their availability for interaction with target microbes, steric hindrance, or alteration in properties due to complexation [84].

GENERAL CONCLUSION AND PERSPECTIVES

The major objective of this work was to synthesize, characterize and study the antimicrobial properties of mixed ionic complexes of cobalt(II) and zinc(II) dipicolinates with 1,10-phenanthroline and 4-(dimethyl)aminopyridine.

To attain this objective, direct syntheses in aqueous medium were carried out between 4-DMAP and cobalt(II) acetate on one part and Dipic with zinc(II) acetate on the other part to obtain compound **A** of formula $\mathbf{[Co(DMAP)_6]^{2+}[Zn(Dipic)_2]^{2-}\cdot XH_2O}$. A similar reaction between 1,10-phenanlthroline and cobalt(II) acetate on one part and Dipic with zinc(II) acetate on the other part produced compound **B** of formula $\mathbf{[Co(Phen)_3]^{2+}[Z\ n(Dipic)_2]^{2-}\cdot XH_2O}$. The two complex salts obtained in the course of this work did not melt up to a temperature of 330 °C, the threshold temperature of the instrument indicating the strong nature of the forces holding the constituent ions. However, compound **A** degraded at a temperature of 260 °C under thermal effect indicated by a change in colour. The synthesized materials equally showed solubility in polar aprotic solvents showing their polar nature. However, compound **A** showed excellent solubility even in polar protic solvents while compound B was insoluble in polar protic solvents. Conductimetric measurements equally confirmed the ionic nature of the materials synthesized while UV-visible spectroscopic analysis of each of the materials shows absorption peaks within the visible region characteristic of *d-d* electronic transitions giving rise to red and orange colours for compounds **A** and **B** respectively.

The antimicrobial activities of the target materials **A** and **B** were evaluated against five bacterial strains (*Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Acinetobacter baumannii and Shigella flexineri*) and two fungal strains (*Candida tropicalis, Candida albicans*) by microdilution in liquid medium. Compounds **A** and **B** both showed antimicrobial activities on some bacterial strains and no activity against any of the fungal strains. Compound **A** has a good antibacterial activity against *Staphylococcus aureus* while compound **B** shows a weak activity against *Escherichia coli*.

Upon these findings and analyses, we can successfully confirm that new materials have been synthesized and with antimicrobial properties. However, more analysis will still be required to determine their toxicity and duration of action in living cells.

PERSPECTIVES

Our future research will therefore focus on:

- Conducting a single crystal XRD to ascertain the exact structures of the target materials;
- Investigating the magnetic and optical properties of these compounds to identify their potential applications;
- Determining the MIC of the target materials on other bacterial and fungal strains so as to evaluate their effectiveness or strength in producing a desired biological or chemical response; as well as evaluating their anticancer, antiviral and anti-diabetic properties;
- Use of other methods such as disc diffusion method to determine their antimicrobial properties.

REFERENCES

[1]. E. Coronado, A. Forment-Aliaga, J. R. Galan-Mascaros, C. Gimenez-Saiz, C. J. Gomez-Garcia, E. Martinez-Ferrero, A. Nuez, F. M. Romero, "Multifunctional Molecular Materials", *Solid State Sci*., 5, 917–924, (2003).

[2]. J. Nenwa, G. Bebga , M. Signe, M. Belombe, M. Mohammed, B. P. T. V. Fokwa , "2-Aminopyridinium trans-diaquabis(oxalato-k^2O,O')chromate(III)", *Acta Cryst*., 68, 1325-1326, (2012).

[3]. H. Liu, W. Gu, G. Xu, Y. Feng, F. Kou, L. Feng, S. Yan, D. Liao, P. Cheng, " First μ_3-oxalato-bridged cis and trans configurations Nickel Macrocyclic Complex: Synthesis, Structure and Magnetic Properties", *Inorg. Chem.,* 10, 1099-1101, (2007).

