CHAPTER ONE
ABSTRACT

Electroanalytical methods include some of the most accurate as well as sensitive, instrumental techniques. In recent past a variety of instrumental methods have been suggested by various workers for qualitative as well as quantitative analysis. Polarography has proved to be a versatile electrochemical technique that makes use of d.m.e. as a working electrode.

The polarographic technique was discovered by Prof. Heyrovsky, and rapidly gained prominence among other physiochemical methods of analysis. This technique can be used with small quantities of samples ranging from miligram to micrograms levels.

The present investigation has been undertaken mainly with the views to:

(1) determine the stoichiometry and stability constants of ternary complexes of some selected metals and ligands.

(2) find out the effect of size, basicity and steric hindrance on the solution stability of Mn(II), Cd(II) and Zn(II) with some selected L-amino acids and picolines.

(3) elucidate the probable structure aspects in complex formation of Mn(II), Cd(II) and Zn(II) with L-amino acids and picolines.

(4) to calculate the thermodynamic parameters such as free energy change ($\Delta G$), enthalpy change ($\Delta H$) and entropy change ($\Delta S$) of ternary complexes.

Polarographic studies have been done on the mixed ligand complexes of the type [MLX], [ML$_2$X] and [MLX$_2$] where M = Mn(II), Cd(II) and Zn(II), L = L-tyrosine, L-arginine,
L-methionine, L-hydroxytryptophane, L-tryptophane, L-hydroxyproline, L-proline and L-histidine and, $X = \alpha$, $\beta$ - and $\gamma$-picoline. All these systems have been investigated in solution.

The thesis have been divided in four chapters. Each chapter has been designed in such a way so that it has its separate identity. Literature and relevant references have been included in each chapter.

First chapter of this thesis deals with brief introduction, importance of coordination chemistry, behaviour of amino acids, importance of amino acids and their compounds and biochemical importance of their mixed ligand complexes. This chapter also includes the survey of relevant literature on the binary and ternary complexes in solution of transition metal ions. The object of the recent investigation and the theories explaining formation of complexes between metal and ligands have been covered.

Second chapter narrates the complex formation techniques with the details of polarography. This chapter also covers the methods used to determine stoichiometry and stability constants of the complexes.

Third chapter gives the information about the equipments and materials used in this study. The experimental procedure of the present work is briefly described. This chapter also covers the data and graphs.

Fourth chapter compares the details of the results and discussion on the solution stabilities of the ternary complexes with the probable structures of complexes and the factors affecting the stability of complexes. In addition with these the
thermodynamic stability of the complexes, the tentative structures of complexes, the factors affecting the stability of complexes and some conclusions drawn have been given.

Appendices and the list of publication of research papers have also been added at the end of this chapter.
1.1 INTRODUCTION

It is during the last forty years that one thing has become quite clear and can not escape the notice of any researcher or keen student of chemistry. This development is the coordination among different branches of chemistry. The chemistry of complex compounds has encompassed a number of domains of chemistry and has become a bridge to combine closely and logically the inorganic, organic, physical and other branches of chemistry. In this way, it expresses the unity of chemistry as the science dealing with the structure of matter. The countless theories and methods used here explain the popularity of this domain among the scientists. The theories of coordination embrace a wide range of interatomic, interionic and intermolecular reactions in the solid phase\(^1\) as well as in solution\(^2-3\). The chemistry of complex compounds has thus become the most suitable ground on which to develop and at the same time to verify a number of theories and above all the theories of chemical bond and structures of compounds thereby attracting considerable attention from the chemists, physicists and even mathematicians. The progressive development of the valence bond theory\(^4-9\), viz., the crystal field theory\(^10-18\) and further the ligand field and molecular orbital theories\(^19-30\) developed on the basis of quantum chemistry\(^31-35\) allows chemists to relate the electronic structures and configurations of complex compounds to their physical and chemical properties.
1.2 IMPORTANCE OF COORDINATION CHEMISTRY

The significance of the coordination compounds in various branches of theoretical and applied chemistry and allied fields is now recognised. In quantitative analysis, coordination compounds are widely used in gravimetric, volumetric and colorimetric determinations as well as in polarimetry and microscopy. It is generally said that, "the chemistry of solutions is the chemistry of complexes". Coordination compounds are widely used in electrodeposition, deposits obtained from the simple salt solutions are sometimes loose, nonadherent, coarsely crystalline and generally undesirable, while metal deposits from appropriate complex salt solutions are often smooth, adherent and of high protective and decorative value. As a consequence of the ability of coordinated metal ions to influence many of the complex reactions upon which the vital processes of living organisms depend, coordination compounds of many varieties are found widely distributed in nature; chlorophyll, blood pigments, metallo-proteins, metallo-enzymes, many vitamins, cytochrome etc. are the few examples of this series. In the past few decades the importance of coordination in dyeing has been recognised. Most dyestuffs are synthetic organic compounds; and of these, the large class of metal-dye compounds called "dye-lakes" are of great interest to the coordination chemists. Coordination phenomenon is used in water softening by "tying up" alkaline earth ions in soluble complex ions and thus preventing the formation of precipitates. The acetyl acetonates of metals are used in the purification of metals.
The chemistry of complexation has also got great importance in the field of pharmaceutical science. If the ligand forms a stable, water-soluble metal chelate, it is said to be a sequestering agent. Sequestration (Latin: to remove) is the suppression of a property or reaction of a metal without removal of that metal from the system or phase by any process of precipitation or extraction and is usually accomplished by chelation.

