CHAPTER 1

1.1 GENERAL INTRODUCTION AND THEORIES OF COORDINATION COMPOUNDS
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1.1 GENERAL INTRODUCTION AND THEORIES OF COORDINATION COMPOUNDS:

The twenty first century has been predicted as an era of science where specialization and generalization of knowledge will work together complementing one another. There will be great importance of coordination among the various streams of the science subjects and even within the various branches of the chemistry itself. Coordination chemistry has come out as a branch of inorganic chemistry, which has justified its position at the crossroads of the various off-shoots of chemistry.1-3

The coordination compounds in real sense were discovered earlier to the systematic knowledge of coordinate bond, which later became the basis of a wide subject 'Coordination chemistry'. The coordination complexes involve the bonding through donor ligand containing N, O or S atom and metal as acceptor.4,5 Coordination compounds have always been a challenging work to inorganic chemists despite their extensive study. The coordination chemistry is still a potential research field as it involves possibilities of synthetic modes and stereo-arrangement of complexes and their applications to environment, bio-systems and various fields of human activities.

The word 'complex' employed by Albert acquired a new meaning and significance with the enunciation of coordination theory by Alfred Werner.6 This theory became the basis of understanding the existence of complex compounds, their structures and stereochemistry. Werner did not give any substantial theoretical background and this was the reason why 'Werner's Theory' was not accepted popularly upto
1916. Later on, Sidgwick and Lowry explained the idea of Werner with the electronic theory of valency.\textsuperscript{7,8}

None of the above theories could explain satisfactorily the bonding in complexes. Recently, based on wave mechanical concept, four important theories were proposed, which can be applied to study the structures, stability and general properties of compounds. These are:

1. Valence Bond Theory (V.B.T.)
2. Crystal Field Theory (C.F.T.)
3. Adjusted Crystal Field Theory (A.C.F.T.) Or Ligand Field Theory (L.F.T.)
4. Molecular Orbital Theory (M.O.T.)

1.11 VALENCE BOND THEORY (V.B.T.)

This theory was developed by Pauling\textsuperscript{9} based on quantum mechanics and concentrated on the structure and magnetic properties of the central atom in the complex, but has very little to do with the interpreting the electronic spectra, thermodynamics and kinetic properties of complexes. Most structures can be understood on the basis of repulsion between pairs of electrons or the use of hybridised orbitals. The following assumptions explain the theory in detail.

(i) The central metal tries to arrange a number of orbitals almost always equal to its coordination number by the use of process of hybridisation in which the ligand electrons are accommodated.

(ii) Whenever a filled orbital of ligand overlaps with the vacant hybridised orbital of metal; a $\sigma$-coordinated bond is formed.
(iii) In addition to the $\sigma$-bond, there is also the possibility of the formation of a $\pi$-bond by overlap between the filled 'd' orbitals on metal with vacant orbital on ligand. This $\pi$-bond changes the charge distribution on both the metal and the ligand in such a way so as to strong the $\sigma$-bond.

Pauling's theory rendered valuable service in understanding the main features of coordination chemistry for nearly twenty years (1930-1950).

The major defects of V.B. theory when applied to metal complexes, were:

(a) Its failure to consider the existence the excited states and an explanation for the spectra of metal complexes.

(b) Though specifying the number of unpaired electrons, it provides no detailed explanation for magnetic behaviour.

In brief, the valence bond theory offers only qualitative interpretation of stereochemical, allied properties and bond type.

1.12 CRYSTAL FIELD THEORY (C.F.T.):

The crystal field theory (CFT) was initiated by Bethe$^{10}$ in 1929 and in the following years it was applied to transition metal complexes by Penny and Schlapp$^{11}$ and by Van Vleck.$^{12}$ It was however, more than two decades later, that the theory came to be popularly accepted by coordination chemists, mainly due to the contribution of Hartmann and Orgel$^{13}$ and was popularised as Ligand
Field Theory by the work of Ballhausen, Orgel, Nyholm, Figgis and Jorgensen \(^{(14-16)}\) in the later years.

According to this theory, the ligands produce a negative field around the metal ions and thus the five 'd' orbitals, which were originally degenerate and equal in energy in the free gaseous metal ion, become differentiated in the presence of electrostatic field, giving one set higher and other lower in energy, depending upon the nature of crystal field around the metal.