[4]. L. Yan-Tuan, Y. Cui-Wei, G. Hua-Shi, “Synthesis and Magnetic Studies of Oxalato-bridged copper(II)-chromium(III)-copper(II) and copper(II)-iron(III)-copper(II) Heterotrinuclear Complexes”, *Polyhedron,* 22, 3223–3230, (2003).

[5]. J. Nenwa, E. D. Djomo, E. N. Nfor, P. L. Djonwouo, M. Mbarki, B. P. T. Fokwa, "Two Novel Organic-Inorganic Hybrid Compounds with Straight and Zigzag Chain Alignments of Cu(II) Centers: Synthesis, Crystal Structure, Spectroscopy, Thermal Analysis and Magnetism" , *Polyhedron*, 99, 26-33, (2015).

[6]. A. Natalia, R. Analu, C. Victoria, E. Javier, J. C. Antonio, A. B. Alzir, F. Gianella, “Development of Copper Complexes with Diimines and Dipicolinate as Anticancer Cytotoxic Agents”, *Pharmaceutics,* 15, 1-18, (2023).

[7]. K. S. Prakash, K. B. Susanta, A. Mohammad, “Transition Metal Complexes Produced From Dipicolinic Acid: Synthesis, Structural Characterization, and Anti-Microbial Investigations”, *Bull. Chem. Soc. Ethiop*., 36, 607-615, (2022).

[8]. J. Meimoun, Y. Phuphuak, R. Miyamachi, Y. Miao, M. Bria, C. Rousseau, G. Nogueira, A. Valente, A. Favrelle-Huret, P. Zinck, “Cyclodextrins Initiated Ring-Opening Polymerization of Lactide Using 4-Dimethylaminopyridine (DMAP) as Catalyst: Study of DMAP/β-CD Inclusion Complex and Access to New Structures”, *Molecules,* 27, 1-13, (2022).

[9]. K. M. Adithya, S. Saranyapavathi, C. Raksha, B. Vrrinda, C. Geethu, N. V. Kulkarni, B. I. Kharisov, “Transition metal complexes of 4-aminoantipyridine Derivatives and their antimicrobial properties”, *Russ. J. Coord. Chem*., 48, 692-724, (2022).

[10]. F. J. Teixeira, L. S. Flores, T. Valverde, L. B. L. Escobar, M. S. Reis, C. C. Correa, “Synthesis and Magnetic Properties of two cobalt-coordination polymers containing 1,10-phenanthroline and alkyldicarboxylates ligands”, *J. Mol. Struct.,* 1261, 1-11, (2022).

[11]. M. O. Agwara, P. T. Ndifon, N. B. Ndosiri, A. G. Papoudam, D. Yufanyi, A. Mohamadou, “Synthesis, Characterization and antimicrobial activities of cobalt(II), copper(II), and zinc(II) Mixed-ligand complexes containing 1,10-phenanthroline and 2,2-bipyridine”, *Bull. Chem. Soc. Ethiop.*, 24, 383-389, (2010).

[12]. M. O. Agwara, N. B. Ndosiri, M. Mohamadou, A. M. Conde, “Synthesis, Characterization and antimicrobial evaluation of Mn(II), Co(II), Ni(II), Cu(II) and Zn(II) complexes of pyridine-2-carboxylic acid”, *RJPB CS.*, 4, 1370-1381, (2013).

[13]. S. N. Sovari, F. Zobi, “Recent Studies on the Antimicrobial Activity of Transition Metal Complexes of Groups 6-12”, *Molecules*, 2, 418-452, (2020).

[14]. M. C. Durrant, “Transition Metal Chemistry: Past, Present and Future”, *Transit. Met. Chem.*, 44, 1-3, (2019).

[15]. S. Rafique, M. Idrees, A. Nasim, H. Akbar, A. Athar, “Transition Metals Complexes as Potential Therapeutic Agents” , *Biotechnol. Mol. Biol.*, 5, 38 - 45, (2010).

[16]. Q. Dehaine, L.T. Tijsseling, H. J. Glass, T. T. Anen, A. R. Butcher: “Geometallurgy of Cobalt Ores: A Review”, *Miner. Eng.*, 160, 106656-106683, (2021).

