CHAPTER - III A

INFRA RED SPECTRA OF TERNARY COMPLEXES OF COPPER (II) WITH DIFFERENT AMINO ACIDS
Summary

The IR spectral assignment gives the basic idea about the bonding mode within the compounds. Hence from the position and comparative shifting of characteristic frequencies of particular groups the bonding of copper (II) ion with ligand can be explained.

After complexation, $\tilde{\nu}$-$\text{NH}_3^+$ frequencies which are observed at $\sim$3000, $\sim$ 2950 and $\sim$1640 cm$^{-1}$ in free ligands completely absent, confirms the envolvement of -NH$_2$ group. Similarly the comparative positions of $\tilde{\nu}$ coo$^-$ (asym and sym) in ligands and their complexes supports the envolvement of -coo$^-$ group by deprotonation and confirms its monodenticity. All newly synthesised complexes show a weak band at $\sim$ 780 due to presence of water molecule in co-ordination sphere.
3.1 Infra-Red Spectra

The infra-red region is of great importance in studying simple and complex compounds. The extra interpretative knowledge that can be gained form the study of spectra in IR-region provides a more complete picture of a molecule and the inter and intra molecular forces which effect characteristic frequencies. Specially for metal complexes the IR-spectral range can be devided in to two ranges, the high frequency (4000-667 cm\(^{-1}\)) and low frequency (667-50 cm\(^{-1}\)).

(i) The high frequency vibrations are ligand sensitive. The characteristic frequencies for important functional groups occur in higher range portion (400-1400 cm\(^{-1}\)) of this spectrum, while the lower range portion (1400-667 cm\(^{-1}\)) shows unique absorption for particular compound because of both stretching and bending modes.

(ii) The low frequency vibrations are metal sensitive, originated due to metal ligand bond. The spectra in this region gives the direct informations about the metal ligand co-ordinate bond.

By compairing the infra-red spectra of co-ordinate compounds with the infra-red spectra of pure ligands, we can determine the presence, its strength and extent of interaction of cental metal atom with the ligands.

Chart of infra-red characteristic frequencies have been
combined by Colthup and are extensively used for the interpretation of IR-spectral data. In investigating the IR- spectra, one has to rely upon the data available in the existing literature regarding IR absorption bands of different structural units.

In the present investigation the infra-red spectra of the ternary complexes of copper and infra-red spectra of pure ligands were recorded on IR - spectrophotometer shimadzu 8201-PC (4000-350 cm⁻¹) FTIR in KBr. (Fig 3.01 to 3.11).

The spectra of ternary complexes have been compared with the ligands' to arrive some meaningful conclusions. The spectra of both the complexes and ligands are compiled in table (Table 3.1 and 3.2). The changes in the characteristic group frequencies of ligands on chelation with metal ion can be presumed to be on account of the co-ordination.

As regards chelation through amino acids, the IR-spectra exhibits significant features in ν - NH₂ and ν - COO⁻ regions. The groups -NH₂, -COO⁻ and deprotonated amide group have been found to be metal sensitive, therefore the frequencies assigned to them have been looked upon a proof of complexation. New bands appear in the complexes in the lower frequency region at ~400 cm⁻¹ and ~ 500 cm⁻¹, which may be assigned as Cu-O and Cu-N bands respectively. This may be taken as a support for bonding between nitrogen atom of amino group¹⁻³ and oxygen of the carboxylate group⁴ to the metal ion.
Fig. 3.05 - INFRARED SPECTRA