Thus, in octahedral complexes, where the ligand are present at the six apices of an octahedron, the \(d_{xy}\), \(d_{yz}\) and \(d_{xz}\) orbitals or \(t_{2g}\) set is more stable (lower in energy) than \(d_{z^2}\) and \(d_{x^2-y^2}\) orbitals or \(e_g\) set. The explanation of this can be given in a precise manner. In \(e_g\) set, the electron will be repelled more by the negatively charged ligands on the octahedral axis than with those in the former orbitals i.e., in \(t_{2g}\) set, which tends to put their electrons in the empty corner of the cube corresponding to the octahedron.

Once the 'd' orbitals are separated by an energy difference \(\Delta_0\), known as crystal field stabilization energy, the principles governing the distribution of electrons in two levels, have also to be considered:

(i) Electrons tend to occupy the orbitals of lowest energy in a ligand field.

(ii) Electrons go into different orbitals with their spin parallel.
In case of tetrahedral complexes, the reverse situation occurs because the negative ligands are then at alternate corners of the cube while the octahedral axes are empty.

The energy difference $\Delta_r$ is crystal field stabilization energy for tetrahedral complex. The values $\Delta_0$ and $\Delta_t$ depend upon the strength of the ligand field and are very important in governing the distribution of electrons in two sets. It is thus expected that if the ligand field is weak, high spin or if it is strong, a low spin complex will be formed.

The above results are obtained in case of regular octahedral or tetrahedral configuration but the splitting pattern for distorted octahedral and planar complexes is different.

1.13 ADJUSTED CRYSTAL FIELD THEORY (A.C.F.T.) OR LIGAND FIELD THEORY (L.F.T.):

Crystal Field Theory does not take into consideration any orbital overlap. The Ligand Field Theory is simply an extension of the electrostatic approach but also allows for some covalent interaction between the orbitals on the metal and the ligand. A number of evidences based on esr, nmr, and d-d absorption bands lead to the above conclusions. There are three kinds of possible interactions, the $\sigma$-overlap of orbitals, the $\pi$-overlap of orbitals or the $d_{\pi}$-$p_{\pi}$ overlap between the filled 'd' orbitals on the metal with the empty 'p' orbitals on the ligand.

The ligand field theory has been successfully used to interpret the most favourable coordination number, stereochemistry
paths for substitution reactions, magnetic and thermodynamic properties for complexes. Three important parameters of interelectronic interactions such as, the spin orbit coupling constant and the two Racah parameters B and C are taken into consideration for the orbital overlap. Many chemists have used this theory with remarkable success to interpret the properties of metal complexes.\(^{17,18}\)

The treatment envisages that overlapping on metal electrons are dragged out to some extent under the influence of the nuclei of ligand atoms, thereby reducing their mutual interaction. It has been found that the magnitudes of the parameters are reduced in complexes in comparison to their free ion values. From magnetic and spectral studies, it has been inferred that good agreement between theory and experiment exists if all the three parameters are taken to 70-80 % of their free ion values.

1.14 MOLECULAR ORBITAL THEORY (M.O.T.):

The theory, which has been developed by Hund\(^{19}\) Mulliken\(^{20}\) and worked out by Van Vleck,\(^{21}\) Cotton,\(^{22}\) etc. starts with orbital overlap, whenever permitted by symmetry, to give molecular orbitals, which are polycentric in nature and are of three different types.

(i) **Bonding Orbitals** - In which an electron has lower energy than it possessed prior to coordination.

(ii) **Non-Bonding Orbitals** - In which electrons have the same energy as these possessed prior to coordination.
(iii) **Anti-Bonding Orbitals** - In which the energy of electron is greater than that of either atomic orbitals.

In case of an octahedral complex one 's', three 'p' and two 'd' (e₉) orbitals are suitable for σ-bonding. If each of the six ligands contains one σ-orbitals these overlap effectively to give six bonding and six anti-bonding molecular orbitals. The other 'd' orbitals i.e. the t₂₉ orbitals, are suitable only for π-bonding and can result in π-molecular orbitals only if the ligands also possess π-orbitals, otherwise these remain unmatched in the centre of the energy level diagram and correspond to non-bonding orbitals.

In octahedral complexes, the six bonding σ-orbitals, three T₁u orbitals, three A₁g and two Eg orbitals have more the character of ligand orbitals due to their close proximity to ligand atomic orbitals (LGO'S) and hence the electrons occupying these orbitals are mainly ligand electrons. The metal ion electrons distribute themselves first in the T₂₉ level and then in the anti-bonding molecular orbitals in the sequence of their energy.

The molecular orbital theory is very useful in explaining the electronic structure but its weakest point is its complexity because of which this is seldom applied.