[17]. D. Barałkiewicz, J. Siepak, “Chromium, Nickel and Cobalt in Environmental Samples and Existing Legal Norms”, *J. Enviro. Sci.*, 8, 201-208, (1999).

[18]. W. Betteridge, “The Properties of Cobalt”, *J. Mater. Sci.*, 24, 51-142, (1979).

[19]. D. Lison, S. V. D. Brule, G. V. Maele-Fabry, “Cobalt and its Compounds: Update on Genotoxic and Carcinogenic Activities”, *Cri. Rev.Toxicol.*, 48, 522-539, (2018).

[20]. D. Vusak, N. Smrecki, S. Muratovic, D. Zilic, B. Prugovecki, D. Matkovic-Calogovic, “Structural Diversity in the Coordination Compounds of Cobalt, Nickel and Copper with N-Alkylglycinates: Crystallographic and ESR Study in the Solid State”, *RSC.*, 38, 23779-23790, (2021).

[21]. J. Blahut, L. Benda, J. Kotek, G. Pintacuda, P. Hermann, “Paramagnetic Cobalt(II) Complexes with Cyclam Derivatives: Toward 19 F MRI Contrast Agents”, *Inorg. Chem.*, 59, 10071-10082, (2020).

[22]. L. Korecz, A. A. Saghier, K. Burger, “Determination of the Coordination number and Geometry of the Coordination Sphere of The Central Tin atom in Stannatrane Complexes by Mossbauer Spectroscopy”, *Inorg. Chem. Acta*, 58, 243-249, (1982).

[23]. S. A. Carabineiro, L. C. Silva, P. T. Gomes, L. C. J. Pereira, L. F. Veiros, S. I. Pascu, M. T. Duarte, S. Namorado, R., T. Henriques, “Synthesis and Characterization of Tetrahedral and Square Planar Bis(iminopyrrolyl) Complexes of cobalt(II)”, *Inorg.Chem*., 46, 6880-6890, (2007).

[24]. A. M. Shalash, H. L. A. Ali, “Synthesis, Crystallogarphic, Spectroscopic Studies and Biological Activity of New Cobalt (II) Complexes with Bioactive Mixed Sulindac and Nitrogen Donor Ligands”, *Chem. Cent. J.*, 11, 1-11, (2017).

[25]. A. Waris, M. Din, A. Ali, S. Afridi, A. Baset, A. U. Khan, M. Ali, “Green fabrication of Co And Co_3O_4 Nanoparticles and their Biomedical Applications: A Review”, *Open Life Sci.*, 16, 14-30, (2021).

[26]. S. S. Afolabi, M. O. Zakariyah, M. H. Abedi, W. Shafik, “A Survey on cobalt Metallurgical Processes and its application’’, *J. Indian. Chem. Soc*., 98, 100179, (2021).

[27]. J. V. Dyk, J. J. Battista, P. R Almond, “A retrospective of Cobalt-60 radiation therapy: The atom bomb that saves lives”, *Med. Phys. Int. J.*, 4, 327-350, (2020).

[28]. A. Chen, M. Li, Z. Qian, Y. Ma, J. Che, Y. Ma, “Hemimorphite Ores: A Review of Proclessing Technologies for Zinc Extraction”, *JOM*., 68, 2688-2697, (2016).

[29]. S. F. Sousa, P. A. Fernandes, M. J. Ramos, “The Carboxylate Shift in Zinc Enzymes: A Computational Study”, *J. Am. Chem. Soc*., 129, 1378-1385, (2007).

[30]. J. R. Bishop, D. W. Emerson, “Geographical Properties of Zinc Bearing Deposits”, *Aust. J. Earth. Sci*., 46, 311-328, (2002).

[31]. Z. Liu, Y. Mooi, P. J. Tiong, R. A. A. Talip, N. Jasin, V. Y. Mian, M. G. Tay, “Five-Coordinate Zinc(II) Complex: Synthesis, Characterization, Molecular Structure, And Antibacterial Activities of Bis-[(E)-2-Hydroxy-N-{1-(4-Methoxyphenyl)Ethylidene}Benzohydrazido] Dimethylsulfoxidezinc(II) Complex”**,** *Int. J. Inorg. Chem*., 2017, 1-8, (2017).