Biological materials are often dependent on formation of metal chelates. The stabilization of insulin with zinc, the enzymatic bond formation and rupture processes of carbohydrates and nucleoproteins, the iron in heme, magnesium in chlorophyll and cobalt in vitamin B$_{12}$ are examples of systems in which metal chelate complexes are essential for biological activity. Many enzymes contain metals which are essential for the activity of the enzyme system. Removal of metal or lack of the metal can inactivate the enzyme and therefore trace amounts of copper, zinc, manganese, cobalt etc. are required for biological processes$^{36-37}$. Cobalt is found associated in vitamin B$_{12}$, copper with enzyme tyrosinase, zinc in carbonic anhydrase, molybdenum occurs in xanthine dehydrogenase.

The applications of coordination compounds have also extended in many important fields such as laboratory, industry particularly for the identification and separation of chemical elements, preparation of reactor materials, extraction of elements, preparation of "fine chemicals" such as perfumes, paints and pigments, agricultural chemicals, food additives, sweeter.
etc., molecular analysis, enantioselective catalysis and chiral catalysis are also the important fields in which coordination compounds play important role. Day by day new developments are being made in coordination chemistry and in future, this branch will definitely open new doors in the modern scientific world.

1.3 COORDINATION BEHAVIOUR OF AMINO ACIDS

Amino acids, like proteins, are amphiphilic substances with a hydrophilic aminocarboxylate end and a hydrophobic side chain as shown below.

\[
\begin{align*}
\text{H} \\
\text{R} & \quad \text{C} & \quad \text{COO}^- \\
& \downarrow \\
\text{Hydrophobic} & \quad \text{NH}_3 & \quad \text{Hydrophilic}
\end{align*}
\]

The side group in amino acids is usually non-coordinating but its nature seems to be more important atleast in two ways. The hydrophobicity of the side chain governs the solubility of amino acids in non aqueous solvents and also the stabilisation of the concerned amino acid metal chelate in solution.

In cases where the so-called hydrophobic end possesses coordinating oxygen or nitrogen donor sites, the amino acid may show ambidentate behaviour. In the ternary complexes of the type \([\text{Cu(II).A.his.}],\) where \(\text{A}=\alpha,\alpha'-\text{dipyridyl},\ \text{dipyridylketone or 1,10-phenanthroline},\ \text{his.=histidine, histidine has been found to coordinate through its amino acid end (0 , Ndonor) ata lower pH and through the imidazole nitrogen and amino nitrogen (N,N donor), like a histimine at a higher pH range}.\) Histidine may form a protonated complex unlike several other simple amino
acids. In the sulphur containing amino acids such as methionine and cysteine no evidence of sulphur coordination has been observed in the binary complexes of Cu(II), Zn(II), Cd(II).

1.4 IMPORTANCE OF AMINO ACIDS AND THEIR COMPOUNDS

Amino acids and their compound with transition metal ions are used in biology, medicine, industry and laboratory. Amino acids form strong complexes with transition metal ions therefore, they play an important role to excrete the excess of pollutants in vivo. In human blood and serum the concentrations of various metal ions are fixed (Appendix-1). When their concentrations become in excess, the human being suffers from several diseases such as cancer of bladder, breast, intestine, leukemic system, lungs, ovary, pancreas, prostate, rectum and skin. In addition to these, transition metals are the most active carcinogens. Direct injection into tissues of Cd(II), Co(II), Cu(II), Fe(II) or Ni(II) initiates tumors in animals. The concentration of these pollutants can be reduced by ligand therapy. These ligands are L- amino acids but in order to obtain the optimal dosage of these ligands, formation constants for pollutants L-amino acids complex should be available for computer model calculations and the specificity of the administered drugs for pollutant compared to the essential metal must be known (again this is formation constant dependent).
1.5 BIOCHEMICAL IMPORTANCE OF MIXED LIGAND COMPLEXES WITH AMINO ACIDS

The structural relationship of amino acids with proteins is responsible to a good extent for their biochemical importance and also that of their complexes with the metal ions present in body fluid. Although it is difficult to reproduce in vitro exact structural conditions existing in the biosystems, it may, however, be responsible to mimic them by choosing simple models. The mixed ligand complexes of the type [metal. dipy. amino acid] or [metal. phen. amino acid] have been regarded as simple models for the ternary system like [metal ion - enzyme - ATP] or [metal ion - enzyme - inhibitor].

It has been commented that "Biochemistry is the coordination chemistry of living systems". The role of metal ions in biological systems has been discussed in several texts. A mixed ligand complexes play a central role in such systems, in recent years to assemble information on their formation and stability and on the mutual influence of two ligands bound to the same metal ion. Although Cu(II) has received greater attention in studying such mixed ligand complexes. Some data are available on Co(II), Ni(II) and Zn(II) systems and even on Mn(II) mixed ligand complexes.

A few examples may be cited to indicate the important role played by the ternary complexes. The ternary system [Cu(II). histidine. albumin] is involved in the transport phenomenon across biological membranes. The [Cu(II). histidine.threonine] is another ternary system which plays an important role in metal
ion transfer in biological systems\textsuperscript{74-75}. Dopa acts as a neurotransmitter and is used in the treatment of Parkinsonism\textsuperscript{76}. It has been suggested that chelation with Cu(II) and Zn(II) checks its decarboxylation which may help in improved transport of dopa to brain. Glutamine and its metal complexes play a significant role in cancer therapy\textsuperscript{77-78}.

Mixed ligand complexes containing nucleotides and amino acids as co-ligands have also been considering to be of great interest with regard to biological systems\textsuperscript{40,79-80}.

Intramolecular hydrophobic stacking interactions in ternary complexes containing amino acids\textsuperscript{40,81} appear to be important for the synthesis of proteins and determination of the amino acids sequence.