Studies in the field of coordination chemistry in solid state and solution have engaged the attention of chemists. Solid state comprises synthesis of solid complexes, their elemental analysis, spectral analysis, viz. infrared, ultraviolet visible, electron spin-
resonance, mossbourn, X-ray etc. Study in solution comprises kinetic and thermodynamic aspects, kinetic studies deal with rate mechanism of chemical reaction while thermodynamic studies mainly contain the stabilities of complexes formed in solution, under variety of conditions. There are several electrometric techniques viz. pH-metry, Polarography, Amperometry, Conductometry, Electrophoresis, Voltametry, Chromatography etc; which are being employed frequently for discovering the physico-chemical phenomena of active chemical species.\(^{(23-31)}\)

### 1.2 PHYSICO CHEMICAL TECHNIQUES IN THE CHARACTERIZATION OF METAL COMPLEXES:

The characterization of a coordination compound normally involves the identification as well as structural determinations. Among various physico-chemical techniques the elemental analysis, magnetic susceptibility, thermal and conductance help in deciding the molecular formulae of the complexes; while the sophisticated spectral methods help to establish the actual bonding site of ligands to metal and also the stereo-arrangement of the complexes. The present investigation is concerned with the structural characterization of the metal complexes with the help of following well-known techniques:

1. Elemental Analysis
2. Molar Conductance
3. Magnetic Susceptibility
4. Infrared Spectroscopy
5. Electronic Spectroscopy (ultraviolet-visible spectra)
6. Electron Spin Resonance Spectroscopy
7. Thermogravimetric Analysis

1.21 ELEMENTAL ANALYSIS:

The molecular formula of the coordination compound can be deduced from elemental analysis. For the determination of metal contents, the complex was decomposed by heating with concentrated nitric acid and contents were estimated by well known standard analytical procedures. The percentage of C and N have been estimated microanalytically at Central Drug Research Institute (C.D.R.I.), Lucknow.

1.22 MOLAR CONDUCTANCE:

The electrical conductivity measurements have been used to determine the charged type of the complex molecules. In most cases, molar conductance (not the equivalent conductance) of charged complex falls in a predictable range, at a given concentration.

As a result of the passage of electric current, an electrolyte gets decomposed into ions. These ions in solution are responsible for the conductance. The standard unit of conductance which is the specific conductance i.e. reciprocal of specific resistance. A molar conductance may be defined as the conducting power of all the ions produced by one gram mole of an electrolyte in a given solution.

As a first approximation, one should expect the contribution of an ion \( I^{n^+} \) to the molar conductivity to be about 60 mhos(s) and accordingly for uni-univalent salt, MA type 120 Ohm\(^{-1}\) cm\(^2\)
while for a uni-bivalent electrolyte, $MA_2$ or $M_2A$ will be about $240 \text{ Ohm}^{-1} \text{ cm}^2$. The approximate value of the conductance varies with the change in size of ion, temperature, di-electric constant, relative velocity of ion and viscosity of the solvent.\(^{(32-36)}\)

1.23 MAGNETIC SUSCEPTIBILITY: \(^{(37-40)}\)

The measurement of magnetic susceptibility has been of great value in characterization of transition metal complexes. The susceptibility measured for a given substance will consist of contributions, from paramagnetic and diamagnetic susceptibilities, the former being much greater. The diamagnetic susceptibility is a negative quantity. The diamagnetic effect does not exist in the absence of magnetic field but is present in all substances placed in a magnetic field. All compounds have this property to some extent and are usually independent of field strength and temperature. Its numerical value is less than unity.

Paramagnetism is caused by the presence of unpaired electrons in molecules. When such a field is placed in an external homogeneous field, realises attraction by the magnetic field with a force proportional to field strength.

In practice, the gram susceptibility is measured and this is then converted into molar susceptibility. One obtains the effective moment by the following equation:

$$\mu_{\text{eff}} = 2.84 \sqrt{X_M \cdot T} \quad \text{B.M.}$$
1.24 INFRARED SPECTROSCOPY: *(41-45)*

The most fundamental information that may be obtained from infrared spectra is the knowledge of interatomic force in terms of force constant within a molecule. This gives important information about electronic structure and bonding in molecules. Absorption of infrared radiation in the frequency range of 10,000 – 20,000 cm\(^{-1}\) by the inorganic molecules is used for their molecular vibration. These vibrations comprise the motions of the atomic masses in the material about centres of vibrations. Electromagnetic radiation can induce transition among the vibrational energy levels only when the dipole moment changes either in magnitude or in the direction of the molecule and then a vibrational spectrum can be expected.