[32]. E. Cavero, S. Uriel, P. Romero, J. L. Serran, R. Gime´nez, “Tetrahedral Zinc Complexes with Liquid Crystalline and Luminescent Properties: Interplay Between Nonconventional Molecular Shapes and Supramolecular Mesomorphic Order”, *J. Am. Chem. Soc*., 129 , 1-11, (2007).

[33]. M. Porchia, M. Pellei, F. D. Bello, C. Santini, “Zinc Complexes with Nitrogen Donor Ligands as Anticancer Agents”, *Molecules*, 25, 1-41, (2020).

[34]. M. J. Brabha, M. A. Malbi, “Synthesis, Characterization, and Biological activity of Zinc Complexes with Ethylenediamine and its Derivatives”, *Chem. Phys.*, 7, 100248-100254, (2023).

[35]. S. Ghosh, “Syntheses and Characterization of N,N Donor Ligands Atis”, *Indian Institute Of Science Education And Research Kolkata. Summer research report*, 1-27, (2023).

[36]. P. K. Sahoo, S. K. Biswal, M. Azam, “Transition Metal Complexes produced from Dipicolinic Acid: Synthesis, Structural Characterization, and Anti-Microbial Investigations”, *Bull. Chem. Soc. Ethiop.*, 36, 607-615, (2022).

[37]. H. Park, A. J. Lough, J. C. Kim, M. H. Jeong, Y. S. Kang, “Different coordination modes of Hdipic and Dipic ligands to nickel (II) ion in the same Environment”, *Inorg. Chem. Acta*, 360, 2819-2823, (2007).

[38]. N. Buyukkidan, C. N. Buyukkidan, C. Yenikaya, H. IIkimen, C. Karahan, C. Darcan, T. Korkmaz, Y. Suzen, “Synthesis, Characterization and Biological Activities of Metal(II) Dipicolinates Complexes derived from Pyridine-2,6-Dicarboxylic Acid and 2-(piperazin-1-yl)ethanol”, *J. Mol. Struct.*, 1101, 139-146, (2015).

[39]. R. J. Wallace, “Symposium on ‘Plants as Animal Foods: A Case of Catch 22: Antimicrobial Properties of Plant Secondary Metabolites*”, Proc. Nutr. Soc., 63*, 621-629, (2004).

[40]. X. Song, M. Han, F.He, S. Wang, C. Li, G. Wu, Z. Huang, D. Liu, F. Liu, P. Laborda, X. Shi, “Antifungal Mechanism of Dipicolinic Acid and its Efficacy for the Biocontrol of Pear Valsa Canker”, *Front. MicroBiol.*, 11, 1-10, (2020).

[41]. R. Gail, L. Chi, M. Godzala III, P. J. Kostyniak, J. J.Smee, A. M. Trujillo, J. A. Alfano, W. Ding, Z. Hu, D. C. Crans, “Anti-Diabetic Effects of a Series of Vanadium Dipicolinates Complexes in Rats with Streptozocin-Induced Diabetes” , *Coord. Chem. Rev.*, 255, 2258-2269, (2011).

[42]. S. Abdolmaleki, M. Ghadermazi, M. Ashengroph, A. Saffari, S. M. Sabzkohi, “Cobalt (II), Zirconium(IV), Calcium(II) Complexes with Dipicolinic Acid and Imidazole Derivatives: X-ray Studies, Thermal Analyses, Evaluation as in Vitro Antibacterial and Cytotoxic Agents”, *Inorg. Chem. Acta, 480,* 70-82, (2018).

[43]. A. M. Mengesha, “The Study of Antimicrobial Activities of Various Transition Metal Mixed Ligand Complexes Containing 1,10-Phenanthroline with Any Other Ligands”, *Int. J. Bioorg. Chem.*, 7, 1-10, (2022).