Aromatic amino acid residues are often in the active center of the enzyme, e.g. a tryptophanyl group in heavy meromycin\textsuperscript{82-83}. 
1.6 SURVEY OF RELEVANT LITERATURE

For the present investigation, the literature of some transition metal complexes with L-amino acids and picolines has been surveyed.

Transition metals occupy the position in the modern periodic table in the subgroups IB, IIB, IIIB, IVB, VB, VIB, VIIB, and VIIIB form four transition series. The first series (3d) starts from Sc to Zn and the second (4d) starts from 39Y to 48Cd. The third series begins with 57La to 71Lu followed by 72Hf to 80Hg and the fourth series starts from 89Ac to 103Lw followed by 104Ku, 105Ha to the elements of atomic number 112 (to be discovered).

In the modern period table, these elements serve as a bridge between the highly electropositive ‘S’ and highly electronegative ‘P’ block elements, therefore, their properties are intermediate between the ‘S’ and ‘P’ blocks elements. These elements have many physical and chemical properties in common such as metallic character, melting and boiling points, density, reactivity, ionization potentials, color, variable valency, catalytic and magnetic properties and ability to form complexes.

The coordination chemistry related to the role of metal ions and their complexes in biochemistry has been reviewed extensively\textsuperscript{39, 58-61, 84-86}.

A brief account of the literature survey on some recent publications having relevance to the present investigations has been given in the following paragraphs.
1.6.1: Binary Complexes in Solution

In binary complexation in solution attempts have been made by several workers to correlate the observed solution stabilities with the characteristics of metal ions or ligands.

Glasston and Hammel$^{87}$ have reported $p^K$ values of histidine.

Shade et al.$^{88}$ have studied the nature of bonding of L-histidine with metal ion.

Lehninger$^{89}$ studied the histidine complexes with metal ions.

Maley and Mello$^{90}$ reported the Cu, Co, Zn and Mn complexes of histidine, glycine, alanine, valine and leucine. The stability trend of these complexes have been discussed.

Pleticha$^{91}$ reported the polarography of iron group metals in the presence of a few amino acids.

Albert et al.$^{92}$ have studied the enthalpy and entropy changes in the metal-ligand complexation of Cu, Zn with tryptophane, alanine and ATP.

Li and Doody$^{93}$ have reported Mn and Zn complexes with L-arginine. Mn and Zn formed 1:1, 1:2, and 1:3 complexes with L-arginine.

Ellenbogen$^{94}$ reported $p^K$ values of histidine, arginine and L-citrulline.

The histidine complexes with different metal ions were found in literature$^{95}$.

Some transition metal complexes with tyrosine using different techniques have been reported in the literature$^{96-97}$.

Li and Manning$^{98}$ reported Zn, Cd, and Pb complexes with histidine, methionine and cysteine. They determined $\log K_1$ and
logK₂ values also by polarographic technique.

Some references regarding the proline complexes with metal ions have also been found in the literature.²⁹

Some compounds of Fe and proton dissociation constants of arginine were reported by Perrin.¹⁰⁰

Li and White¹⁰¹ reported histidine complexes with some metal ions.

Some complexes of tryptophane and hydroxytryptophane have also been reported in the literature.¹⁰²

Pelletier¹⁰³ reported the Fe, Co, Ni, Mn, Zn and other metal complexes of arginine over the range 17-40°.

Rao and Subramanyam¹⁰⁴ have investigated the Cd complexes with glycine, DL-valine, DL-alanine, L-asparagine and L-glutamic acid using polarographic technique.

Pysz Jr et al¹⁰⁵ studied some complexes of Cd with amino acids. They observed that the stability of complexes decreased with increase of size of the chelating ring.

The structural properties of Cr complexes with various amino acids were reported by Khan and Malik¹⁰⁶. They took arginine hydrochloride, methionine, glycine, alanine, asparagine, serine, leucine, lysine, valine and aspartic acid as the ligands.

Chakravorty et al¹⁰⁷ have reported histidine complexes with transition metal ions.

Some histidine complexes with different metal ions have also been reported in the literature.¹⁰⁸-¹⁰⁹

Husain et al¹¹⁰ have reported Cr complexes with various amino acids.
Lenz and Martell\textsuperscript{111} have determined the stability constants of Ag, Cu, Co, Hg, Mg, Mn, Ni, Pb, Sr and Zn with some amino acids. They also determined the acid dissociation constants.

Martin and Mathen\textsuperscript{112} have studied histidine complexes with metal ions.

Sharma and Mathur\textsuperscript{113} reported some amino acids complexes.

Desai and Kabadi\textsuperscript{114} have determined successive formation constants of pyridine, $\beta$-picoline and $\gamma$-picoline.

Quintin and co-workers\textsuperscript{115} have studied tryptophane complexes with different metal ions.

Suffet and Purdy\textsuperscript{116} investigated Cd complexes with tryptophane.

Reference of proline complex has been traced out in the literature\textsuperscript{117}.

Perrin and Sharma\textsuperscript{118} have studied histidine complexes with metal ions.

Some histidine complexes with different metal ions have also been reported in the literature\textsuperscript{119-120}.

Some amino acids complexes with different metal ions have also been reported in the literature\textsuperscript{121}.

Sigel\textsuperscript{122} reported Co, Ni, Cu or Zn complexes with $\gamma$-picoline.

Nazarova\textsuperscript{123} has determined the first stepwise stability constants of Cd with pyridine, $\beta$-picoline, quinoline, 3-bromopyrodine and Et-nicotinate and compared their dissociation constants.

Israeli and coworkers\textsuperscript{124} have studied histidine complexes.
Aihara et al.\textsuperscript{125} have reported amino acid complexes with some metal ions.