\[ \text{Cu}^{II}(\text{Met})(\text{Trp})(\text{H}_2\text{O})_2 \]
Fig. 308-IR SPECTRA
Fig. 309-IR SPECTRA
Fig. 3.10 - IR SPECTRA
Fig. 3.11 - IR SPECTRA
<table>
<thead>
<tr>
<th>SNo.</th>
<th>Amino Acids</th>
<th>$^{1}$NH$_{3}$ absorption band</th>
<th>$^{1}$NH$_{3}$ deformation &amp; bending band</th>
<th>$\nu$ (coo')</th>
<th>$\nu$ (C-C-N)</th>
<th>$\nu$ (C-S)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Asym cm$^{-1}$</td>
<td>Sym cm$^{-1}$</td>
<td>Asym cm$^{-1}$</td>
<td>Sym cm$^{-1}$</td>
<td>Sym. streching cm$^{-1}$</td>
</tr>
<tr>
<td>1.</td>
<td>ALANINE</td>
<td>3088</td>
<td>2950</td>
<td>1623</td>
<td>1597</td>
<td>1412</td>
</tr>
<tr>
<td>2.</td>
<td>SERINE</td>
<td>3093</td>
<td>3157</td>
<td>1659</td>
<td>1578</td>
<td>1433</td>
</tr>
<tr>
<td>3.</td>
<td>PROLINE</td>
<td>2964</td>
<td>-</td>
<td>-</td>
<td>1631</td>
<td>1408</td>
</tr>
<tr>
<td>4.</td>
<td>LEUCINE</td>
<td>3020</td>
<td>2920</td>
<td>1620</td>
<td>1570</td>
<td>1480</td>
</tr>
<tr>
<td>5.</td>
<td>TYPHTOPHAN</td>
<td>3355</td>
<td>3010</td>
<td>1640</td>
<td>1580</td>
<td>1430</td>
</tr>
<tr>
<td>6.</td>
<td>METHEONINE</td>
<td>2922</td>
<td>2862</td>
<td>1625</td>
<td>1583</td>
<td>1412</td>
</tr>
<tr>
<td>SNo.</td>
<td>Complex</td>
<td>‘NH$_3$’ absorption band</td>
<td>‘NH$_3$’ deformation &amp; bending</td>
<td>ν(-NH$_3$)</td>
<td>ν(-C=O)</td>
<td>ν(C-S)</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>-------------------------------</td>
<td>-------------</td>
<td>---------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Asum cm$^{-1}$</td>
<td>Sym cm$^{-1}$</td>
<td>Asum cm$^{-1}$</td>
<td>Sym cm$^{-1}$</td>
<td>cm$^{-1}$</td>
</tr>
<tr>
<td>1.</td>
<td>[Cu$^{II}$ (Met) (Pro) (H$_2$O)$_2$]</td>
<td>Ab</td>
<td>Ab</td>
<td>3392</td>
<td>3190</td>
<td>1600</td>
</tr>
<tr>
<td>2.</td>
<td>[Cu$^{II}$ (Met) (Ala) (H$_2$O)$_2$]</td>
<td>Ab</td>
<td>Ab</td>
<td>3223</td>
<td>3175</td>
<td>1610</td>
</tr>
<tr>
<td>3.</td>
<td>[Cu$^{II}$ (Met) (Ser) (H$_2$O)$_2$]</td>
<td>Ab</td>
<td>Ab</td>
<td>3317</td>
<td>3140</td>
<td>1624</td>
</tr>
<tr>
<td>4.</td>
<td>[Cu$^{II}$ (Met) (Leu) (H$_2$O)$_2$]</td>
<td>Ab</td>
<td>Ab</td>
<td>3302</td>
<td>3136</td>
<td>1620</td>
</tr>
<tr>
<td>5.</td>
<td>[Cu$^{II}$ (Met) (-Trp) (H$_2$O)$_2$]</td>
<td>Ab</td>
<td>Ab</td>
<td>3365</td>
<td>3200</td>
<td>1600</td>
</tr>
</tbody>
</table>
(i) It is worthwhile to mention here that free amino acids exist as "Zwitter ions", (\(\text{NH}_3\cdot\text{AA}.\text{COO}^-\)) and the infra-red spectra of these can not be compared entirely with those of metal complexes, as amino acids in metal complexes do not exist as zwitter ions. Free amino acids with \(\text{NH}_3\) functional group in particular show \(\tilde{\nu} - \text{NH}_3\) in the 3130 - 3030 cm\(^{-1}\) range\(^5\).

In the complexes \(\text{NH}_3\) gets deprotonated and binds to metal through the neutral \(-\text{NH}_2\) group. The transformation of \(\text{NH}_3\) to \(-\text{NH}_2\) must result in an upward shift in \(\tilde{\nu} - \text{NH}_2\) and free amino acids. At the isoelectric point, they must show \(\tilde{\nu} - \text{NH}_2\) in the region 3500-3300 cm\(^{-1}\),\(^6,8\) but the N-substituted amino acids such as N-phenylglycine, sarcosine or proline can only have the group which absorbs near 2900 cm\(^{-1}\),\(^9\).