Two important modes of vibration are possible for a molecule; stretching and bending vibrations. The former requires more energy. In stretching vibrations, atoms vibrate along the bond axis. There are two types of stretching vibrations observed: (i) Symmetric (ii) Asymmetric. In bending vibrations, atoms vibrate perpendicular to the bond axis. Four types of bending vibrations are assigned, which are: (i) Scissoring (ii) Rocking (iii) Twisting and (iv) Wagging.

From the observation of infrared spectra of a number of compounds having a common group, it has been found that a particular group absorbs a narrow range of frequency called the group frequency. The observation of a particular band is strong evidence for the presence of a specific group. Sometimes the band may be difficult and weak to observe or it may be masked by a strong neighbouring band.
There are certain limitations for the concept of group vibration as it rests on the assumption that the vibrations of the particular group are relatively independent of the molecule. But in some systems it is not possible to isolate the group frequencies due to the coupling of frequency. The symmetry of the molecule affects its vibrational mode. It has been observed that the molecule having more symmetrical structures exhibits fewer distinct vibrational modes. Moreover, the temperature and physical state also affect the frequencies in some substances.

Thus, infrared spectroscopy provides one of the applicable technique for determining the mode of coordination of the ligand with the metal ion. This is often used as a technique to provide fingerprints for identification which is a function of the constituent atoms, bond lengths and bond angles. As a result of coordination of a metal ion with a ligand, the following changes take place usually in the infrared spectra:

(i) Appearance of new bands and splitting of degenerated modes due to lowering of the symmetry.
(ii) Shifting of the frequency bands and
(iii) Increase in the intensity of the spectra

The coordination of the ligand with metal, lowers its symmetry which results in splitting of forbidden vibration. The stronger, the metal ligand bond, larger will be the splitting of the degenerated mode. The shift in frequency, the magnitude of splitting and the
intensity of newly permitted bands are useful as a measure of the effect of coordination.

In the IR spectra of complexes prepared by Schiff bases, the most important is the azomethine vibrational frequency, because it changes on complexation. It may either increase or decrease depending upon many factors such as coordination, extent of \( \pi \)-bonding, presence or absence of substituents in the adjacent position and also on the type of the studied compound. This vibration in free schiff bases usually occurs in the region 1640-1470 cm\(^{-1}\) and on coordination a negative shift is theoretically expected. But in some complexes it may also be observed that the extent of \( \pi \)-bonding between metal ion and ligand is so large that the effect of coordination is not seen in the shifting of the frequency to lower wave number but rather to high wave number although the azomethine group is involved in coordination. Various other bands due to stretching vibrations of aromatic rings, C-H, N-H, M-O, M-N and deformation vibrations of CH, NH or OH are also observed in the infrared spectra.

A number of interpretations of numerous band in ligands and their shifting due to metal complex formation are illustrated by Nakamoto, Bellamy, Randall and Adams. They have been referred in the present investigation.

1.25 ELECTRONIC SPECTROSCOPY\(^{(26,36,48-48)}\)

When a molecule absorbs visible or ultraviolet radiation, an electron in the molecule undergoes a transition from a lower to a
higher energy level. The study of electronic spectra of transition metal complexes helps in understanding the electronic structure and bonding. Absorption in the UV-visible region of the spectrum is dependent on the electronic structure of the molecule.

In the metal complexes three main kinds of spectra are obtained:

1. **Ligand Spectra**: Organic molecules frequently act as ligands in transition metal complexes and they exhibit characteristic spectra. On complexation, the ligand spectral bands are shifted to a lower wave number. The magnitude of the shift is a measure of the oxidation state of the metal atom. These intra-ligand transitions usually occur in ultraviolet region.

2. **Charge-Transfer Spectra**: Transition involving transfer of an electron from ligand to metal or vice-versa, is known as charge transfer (C-T) transition and certain ligands show distinct charge transfer bands of high intensity. This concept can not be explained by Crystal Field Theory and represent the tendency of ligands to reduce the metal ion or vice-versa.