Gaur and Sharma\textsuperscript{126} reported complexes of Cd with $\beta$- and $\gamma$-picoline by polarographic technique.

Pantani, Francesco\textsuperscript{127} have studied the picoline complexes of Co, Ni, and Zn by polarography, spectrophotometry, potentiometry and amperimetric titrations.

Das and Rao\textsuperscript{128} have reported Mn complexes with $\beta$- and $\gamma$-picoline and 4- vinyl pyridine.

Maggio et al.\textsuperscript{129} studied the complex formation between bis(salicylaldoximate) Ni (II) and $\alpha$, $\beta$- and $\gamma$-picoline in benzene solution.

Raju and Mathur\textsuperscript{130} investigated histidine complexes.

Childs and Perrin\textsuperscript{131} have studied the Mn complexes of proline.

The histidine complexes with metal ions were found in literature\textsuperscript{132-133}.

Some amino acids complexes with different metal ions have also been reported in the literature\textsuperscript{134-135}.

Girdhar and coworkers\textsuperscript{136} have investigated proline complexes.

Some complexes of tryptophane and hydroxytryptophane have also been reported in the literature\textsuperscript{137}.

Potentiometric studies on the complexation of Mn, Zn, Ni, Co, Ca, Hg and Cu with arginine, citrulline or ornithine have been done\textsuperscript{138}.

Chidambaram and Bhattacharya\textsuperscript{139-140} investigated the solution stabilities of Ni, Vo and Zn with $\alpha$- or $\beta$-alanine, leucine,
glycine, isoleucine and valine, the solution stabilities lie in the order of ligand basicity.

Cu complexes of histidine have been extensively investigated in solution.\textsuperscript{141-142}

Khan and coworkers\textsuperscript{143} have studied complex formation between methionine and different metal ions.

Malik and Aslam\textsuperscript{144} have discussed some structural properties of arginine.

Watt et al\textsuperscript{145} reported Cu and Zn complexes of methionine.

Some references regarding Cu complexes of histidine have been found in literature.\textsuperscript{146-148}

Lal and Christian\textsuperscript{149} reported the Ni complexes with tryptophane in triton X-100.

Barnes and Pettit\textsuperscript{150} have studied histidine complexes.

Some transition metal complexes with tyrosine have been reported in literature.\textsuperscript{151-152}

Proline complexes have been reported in the literature.\textsuperscript{153-154}

Bhattacharya and Sharma\textsuperscript{155} have investigated Ni, Cd, and Mg complexes with pyridine, $\alpha$-\$\beta$-and $\gamma$-picoline.

Weber and Simeon\textsuperscript{156} reported tryptophane and hydroxytryptophane complexes.

Cu complexes of histidine have been investigated in solution.\textsuperscript{157-158}

The histidine complexes with different metal ions were found in literature.\textsuperscript{159}

Sigel\textsuperscript{160} reported Cu complexes of histidine.
Reference regarding the methionine complexes have been reported in the literature\textsuperscript{161}. Some transition metal complexes with tyrosine have been reported in the literature\textsuperscript{162}.

Walker and Williams\textsuperscript{163} reported the formation constants of Cd with various amino acids potentiometrically.

Farooq and Ahmed\textsuperscript{164} have studied methionine complexes with different metal ions.

Weber\textsuperscript{165} has reported the formation constants of some tyrosine and tryptophane derivaties.

Cu and Pd complexes involving an acid and or basic amino acid has been examined from their circular dichroism, \textsuperscript{1}H-NMR spectra and isolation of various ternary complexes\textsuperscript{166}.

Joshi and Bhattacharya\textsuperscript{167} studied the stability of the Cd, Cu, Ni, Zn complexes with aspartic acid, glycine, leucine, or \(\alpha\)- or \(\beta\)-alanine.

Haq and Khan\textsuperscript{168} reported Cu complexes with L-hydroxyproline.

Pettit et al\textsuperscript{169} studied Cu complexes of histidine in solution.

Amino acid complexes with Pd and Cu have been investigated by some workers\textsuperscript{170-171}.

Marker and coworkers\textsuperscript{172} investigated proline complexes.

Some references regarding the complex formation between methionine and different metal ions have also been reported in the literature\textsuperscript{173-174}.

DasGupta and Pathak\textsuperscript{175} studied Ni complexes with pyridine, \(\beta\)-picoline and \(\gamma\)-picoline in the temperature range of 25\(^\circ\)C - 40\(^\circ\)C polarographically.
Gaur et al. have determined the values of stability constants of Zn complexes with L-hydroxy proline.

Natrajan and coworkers have reported Cu complexes of histidine.

Some complexes of tyrosine with transition metal ions have been reported in the literature.

The polarographic study of Cd with glycine and histidine complexes was made by Islam and Bhatt.

Goodman et al. studied Cu complexes of histidine.

Yamauchi and Odani have reported Cu and Pd complexes involving an acid and or basic amino acid.

Sandhu and Kumar studied the formation of complexes with Ni, Cd, Zn, Pb and Cu with N-benzoylglycyl-L-leucine potentiometrically. The thermodynamic parameters have also been determined.

A potentiometric and spectrophotometric studies on the complexes of Cu with tyrosine containing dipeptides i.e. L-tyrosyl-glycine, L-tyrosyl-D-Leucine, glycylytyrosine etc. have been discussed.

Saxena and Sharma investigated a stability trend of Zn, Hg and Cd complexes with valine potentiometrically.

Gargley and Farkas reported binary complexes of Cd with amino acids by pH metric and colorimetric technique.