In the present complexes the infra-red characteristic bands occur in the region 3392-3223 cm\(^{-1}\), which are lower compared to those of free \(\tilde{\nu} - \text{NH}_2\). The \(\delta - \text{NH}_2\) i.e bending or deformation vibration band which occurs at \(\sim 1640\) cm\(^{-1}\) are completely absent in spectra of metal complexes. Hence it can be concluded that the nitrogen of the amino group is involved in co-ordination\(^{10,18,19}\). It is also confirmed that Cu-N bond is covalent in nature\(^11\).

(ii) All free amino acid show sharp absorption band in the region of 1600-1400 cm\(^{-1}\) in their infrared spectra confirming the presence of ionised carboxylate group\(^12\). The IR-spectra show strong
evidence in support of the involvement of carboxylate group in coordination with metal. In comparison with free amino acids the $\overline{\nu}$-COO$^-$ (asym) show positive shift and $\overline{\nu}$-COO$^-$ (sym) records negative shifts. The large $\Delta \overline{\nu}$(COO$^-$) between the asym and sym. $\overline{\nu}$-(COO$^-$) frequencies in this complex compared with the free ligand indicates that the carboxylate group is strongly bound$^{14}$. This is known as Nakamot rule$^{13}$, which confirms the monodenticity$^{29}$ of the cobaloxylate group.

Thus it may be concluded that amino acids act as monobasic, bidentates in these complexes containing through amino-N and carboxylate-O.

(iii) Other low intensity bands observed in far IR region 600-400 cm$^{-1}$ are due to $\overline{\nu}$(M-N) and $\overline{\nu}$(M-O) strech. Nakamoto and Fujita$^{15}$ made assignment for M-N streching in amino complexes in 509-419 cm$^{-1}$ region. Shimanouchi and Nakagawa$^3$ measured the spectra of various metal ammine complexes. They found the M-N streching vibrations between 510-318 cm$^{-1}$.

In the IR-spectra of our newly synthesized complexes of copper, Cu-N bands are observed $\sim$500 cm$^{-1}$ which is in support of Nakamoto's assignment$^{13}$.

(iv) The metal oxygen streching vibration observed in low frequency region due to low bond order and heavy mass of the metal. In present complexes this band was observed in the range 434-385 cm$^{-1}$. 
(v) In general, lattice water absorbs at 3550-3200 cm\(^{-1}\) (asym and sym -OH streching)\(^{16}\) and at 1630-1600 cm\(^{-1}\) (non bending). In addition to the three fundamental modes of free water molecules co-ordinated water is expected to show other modes. The rocking and metal oxygen streching modes will become IR-active, if the metal oxygen bond is sufficiently covalent. The presence of these bands in aquo complexes was first suggested by Fujita, et-al\(^{15}\), Gamo\(^{17}\) assigned the bands at 880-650 cm\(^{-1}\) of inorganic salts to the rocking mode of co-ordinated water.

Our synthesised complexes show these bands at \(\sim\)800cm\(^{-1}\) which are further supported by Nakagawa and shimanouchi assignent\(^{21-24}\).
CHAPTER - III B

ELECTRONIC SPECTRA OF TERNARY COMPLEXES
OF COPPER (II) WITH DIFFERENT AMINO ACIDS
Summary

Electronic spectra of newly synthesised complexes in water were recorded in order to evaluate geometry of the complex. All complexes show one asymmetric absorption band around $16,000 \text{ cm}^{-1}$ which may be assigned to the transition $^2\text{Eg} \rightarrow ^2\text{T}_{2g}$. Single band observed in all newly synthesised copper (II) complexes, suggest distorted octahedral trans geometry. The value of $\lambda_{\text{max}}$ and molar extinction co-efficient not changed on further dilution. This confirms that complexes are neither associated nor dissociated.
3.2 Electronic Spectra

Electronic spectral studies of newly synthesised ternary complexes of copper (II) have been carried out in order to find out the stereochemistry of the complexes.

It is possible to find out point symmetry in co-ordination sphere and to assign possible geometry of isomers on the basis of electronic spectra\textsuperscript{27-29}, Jorgensen\textsuperscript{23}, Griffith\textsuperscript{24}, Orgel\textsuperscript{25} and Lever\textsuperscript{26} etc have studied electronic absorption spectra of transition metal complexes in detail.