3. **d-d Transition Spectra**: This spectra occurs in the near infrared, visible and ultraviolet region (10,000 - 30,000 cm⁻¹ or 1000 - 333 nm). Lower frequencies are not easily accessible at experimental level and the higher frequencies though accessible, are overshadowed by the charge transfer and the intra-ligand transitions. This has limited the study of d-d transitions only in the visible region of spectrum. These transitions are considered
to be totally within the metal ion in the CFT or LFT model. Molecular Orbital Theory treats these transitions as arising due to the excitation of the electrons from the $t_{2g}$ level to the $e_g$ levels, belonging largely to the metal itself. These d-d electronic transitions are weak because of the reason that the transitions of the same quantum shall be forbidden.

**SELECTION RULES FOR ELECTRONIC TRANSITION:**

Quantum mechanics imposes restrictions on electronic transition in terms of selection rules that arises from the properties of the wave function:

(a) **Spin Selection Rule** – Transition in which the spin multiplicity changes are not allowed that is $\Delta S = 0$. The transition $S^2 - S'P^1$ is allowed only if the spin of the two electrons in $S'P^1$ state is $+\frac{1}{2}$ and $-\frac{1}{2}$ (singlet state); the transition to the triplet state ($3p$) is forbidden.

(b) **Laporte's 'Orbital' Selection Rule** – Any electronic transition is allowed only if $\Delta l = \pm 1$. Thus only the transition between an even state (g) and odd state (u) are permitted, i.e. $g < \ldots \ldots \ldots > u$ but $g<\ldots 1 \ldots > u$ and $u<\ldots 1 \ldots > u$

The d-d transitions are "Laporte" forbidden; since the change is $l=0$. The strictness of the selection rule is slightly diluted due to the slight mixing (d-p mixing) of the orbitals or states in some cases resulting slightly enhanced intensity of the observed bands. Coupling of this type occurs in complexes which do not possess a centre of
symmetry. Thus, Laporte allowed transitions are very intense, whilst Laporte forbidden transitions vary from weak intensity (if the complex is non-centro-symmetric) to very weak if it is centro-symmetric.

From the number, position and intensity of the bands in the spectrum, it is possible to obtain information on the symmetry around the central metal ion, relative orders of energy levels, 10 Dq and other parameters. In addition to this, when the ligand also absorbs in the visible region, the change in absorption bands indicates the complex formation.

1.26 ELECTRON SPIN RESONANCE SPECTROSCOPY (ESR): [49-53]

It is also known as electron paramagnetic resonance (EPR) spectroscopy. In this technique, one examines the energy absorbed from a microwave radiation by a paramagnetic system (molecules possessing electrons with unpaired spins) \( m_S = \pm \frac{1}{2} \) when a steady magnetic field is applied at right angle to the direction of H-Vector of the microwave radiation.

In EPR, a transition between two different electron spin energy states occurs upon absorption of a quantum of radiation in the \( r_7 \) or microwave radiation. The energy \( E \) of transition is given by the following expression:

\[
E = h \nu = g \beta H^0
\]
When an unpaired electron comes in vicinity of a nucleus with a spin I, an interaction takes place which causes the absorption signal to be split into $2I + 1$ components (due to nuclear spinelectron spin coupling). The energies of the levels are given by the following relation:

$$E = g\beta_H m_s + A m_s m_I$$

Where $A$ is reflected as the hyperfine coupling constant. This was first observed by Zavoyskiy and later by Cummerow and Halliday. It has now become one of the most important tools for the study of paramagnetic substances because ESR-spectrum is extremely sensitive to surrounding of the paramagnetic ion in the system. It provides information about the symmetry of surrounding, the nature and strength of bonding, extent of delocalisation of unpaired electrons, relative energies of various filled and unfilled molecular orbitals in the bonding scheme in both, solid and solution.

1.27 THERMOGRAVIMETRIC ANALYSIS: **(54-60)**

The technique of thermogravimetry was brought forward by the attempts made by Duval at the beginning of the 20th century. TG provides to analyst, a quantitative measurement of any weight change associated with a transition. The change in weight of a sample followed during continuous increase in temperature is thermogravimetry. The curves are characteristic for a given compound because of the unique sequence of physico-chemical reactions occurring at definite temperature ranges and rates.
The study of $T$ vs $\Delta w$ gives the information about the kinetics of decomposition, order of reaction, energy of activation and rate of reaction. For complexes containing water molecules, it has been possible to differentiate between lattice and coordinated water. It also helps in deciding the dehydration and decomposition temperature. The data may be employed to know the stabilities of metal complexes. The TGA and DTA are also very useful in characterization of the highly stable, heat resistant and explosive compounds.

The way and steps of thermal degradation reflects some significant information about the mechanism of formation of the compound.