Polarographic study on the complexes of Cu, Co, Ni and Mn with methyl guanidioacetic acid has been discussed. The order of stability with respect to metal ion has been observed with Mn forming least stable complex and Cu the most stable.
Mayadeo and Bhattacharya\textsuperscript{188} have studied the complex formation of Cu, Zn, Ni, Co and Mg with 2-hydroxy-1-naphthalidine-sulphamethoxazole pH metrically. The Irving-Williams order of stability has been observed with Mg forming the least stable complexes.

Rainer and Rode\textsuperscript{189} have reported Cd and Hg complexes with proline, glycine, alanine and leucine pH metrically.

II‘Yasova and coworkers\textsuperscript{190} determined complex formation constants for Co, Ni, Cu and Zn with S methyl methionine and methionine.

Nourmand and Meissami\textsuperscript{191} reported methionine complexes of Cd by potentiometric technique.

Felcman and Dasilva\textsuperscript{192} have determined the polyamino-carboxylate chelates with transition metal ions and the chelates stability has been reported to be invariably dependant on the denticity of the ligand and the number and size of the rings formed.

Casella and Gullotti\textsuperscript{193-194} investigated Cu complexes of histidine in solution.

Nourmand and Meissami\textsuperscript{195} have studied Cu complexes of methionine.

Nadhim Al-Ani and Olin\textsuperscript{196} studied Cu complexes with proline, serine, threonine and tyrosine in their d - and l - forms.

Coli and coworkers\textsuperscript{197} have investigated Cu complexes of histidine.

Cu complexes with many simple histidine containing oligopeptides have been investigated\textsuperscript{198}. 
Ishiguro et al\textsuperscript{199} investigated the formation of glycinate complexes with Ni in water and in aqueous dioxane-water medium by potentiometric and colorimetric studies.

Mayadeo and Banavali\textsuperscript{200} have determined the formation constants of the complexes of some biologically important trace metals with bidentate ligands.

Gaizer et al\textsuperscript{201} have reported the protonation and complex formation of cis- and trans-isomer of alycyclic amino acids with Ni, Cd, Cu and Hg.

Dubey and Nepal\textsuperscript{202} have investigated the complex formation of Zn, Co, Fe, Mn, Ni, and Cu with catechohl and pyrogallol by pH-metry.

Malhotra and coworkers\textsuperscript{203} have studied kinetics and mechanism of the interaction between Co and L-tyrosine.

Kala and RamReddy\textsuperscript{204} reported Cu and Ni complexes with proline and hydroxy proline.

Malhotra and Prakash\textsuperscript{205} have also studied amino acid complexes.

Khatri and Singh\textsuperscript{206} have investigated the Zn complexes of tryptophane polarographically.

Pitre and coworkers\textsuperscript{207} have determined the composition and formation constants of Zn with \(\gamma\)-picoline.

Singh et al\textsuperscript{208} investigated Cd complexes with picolines polarographically.

Nair and coworkers\textsuperscript{209} have studied histidine complexes.

Verma and Verma\textsuperscript{210} studied the binary complexes of Cu with glycylglycine by pH metric technique.
Nema and Khan\textsuperscript{211} studied Cd complexes with amino acids by polarographic technique.

Fridman and Dzhusueva\textsuperscript{212} have reported Cu complexes with amino acids by spectrophotometric technique.

Mohan and coworkers\textsuperscript{213} have investigated Cu complexes of methionine, tryptophane, valine, phenylalanine, ethionine and histidine at $\mu=0.2$ M KNO$_3$.

Cu complexes of L-leucine, L-valine, or L-nor-valine have been studied in water-dioxane medium\textsuperscript{214}.

Madhav and Nemade\textsuperscript{215} have reported Cd complexes with glutamine and citrulline by polarographic technique.

Ali and Patnaik\textsuperscript{216} reported several 1:1 and 1:2 aspartate complexes of Co, Ni, Cu and Zn using pH metric technique.

Kamakshi et al\textsuperscript{217} studied Zn complexes of histidine, histamine and imidazole ligands.

Masuda and Sugimori\textsuperscript{218} have studied the Cu complexes with several dipeptides containing phenyl alanine or tyrosine residue.

Daniel et al\textsuperscript{219} investigated the complexes of Cu with glycyl-L-histidyl-glycine by potentiometric, calorimetric and circular dichroism technique.

Cu complexes with many simple histidine containing oligopeptides have been investigated by several methods\textsuperscript{220-227}.

Masuda et al\textsuperscript{228} have been reported carbon\textsuperscript{13} -NMR spectral data as a function of pH for mixtures of L-histidine and Zn nitrate.

Tanford and shore\textsuperscript{229} have investigated Co complexes with arginine. In this paper some structural properties of arginine
have been discussed.

1.6.2: Ternary Complexes

The study of ternary complexes in solution have attracted attention in recent years. These complexes are encountered in several important areas of chemistry such as environmental\textsuperscript{230}, industrial\textsuperscript{231}, medicinal\textsuperscript{232} and analytical fields\textsuperscript{233}.

The following paragraphs narrate the survey of literature on the ternary complexes.

Some ternary complexes of Cu with different amino acids have been reported in the literature\textsuperscript{234-235}.

Maria et al\textsuperscript{236} have studied mixed ligand complexes of serine and arginine with nitrotriacetic acid taking Cu, Ni, Co, Zn, Mn and Pb.

Griesser and Sigel\textsuperscript{237} have investigated mixed ligand complexes with 2,2 bipyridyl as primary ligand and catechol, glycine, \(\alpha\)-or-\(\beta\)-alanine as secondary ligands.

Parikh and Bhattacharya\textsuperscript{238} reported the mixed ligand complexes of Cu, Ni, Zn and Cd using histidine, iminodiacetic acid or nitrilotriacetic acid and ethelyenediamine or propylene diamine using Irving Rossotti titration technique.