[44]. N. Alvarez, P. Freddi, A. J. Costa-Filho, S. Catellani, N. Veiga, J. Facchin, “ New Insight into the Biophysical Behaviour of an Old Molecule: Experimental and Theoreical Studies of the Interactions between 1,10-phenanthroline and Model Phospholipid Membrane”, *Braz. J. Phys.*, 52, 1-21, (2022).

[45]. L. Viganor, O. Howe, P. McCarron, M. McCann, M. Devereux, "The Antibacterial Activity of Metal Complexes Containing 1,10- phenanthroline: Potential as Alternative Therapeutics in the Era of Antibiotic Resistance". *Curr. Top. Med. Chem.*, 17, 1280-1302, (2017).

[46]. M. McCann, A. Kellett, K. Kavanagh, M. Devereux, A. L. S. Santos, "Deciphering the Antimicrobial Activity of Phenanthroline Chelators", *Curr. Med. Chem.*, 19, 2703-2714, (2012).

[47]. D. Gaelle, D. Yufanyi, R. Jagan, M. Agwara, "Synthesis, Characterization and Antimicrobial Properties of Cobalt (II) and Cobalt (III) Complexes derived from 1,10-phenanthroline with nitrate and Azide Co-ligands", *Cogent Chem*., 2, 1-16, (2016).

[48]. L. N. T. Giang, D. T. T. Anh, H. T. Pouong, N. H. Thanh, N. T. Q. Giang, N. T. Anh, N. V. Tuyen, P. V. Kiem. "DMAP Catalyzed Efficient and Convenient approach for the Synthesis of 3,3-(Arylmethylene)Bis(2-Hydroxynapthalene-1,4-Dione) Derivatives", *Nat. Prod. Commun*., 16, 1-7, (2021).

[49]. A. Anwar, S. Khalid, S. Perveen, S. Ahmed, R. Siddiqui, N. A. Khan, M. Raza Shah, "Synthesis of 4-(Dimethylamino)Pyridine Propylthioacetate Coated Gold Nanoparticles and their Antibacterial and Photophysical Activity", *J. Nanobiotechnol*, 16, 1-8, (2018).

[50]. H. İlkimen, C. Yenikaya, A. Gülbandilar, "Antimicrobial Activity of Proton salts of 3-(Sulfamoylphenylcarbamoyl)Acrylic Acid Derivatives with Aminopyridine Derivatives", *J. Sci. Rep*., 54, 264-272, (2023).

[51]. H. Wang, L. Weng, H. Yang, X. Yang, X. Dong, X. Tan, Y. Wang, "Heterometallic Coordination Polymers: Treatment Activity on Diabetic Foot by Reducing the excess Inflammatory Response in the Plantar Tissue", *J. Chem. Res*., 2021, 49–55, (2020).

[52]. B. Das, J. B. Baruah, "Water clusters in mixed ionic complexes with metal dipicolinates anions", *J. Mol. Struct*., 1034, 144-151, (2013).

[53]. M. Tabatabaee, B. Kukovec, M. Kareroonizadeh, "A unique example of a co-crystal of $[Ag(atr)_2][Cr(dipic)_2]$ and dinuclear $[Cr(H_2O)(dipic)(u\text{-}OH)]_2$ with different coordination environment of Cr(III) ions", *Polyhedron*, 30, 1114-1119, (2011).

[54]. M. V. Kirillova, M. C. Fatima. G. D. Silva, A. M. Kirillov, J. J. R. Silva, A. J. L. Pombeiro, "3D hydrogen bonded heteronuclear Co(II), Ni(II), Cu(II) and Zn(II) aqua complexes derived from dipicolinic acid", *Inorg. Chem. Acta*, 360, 506–512, (2007).

[55]. K. V. Yusenko, D. B. Vasil-chenko, A. V. Zadesenets, I. A. Baidina, Y. V. Shubin, S. V. Korenev, “Double Complex Salts $[Pt(NH_3)_5Cl][M(C_2O_4)_3] \cdot n$H2O (M = Fe, Co, Cr):Synthesis and Study”, *J. Org. Chem.*, 52, 1487-1491, (2007).