If the thermogravimetry is used in association with other physico-chemical methods, like magnetism, IR and electronic spectrophotometry etc. (as in the present investigation), its field of application becomes unlimited. It provides a measure of penetrating more deeply into the structure of complexes.

1.3 SIGNIFICANCE:

The metal complexes of Schiff bases represent an important and interesting class of coordination compound. The complexes of metals viz. Co, Ni, Cu, etc. occur in traces in plant and animal bodies. These elements even in traces play a significant role in physiological and metabolic processes. It is well known that majority of 3d transition elements have registered their importance in many biochemical phenomena. The applications of coordination compounds
appear distinctly increased in past three decades. In recent years, the coordination compounds are being used in the field of biology, medicine, industry and agriculture.

In biological systems these metallic cations are incapable of independent existence. The metal ions cannot enter the cell by themselves. They are however, carried by the chelating agents, which may be lipid soluble. The use of chelating agents depends upon the formation of stable and soluble metal chelates. In course of biocirculation the metal ions compete to bind the chelating biological sites and thus sometimes help in dislodging the bound metals/bio-organic species in the form of soluble chelates. Hence, chelating agents must be of low toxicity and non-metabolizable so as to persist unchanged in the biological systems in order to perform their scavenging functions. They must also be capable of penetrating into the metal storage sites. Further chelates should be much less toxic than their parent ingredients.\textsuperscript{61}

An important application of metal complexes are in the areas of catalysis, dyes and pigments, photography, electrochemistry, extractive metallurgy, geochemistry, nuclear fuel cycle and radio pharmacy, analytical chemistry, biomedical and therapy.

It is a remarkable fact that certain physical and chemical properties of 4-amino acetanilide, 2-4 dinitroaniline, 2-nitrobenzaldehyde and their derivatives, have aroused interest regarding biochemistry and pharmacology of these substances. Several derivatives of these compounds after suitable structural modifications,
are being used as pharmacophores and active chemicals in agriculture. Bio-coordination chemistry has emerged as most potential branch of inorganic chemistry. Coordination compounds can be used in the treatment or diagnosis of disease. Complex can be formed in the body to handle dysfunctions and metal chelation therapy. \(^{(62-63)}\)

Nickel compounds are of great industrial importance and can be used in heterogeneous catalysis, electroplating, batteries, pigments, ceramics and hydrogen storage. \([\text{Ni(NH}_3\text{)}_6]\text{Cl}_2\) has been shown to be potentially applicable in heat pumps. The Nickel-dithiabenzil complex has been used in laser technology. Ni compounds are applicable as stabilizers and anti-oxidants for polymers of numerous types. Salicyladiminato and dithiocarbamato complexes of Nickel (II) have been found significantly active in photostabilization and in thermal oxidative degradation of certain polymeric materials. \(^{(63-65)}\)

Some Nickel complexes of porphyrazines,\(^{(66)}\) o-phenylene diamine\(^{(67)}\) and 3-formyl pentane-2-4-dione have been stated to be purple and red-violet pigments. In silver-dye-bleach process\(^{(68)}\) of photographic dyes and imaging chemistry the Cu and Ni azo dyes are used.

The industrial applications of copper complexes are varied and of great importance Cu\(_2\)O is used as an antioxidant in lubricants, as an absorbent for carbon monoxide and in helium purification. Cu(OH)\(_2\) and CuO finds applications as a plastic stabilizer, in rayon production and in antifouling paints. Several other compounds are used in oil industry, catalysis, as corrosion inhibitor and wood preservator. Copper halides may be used in lubricants as a stabilizer for polymers,
as a decolonizer for ceramics and as an antioxidant. CuI is of potential interest in the initiation of rainfall by cloud seeding and in the production of conducting films. Copper(II) soaps, mainly the oleate and stearate, find application in antifouling paints and as fungicides for textiles. Copper acetylacetonato chelate has been used as a source of copper in Cu-vapour lasers, and it has been investigated as substitute for AgI as an ice-nucleating agent for the initiation of rainfall. Cu complexes are effective smoke retardant for polystyrene and poly vinyl chloride. The complexes of copper diethylidithiocarbamate has been shown to be extremely effective scavenger for perox radicals and can be used to inhibit the auto-oxidation of hydrocarbons. Copper compounds are important as dye-stuff for cotton materials. Copper phthalocyanines have been a good pigment material for cotton, wool and nylon etc.

Coordination chemistry helps us also in understanding the phenomenon of geo-chemical and prebiotic significance. Metal ion and ligands are used in mutual extraction and estimation of their presence in a sample.
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