Some ternary complexes of Cu with different amino acids have been investigated\textsuperscript{239}.

Joshi and Bhattacharya\textsuperscript{240} studied the ternary systems of Cu and Ni with histidine and thioglycollic acid, thiolactic acid, thiomalic acid, glycollic acid, lactic acid or malic acid.

Naumann and Sigel\textsuperscript{241} investigated mixed ligand complexes with 2,2' bipyridyl as primary ligand and catechol, glycine, \(\alpha\)-or \(\beta\)-
alanine as secondary ligand.

Pettit and Swash\textsuperscript{242} studied some ternary complexes of Cu with different amino acids.

Brooker and Pettit\textsuperscript{243} investigated CuLAH system at low pH values, where A=histidine and L=phenylalanine or tryptophane.

Studies of some mixed ligand complexes involving ligands of biological importance and transition metals have been reported by Tandon et al\textsuperscript{244}. They took 1,10-phenanthroline and L-amino acids for their study.

Polarographic study of mixed ligand complexes of Cd with amino acids have been reported by Jain and Kapoor\textsuperscript{245}.

Mixed complexes of Zn with some substituted amines have been studied\textsuperscript{246}.

Bunel et al\textsuperscript{247} reported the mixed ligand complexes of Zn with 1,10-phenanthroline and amino acids by spectrophotometric technique.

Singh and coworkers\textsuperscript{248} have studied the ternary systems involving amino acids polarographically.

Nair and coworkers\textsuperscript{249} have reported Zn complexes with histidine and imidazole or histamine.

Stacked ternary complexes of Co, Ni and Cu with salicylanilide, dithionion and tryptophane have been reported by Kushwaha and his coworkers\textsuperscript{249}.

Gergely and Farkas\textsuperscript{251} have studied ternary complexes of Cd with amino acids and 2-2' bipyridyl by pH metric and calorimetric techniques.

Sigel et al\textsuperscript{252} have determined formation constants of binary
and ternary complexes of Cu with L-alaninamide and diethylene-triamine.

Emanuel and Bhattacharya\textsuperscript{253} have studied mixed ligand complexes of 1,10 - phenanthroline, 2,2' bipyridyl etc. as primary ligands and histidine, histamine, tyrosine, tryptophane, dopa or phenylalanine as secondary ligand.

The complexation study of Cd and Pb with mixed ligand system have also been studied by polarographic technique\textsuperscript{254}.

Nemal'tseva et al\textsuperscript{255} reported the mixed ligand complexes of transition metals with amino acid and ascorbic acid by pH and spectrophotometric technique.

Nigam and his coworkers\textsuperscript{256} have studied ternary complexes of Cu, Co, Ni or Zn with aspartic acid as primary ligand and uracil or thymine as secondary ligands by potentiometric technique.

Ostacoli and coworkers\textsuperscript{257} have studied Cu complexes with L-nor-adrenaline and glycine, L-alanine, L-arginine, L-ornithine, L-lysine, L-aspartic acid and L-glutamic acid.

Deak and Gergely\textsuperscript{258} have investigated mixed ligand complexes of Cu or Ni with 1,10 - phenanthroline or 2,2'-bipyridyl as primary ligands and histidine, histamine, tyrosine, tryptophane, dopa or phenylalanine as secondary ligand.

Spectral and polarographic study of ternary complexes of Cu with glycy1-glycine and amino acids have been reported by Verma and his coworkers\textsuperscript{259}.

Srivastava and his coworkers\textsuperscript{260} have studied mixed ligand complexes of Cu, Co, Ni and Zn complexes with glutamic acid as primary ligand and thymine or uracil as secondary ligands.
Reddy and Rao\textsuperscript{261} have determined the values of formation constant of Mn, Co, Cu, Ni, Zn, Mg, or Ca with cystidine as primary ligand and histidine, glycine, histamine or oxalic acid as secondary ligands.

Emanuel and Bhattacharya\textsuperscript{262} reported ternary complexes of Cu and Ni with 5-nitro-1,10-phenanthroline or 2,2'-dipyridyl-amine and 3,4-dihydroxyphenylalanine, tyrosine, phenylalanine or tryptophane using potentiometric titration in dioxane-water solution.

Lingaiah et al\textsuperscript{263} studied ternary complexes of dioxouranium with 2-hydrxxy-1-naphthaldehyde and some amino acids.

Daniel and coworkers\textsuperscript{264} investigated Cu complexes with L-nor-adrenaline and glycine, alanine, arginine, ornithine, lysine, aspartic acid and glutamic acid. The formation constants have been determined by pH metric titrations at 25°C and 0.1 M KNO₃.

Rebellow and RamReddy\textsuperscript{265} have reported a series of Cu and Ni complexes of the type M.(A/A'/A")ₜ, where A = glycine, alanine, phenylalanine, proline, hydroxyproline, picolinic acid, A' = catechol, picolinic acid-N-oxide, 4-methoxy picolinic acid-N-oxide and 4-ethoxypicolinic acid-N-oxide, A" = 2,2'-bipyridyl, 1,10-phenanthroline and L= piperidine-2-carboxylic acid by potentiometric pH titration.

Devi and RamReddy\textsuperscript{266} have determined formation constants and thermodynamic parameters for the mixed ligand complexes of Cu with picolinic acid-N-oxide and amino acids like proline, hydroxyproline, glycine, alanine and phenylalanine.
Ternary complexes of Cu with glycine, proline, histidine, 
α- or β-alanine and 2'-methyl-4-(or -7) -nitrobenzimidazole, 4 
(or -7) -nitrobenzimidazole etc have been studied267.