The electronic spectra of newly synthesised copper-ternary complexes were plotted in the region 200-800 nm. Here our aim is to interpret the origin of electronic spectra of complexes and to correlate these spectra with bonding. Because atoms in complexes are so compact, the mutual repulsions of their electrons have a strong influence on the energies of their electronic transitions. The role of electron-electron repulsion was originally determined by the analysis of atoms and ions in the gas phase, and much of that information can be utilized in the analysis of the spectra of metal complexes. The main differences between gas phase metal atoms or ions and metal atoms in complexes are changes in symmetry and the resultant, changes in the degeneracy of energy levels.

For co-ordination compounds the ligand field parameter 10 Dq or $\Delta_0$ gives the electronic configurational properties of
them. The value of this parameter depends on interaction between metal ion and ligands and their mutual arrangements in space. The symmetry and nature of interacting orbitals of both the metal ion and ligand decide the geometry of the complex.

In this thesis the electronic spectra of ternary complexes of copper (II) with different amino acids are described. (Fig. 3.13-3.18). Copper is a last element of 3d-series having the electronic configuration [Ar]3d$^{10}$,4s$^{1}$ and in dipositive ionic state [Ar] 3d$^{9}$. Hence it is expected to form distorted octahedral complexes$^{30-31}$. This d$^{9}$ configuration of copper (II) ion give rise to only one free ion R-S term of $^2$D, having multiplicity of two, showing two fold degeneracy in spin and orbit, i.e. in any symmetry all the levels belonging $^2$D have the same interelectronic repulsions.

In an octahedral complex, where the d-orbitals are not all degenerate, it is necessary to take in to account the difference in energy between $t_{2g}$ and $e_{g}$ orbitals as well as electrtron-electron repulsion, the degeneracy removed$^{32-34}$ and the free ion term $^2$D splits in the ligand field of an octahedral complex in to $^2$T$_{2g}$ and $^2$E$_{g}$ spectroscopic terms or levels$^{25}$. According to "Hole formalism Principle" a d$^{n}$ system is equivalent to d$^{(10-n)}$ system with only the level order inverted. The $^2$D state of d$^{9}$ of copper (II) splits up to lower energy ground term $^2$E$_{g}$ and upper energy term $^2$T$_{2g}$. Due to John-Teller Effect, distortion is noticed$^{26,35-41}$, hence $^2$E$_{g}$ state further split in to $^2$B$_{1g}$ and $^2$A$_{1g}$, and $^2$T$_{2g}$ in to $^2$B$_{2g}$ and $^2$E$_{g}$.
hence we expect three closely spaced bands due to the following possible transitions -

\[ ^2B_{lg} \rightarrow ^2E_g \]

\[ ^2B_{lg} \rightarrow ^2B_{2g} \]

\[ ^2B_{lg} \rightarrow ^2A_{1g} \]

Which are in agreement with the experimentally observed facts. The energy level sequence will depend on the amount of tetragonal distortion due to ligand field and J.T. distortion \(^{42}\).

The aqueo copper(II) complex has pale blue colour. The absorption spectrum consists of a broad weak band near 13,000 cm\(^{-1}\)\(^{43-44}\). Tetragonally distorted octahedral complexes give rise to one band appearing at about 16,000 cm\(^{-1}\). This shift from 13,000 cm\(^{-1}\) to 16,000 cm\(^{-1}\) can be taken as an evidence for the presence of co-ordinated copper (II) ion with other ligand. In case of square planar complex a band around 19,000 cm\(^{-1}\) is observed.

The spectral data of the copper complexes synthesised in the present investigation are given in table 3.3. The results indicate an asymmetric absorption band \(^{46-48}\) occurs around 16,000 cm\(^{-1}\), Fig 3.12-3.16 which suggest that the mixed ligand complexes have tetragonally elongated octahedral geometry \(^{49-51}\). Due to the presence of the different ligand in field, the medium field strength is expected which confirmed by appearance of a broad band due
Fig. 3.12 - VISIBLE SPECTRA
Fig: 3.13 - VISIBLE SPECTRA
Figure 3.4: Visible Spectra

[CuII(Met)2(Ser)2(H2O)2]
Fig. 3.19-UV SPECTRA

Absorbance

[CuII\(\text{Met}(\text{Ser})(\text{H}_2\text{O})_2\)]