[56]. T. Liu, R. Yang, G. Zhong, “Synthesis, Structural Characterization, and antibacterial Activity of Novel Erbium(III) Complex Containing Antimony”. *Bioinorg. Chem.,* 2018, 1- 9, (2018).

[57]. A. Frei, J. Zuegg, A. G. Eliott, M. Baker, S. Braese, C. Brown, F. Chen, C. G. Dowson, G. Dujardin, N. Jung, A. P. King, A. M. Mansour, M. Massi, J. Moat, H. A Mohamed, A. K. Renfrew, P. J. Rutledge, P. J. Sadler, M. H. Todd, C. E. Willans, J. J. Wilson, M. A. Cooper, M. A. T. Blaskovich, “Metal Complexes as a Promising Source for new Antibiotics”, *Chem. Sci*., 11, 2627-2639, (2020).

[58]. A. M. Algammal, H. F. Hetta, A. Elkelish, D. H. Alkhalifah, W. N. Hozzein, G. E. Batiha, N. E. Nahhas, M. A. Mabrok, “Methicillin-Resistant *Staphylococcus Aureus”* (MRSA): One Health Perspective Approach to the Bacterium Epidemiology, Virulence Factors, Antibiotic-Resistance, and Zoonotic Impact”, *Infect. Drug Resist.*, 3255-3265, (2020).

[59]. L. Mackane, J. Kandel, (1996). “*Microbiology, essentials and applications* (2nd Edition). McGraw Hill New York.

[60]. R. L. Vogt, L. Dipold, “Escherichia Coli 0157: Outbreak Associated with consumption of ground Beef”, *Public Health Rep.,* 120, 174-178, (2005).

[61]. Spagnolo, A. maria, Sartini, Marina, C. M. Luisa, “ Pseudomonas Aeruginosa in the Health Care Facility Setting”, *Rev. Med. Microbiol.*, 32, 169-175, (2021).

[62]. N. Martins, N. Ferreira, C. F. R. Isabel, L. Barros, S. Silva, M. Henriques, “Candidiasis : Predisposing Factors, Prevention, Diagnosis and Alternative Treatment”, *Mycopathologia*, 177, 223-240, (2014).

[63]. P. Forterre, D. Prangishvilli, “The Origin of Viruses”, *Res. Microbiol.*, 160, 466-472, (2009).

[64]. R. J. White, “The Early History Of Antibiotic Discovery: Empiricism Ruled”, *J. Antibiot*., 978, 3-31, (2011).

[65]. M. A. Abushaheen, Muzaheed, A. J. Fatani, M. Alosaimi, W. Mansy, M George, S. Acharya, S. Rathod, D. D. Divakar, C. Jhugroo, S. Vellappally, A. A. Khan, J. Shaik, P. Jhugroo, “Antimicrobial resistance, mechanisms and its clinical significance”, *Dis. Mon.*, 66, 1-21, (2020).

[66]. E. Christaki, M. Marcou, A. Tofarides, “Antimicrobial Resistance in Bacteria: Mechanisms, Evolution and persistence”, *J. Mol. Evol*., 88, 26-40, (2020).

[67]. J. A. Hendrickson, C. Hu, S. L. Atitken, N. Beyda, “Antifungal Resistance: A Concerning Trend for the Present and Future”, *Curr. Infect. Dis. Rep*., 21, 1-47, (2019).

[68]. V. Balzani, A. Juris, “Photochemistry and Photophysics of Ru(II)- polypridine complexes in Bologna group. From early studies to recent developments”, *Coord. Chem. Rev*., 211, 97-115, (2001).

[69]. Wayne, “Methods for Dilution Antimicrobial susceptibility test for Bacteria that grow Aerobically”, *CLSI M07*, 11, 1-13, (2018).

[70]. Wayne, “Reference Method for Broth Dilution Antifungal Susceptibility testing of yeasts”, *CLSI M27-A3*, 28, 1-25, (2008).