Gupta et al268 studied mixed ligand complexes of Cd with 
ascorbic acid and amino acid by polarographic technique.

Krishnarao and coworkers269 have investigated Cu complexes 
with glycine, alanine, phenylalanine, proline, hydroxyproline and 
N-methylantranilic acid or N-phenylantranilic acid potenti-
ometrically.

Singh and coworkers 270 have done polarographic studies on 
mixed complexes of Cd with picolines and carboxylate ions.

Pitre et al271 have investigated ternary complexes of Zn with 
γ -picoline and citraconic acid by polarographic study.

Bajpai and Saxena272 reported mixed ligand complexes of 
d-block elements with α,α'-dipyridyl and amino acids by pH metric 
technique.

Khan273 studied the complexation between Cd and alanine as 
primary ligand and oxalic acid as secondary ligand by 
polarographic technique.

The mixed ligand complexes of Zn, Cd and Mn with 
adenosine-5'-triphosphate and leucine, alanine, valine, nor-
valine, iso-leucine, aspartic acid, uracil, thymine, methionine, 
threonine or serine have been studied274.

Mohan et al275 have reported ternary Cu complexes 
containing imidazole as a primary ligand and amino acids as 
secondary ligands.

Satyanarayan and coworkers276 have determined formation
constants of ternary complexes of Cu, Ni, Co and Zn with thiodipropionic and aspartic acid, histidine, tryptophane and ethylenediamine pH metrically.

Khan and Nema\textsuperscript{277} reported the mixed ligand complexes of Cd with amino acids and formic acid by polarographic technique.

Fridman et al\textsuperscript{278} studied Cu complexes with amino acids and other acids by spectrophotometric technique.

Verma and Verma\textsuperscript{279} have studied the Cu complexes with glycylglycine and amino acids by pH metric technique.

Nema and Khan\textsuperscript{280} have determined stability constants of ternary complexes of Cd with some amino acids and acetic acid by polarographic technique.

Ternary complexes of Cu involving histidine and other amino acids or dipeptides have been studied\textsuperscript{281}.

Ullah and Bhattacharyya\textsuperscript{282} reported ternary complexes of Cu with malonic, oxalic and amino acids.

Nema and Khan\textsuperscript{283} studied ternary complexes of Cd with amino acids and propionic acid by polarographic technique.

Khatoon and Kabir-Ud-Din\textsuperscript{284} reported 1:1:1, 1:2:1 and 1:1:2 complexes of Cd with amino acids and 2,2' dipyrídyl by polarographic technique.

Pandey and Patel\textsuperscript{285} have investigated mixed ligand complexes of Cu with histidine, aspartic acid and glutamic acid as primary ligands and substituted imidazole as secondary ligands by pH metric technique.

The stability data of ternary complexes of Zn with cysteine as primary ligand and histidine, imidazole as secondary ligand
have been given by Adharani et al.\textsuperscript{286} by potentiometric titration technique.

Ahmed and coworkers\textsuperscript{287} have reported some ternary complexes of salicylic acid and amino acids with Co, Ni and Cu using pH metric technique.

Khan and Dodke\textsuperscript{288-289} reported Cd complexes of amino acids as primary ligand and some other acids as secondary ligand by polarographic technique.

Patel and Bhattacharya\textsuperscript{290-291} investigated homo-binuclear binary and ternary complexes of Cu with amino acids and N - bases by cyclic voltametry, potentiometry and spectrophotometry.

Khan and Khan\textsuperscript{292-293} have studied Cd and Zn complexes with amino acids as primary ligand and vitamin B\textsubscript{5} and Vitamin B\textsubscript{1} as secondary ligand respectively by polarographic technique.

Qureshi and Killa\textsuperscript{294} have investigated simple and mixed ligand complexes of Cu with some amino acids and tartrate anions by differential pulse polarography.

Sharma and Singh\textsuperscript{295} have studied mixed ligand complexes of Co with diamines and amino acids.
1.7 OBJECT OF THE PRESENT STUDY

A careful perusal of the above literature reveals that polarographic methods have not been used extensively for the ternary complex formation between Mn, Cd and Zn with L-tyrosine, L-arginine, L-methionine, L-hydroxytryptophane, L-tryptophane, L-hydroxyproline, L-proline and L-histidine as primary ligands and α-picoline (2-methyl pyridine), β-picoline (3-methylpyridine) and γ-picoline (4-methylpyridine) as secondary ligands. Hence, it is thought worthwhile to undertake the systematic study of complex formation between these metals and ligands.

The values of stability constants (log β) and thermodynamic parameters such as enthalphy change (ΔH), free energy change (ΔG), and entropy change (ΔS) of these complexes are to be determined. The bonding between the metal and ligands, basicity and steric hindrance of ligands, affect the stability of complexes, therefore, these aspects have been discussed in a greater detail, and finally some conclusions will be drawn.

From the above study, valuable informations regarding the complex formation, chemical reactions, equilibria effects of size, basicity, bonding, nature of various groups in the ligands, steric hindrance of ligands will be available that would be very much useful in analytical chemistry, inorganic chemistry, coordination chemistry, eletro-chemistry and technology of non-ferrous and rare metals.
1.8 THEORIES OF COMPLEX FORMATION

A number of theories have been given time to time to explain the formation of complexes between metal and ligands but the most important theories are given below in brief:

1.8.1: Werner's Coordination Theory

An understanding of coordination compounds and their properties began with the work of Alfred Werner. In 1893, Werner proposed an interpretation of coordination compounds which emphasized the number and nature of groups attached to the central metal ion. This theory replaced the older concept of Berzellius (1819), Grahm (1837), Claus (1856), Blomstrand (1969) and Jorgenson (1878-1894), and became a fundamental part of the theory of valence formulated by G.N.Lewis. According to Werner,

1. Most elements show two types of valency
   (a) Primary (i.e. Principal) and
   (b) Auxillary (i.e. Secondary).

2. Primary valencies are those which a metal exercises in the formation of its simple salts and the secondary valencies are those which a metal exercises towards a neutral molecule or an anion in the formation of complex ion.

3. Secondary valencies are directed in space and hence compounds are capable of exhibiting the phenomenon of isomerism.

4. The number of ligands which are arranged around the central metal ion is called the coordination number.

Although this theory explains the structure and stereochemistry of complexes but could not give any theoretical
background for the two types of valencies and this has been a reason why this theory was not accepted up to 1916.

Later on, Lowry and Sidgwick explained Werner's ideas with the help of electronic theory of valency.

1.8.2 : The Valence Bond Theory

One viewpoint is stressed by the valence bond theory chiefly developed for complexes by Pauling. In this theory, it is considered essential that a number of orbitals on the central metal atom is equal to the number of ligands be made available to form coordinate covalent bonds with orbitals on the ligands. Furthermore, by using the criterion that maximum angular overlap of two orbitals forms the strongest covalent bond, it is shown that the original atomic orbitals should be hybridised to form a new set of equivalent bond orbitals with definite directional properties.

Pauling theory has rendered valuable services to the understanding of main features of coordination chemistry and has ability to provide reasonable qualitative explanations but this theory was criticized by many workers as it fails to -

1. account for the relative energies of different structures and coordination numbers.
2. explain the magnetic properties of covalent and ionic compounds.
3. interpret absorption spectra of complexes in the visible region and reaction paths for substitution reactions.
4. predict the geometry of coordination compounds.
1.8.3: The Valence Shell Electron - Pair Repulsive Theory

This theory links valence bond theory and electrostatic theory and is very useful to predict the geometry of molecules or complexes of non-transition elements and also $d^0$, $d^5$ and $d^{10}$ transition metals. This theory is based on the ideas of Sidgwick and Powell\textsuperscript{307} and has been elaborated by Nyholm and Gillespie\textsuperscript{308}. For the non-spherically symmetric transition metals, this theory is not so useful. Although this theory very well explains the stereochemistry of complexes but does not deal with other properties such as bond length.

1.8.4: The Electrostatic Theory

Van Arkel and De-Boer\textsuperscript{309}, and particularly, Garrick\textsuperscript{310} following the pioneering ideas of Kossel, Magnus and Tajans, showed that a fairly simple electrostatic picture of complexes, assuming point charges and dipoles could account for many of their properties.

The parameters needed were the charges and sizes of the central ions and the charges, dipole moments, polarizabilities, and sizes of ligands. By using the ordinary potential energy equations of electrostatics, quantitative calculations could be made for various coordination numbers and stereochemistries.

This theory fairly well explains the electrostatic character of complexes but could not explain many forces such as London attraction forces\textsuperscript{311} and many properties of complexes\textsuperscript{312}. 
1.8.5: The Crystal Field Theory

This theory was developed by Bathe\textsuperscript{313}, Schlapp and Penny\textsuperscript{314} and by Van Vleck\textsuperscript{315}. Hartmann\textsuperscript{316} used this theory to explain d-d spectra of complex in the visible region. Orgel\textsuperscript{317} was the first to emphasize the consequences of the theory for the stability of coordination compounds of the transition elements.

The essence of the theory is that the five d-orbitals which are degenerated and equal in energy in the gaseous metal ion, become differentiated in the presence of the electrostatic field due to the ligand in the presence of the electrostatic field due to the ligand (the crystal field). It is the symmetry of this field, or its regular geometric properties, which gives the name of this theory. Though originally applied to crystalline solids, it is equally applicable to any orderly arrangement of the electrically interacting particles such as a single complex. In particular, those orbitals lying in the direction of the ligand are raised in energy with respect to those lying away from the ligands. By preferentially filling the low lying levels, the d-electrons can stabilize the system, as compared to the case of random filling of the d-orbitals. The gain in bonding energy achieved in this way is called the crystal field stabilization energy (C.F.S.E.). It is caused by the distribution of charge around the central atom of the complex not being symmetrical as assumed in the earlier electrostatic calculations. If the d-orbitals were occupied equally, the resulting electron density would have spherical symmetric.

Although crystal field theory explains well many things such
as the stereochemistry\textsuperscript{318} of the complexes, magnetic properties\textsuperscript{319}, stabilities, redox potentials\textsuperscript{320}, coordinate bond energy\textsuperscript{321} and effective ionic charge\textsuperscript{322}, but it fails to explain the formation of complex involving bonds, the resolution of asymmetric complexes into their optically active modifications and several properties of coordinate compounds\textsuperscript{322}.

1.8.6: The Molecular Orbital Theory

J.H. Van Vleck\textsuperscript{323} was the first to apply this theory in complex formation. The electrons are assumed to move in molecular orbitals which extend over all the nuclei of the system. The molecular orbitals themselves are taken for convenience, as linear combination of atomic orbitals. In the event that a given atomic orbital (A.O.) overlaps appreciably with only one other A.O., the pair may be regarded as forming a localized molecular orbital holding as many as two electrons. This would correspond to the usual conception of a chemical bond. This explains many properties of complexes\textsuperscript{312} but still has some drawbacks. These are:

1. The usual one of any quantum mechanical approach to complex systems, that quantitative calculations of the energy can not be made and

2. The disappearance of the nice pictures of chemically bonded atoms so useful to the chemists. The latter difficulty can be partly avoided by the use of L.M.O.'s.
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