[71]. J. Levisalles, M. Josefowicz, “Composés organiques complexes”, *Flammarion Sciences, Paris*, Tome III, 1-306, (1974).

[62]. T. Lobana, S. Indoria, A. Jassal, H. Kaur, D. Arora, J. Jasinki, “Structures, Specttroscopy and Antimcrobial Properties of Complexes of copper (II) with Salicylaldehyde N-substituted Thiosemicarbazones and 2,2’-bipyridine or 1,10-phenanthroline”, *Eur. J. Med. Chem*., 76, 145-154, (2014).

[73]. H. İlkimen, C. Yenikaya, A. Gülbandılar, M. Sarı, “Synthesis and characterization of a novel proton salt of 2-amino-6-nitrobenzothiazole with 2,6-pyridinedicarboxylic acid and its metal complexes and their antimicrobial and antifungal activity studies”, *J. Mol. Struct.*, (2016), 1120, 25-33.

[74]. O. E. Piro, Echeverría, G. A. Echeverría, R. C. Mercader, A. C. González-Baró and E. J. Baran, “Crystal structure and spectroscopic behavior of three new tris-oxalatoferrate(III) salts”, *J. Coord. Chem.*, 69, (2016), 1–21.

[75]. M. Gruselle, C. Train, N. S. Ovanesyan, V. D. Makhaev, C. Cordier, “Is the unexpected behaviour of the resolved $K_3[Cr^{III}(C_2O_4)_3]$ in aqueous solution responsible for the formation of pure chiral solid phase of a two-dimensional (2D) $[Mn^{II}Cr^{III}(C_2O_4)_3$ NEt(*n*-Pr)(*n*-Bu)(n-C_5H_{11})] network?”, *Mendeleev Commun.*, 14, (2004), 284–285.

[76]. D. N. Kumar, B. S. Garg, “Synthesis and spectroscopic studies of complexes of zinc(II) with N_2O_2 donor groups”, *Spectrochim. Acta*, 64, 141–147, (2006).

[77]. S. Chandra, U. Kumar, “Spectral and magnetic studies on manganese(II), cobalt(II) and nickel(II) complexes with Schiff bases”, *Spectrochim. Acta*, 61, 219–224, (2005).

[78]. S. Yuan, R. Jaramillo, T. Rosenbaum, L. Yu, “Synthesis and Characterization of Conjugated Polymers containing first row Transition Metal Complexes”, *Macromol*., 39, 8652 - 8658, (2006).

[79]. A. J. Lees, “Luminescence Properties of Organometallic Complexes”, *Chem. Rev.,* 87, 711-743, (1987).

[780]. A. X. Zhu, Q. Q. Xu, F. Y. Liu, X. L. Qi, **“**Synthesis, Characterization, and Photoluminescence Properties of a Planar Copper Triazolate Coordination Polymer with Cyanide as Co-Ligand”, *ZAAC*, 637, 502-505, (2011).

[81]. V. S. V. Rani, T. Dhanasekaran, M. Jayathuna, V. Narayanan, D. Jesudurai, “Synthesis, Characterization of Cu (II) Schiff base complexes: Optical and Magnetic Studies”, *Mater. Today*, 5, 8784 - 8788, (2018).

[82]. M**.** I. Khan, A. Khan, H. Iqbal, M. A. Khan, S. Gul, M. Igbal, I. Rahman, F. Khuda, “Spectra, XRD, and Biological Properties of new Mononuclear Schiff base Transition metal Complexes”, *Inorg. Chem. Commun.*, 35, 104-109, (2013).

[83]. H. Naeimi1, Z. S. Nazifi1, S. M. Amininezhad, M. Amouheidar, “Synthesis, Characterization and in vitro Antimicrobial activity of some new Schiff bases and their complexes”, *J. Antibiot.,* 66, 687-689, (2013).

[84]. B. B. Beyene, G. A. Wassie, “Antibacterial activity of Cu(II) and Co(II) porphyrins: role of ligand modification”, *BMC chem*., 51, 1-8, (2020).