Wavelength (nm)
<table>
<thead>
<tr>
<th>SNo.</th>
<th>Complex</th>
<th>$\bar{\nu}_{\text{max}}$ cm$^{-1}$</th>
<th>Absorbance</th>
<th>Molar Concentration</th>
<th>$\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>[Cu$^{II}$ (Met) (Pro) (H$_2$O)$_2$]</td>
<td>16.318</td>
<td>0.346</td>
<td>$5.5 \times 10^{-3}$</td>
<td>62.90</td>
</tr>
<tr>
<td>2.</td>
<td>[Cu$^{II}$ (Met) (Ala) (H$_2$O)$_2$]</td>
<td>16.113</td>
<td>0.350</td>
<td>$5.9 \times 10^{-3}$</td>
<td>59.32</td>
</tr>
<tr>
<td>3.</td>
<td>[Cu$^{II}$ (Met) (Ser) (H$_2$O)$_2$]</td>
<td>15.974</td>
<td>0.328</td>
<td>$5.6 \times 10^{-3}$</td>
<td>58.57</td>
</tr>
<tr>
<td>4.</td>
<td>[Cu$^{II}$ (Met) (Leu) (H$_2$O)$_2$]</td>
<td>16.103</td>
<td>0.291</td>
<td>$5.1 \times 10^{-3}$</td>
<td>56.17</td>
</tr>
<tr>
<td>5.</td>
<td>[Cu$^{II}$ (Met) (Trp) (H$_2$O)$_2$]</td>
<td>16.005</td>
<td>0.288</td>
<td>$5.0 \times 10^{-3}$</td>
<td>57.60</td>
</tr>
</tbody>
</table>

Table - 3.3
Spectrals Data Of Ternary Complexes of Copper (II) in Visible Region
to mixing of a three closely spaced bands arising form the John-Teller distortion. This absorption band is of higher frequency than for tetrahedral geometry. The values of molar extinction co-efficient lie between 56 to 76. Therefore tetragonally distorted octahedral geometry is confirmed.

Hathway et-al\textsuperscript{30} studied similar type of complexes and concluded on the basis of electronic spectral studies that trans-isomers give a single band while cis-isomers give two bands differing by 5 k. cal mole\textsuperscript{1}. On the basis of above conclusion trans configuration for the present complexes may be assumed\textsuperscript{53}.

The change in concentration of complexes does not show any change in $\lambda_{max}$, hence the complexes do not undergo dissociation or association in aqueous medium.

A band in the region 230-255 nm is reported due to charge transfer transitions ($\sigma_{Cu} - N \rightarrow 3d_{x^2 - y^2}^\rightarrow$)\textsuperscript{54-57}. In our complexes this band appeared at 230-240 nm (Fig. 3.17 to 3.19).

Ternary complexes are generally more stable than binary complexes\textsuperscript{58-63}. On this basis the $\overline{\overline{\nu}}_{max}$ values of ternary complexes with the average values of $\overline{\nu}_{max}$ for parent binary (1:2) complexes were compared. Almost in all the cases the value of $\overline{\nu}_{max}$ of ternary complexes are more than the average $\overline{\nu}_{max}$ values of binary complexes.
CHAPTER - III (C)

MAGENETIC PROPERTIES OF COPPER (II)
TERNARY COMPLEXES WITH DIFFERENT AMINO ACIDS
Summary

Volume Susceptibility measurements of the complexes were done applying Faradays Method. The results indicate paramagnetic nature of the complex containing one unpaired electron.
3.3 Magnetic Properties of Complexes

When an object is placed in a magnetic field, in general a magnetic moment is induced in it. This phenomenon is analogous to the induction of an electric moment in an object by an electric field but, differs from it in that an induced magnetic moment have either direction in relation to the applied field, material is called paramagnetic or ferromagnetic depending on whether the field due to the induced moment is small or large in comparison with the external field. If the moment is antiparalled to the external field the material is called diamagnetic, the moment in this case is always small.

If, \( I \) is the intensity of magnetization induced in a body, by an applied magnetic field \( (H) \), the volume magnetic susceptibility\((\chi)\) is defined by the equation

\[
I = \chi \cdot H, \text{ or } \chi = I / H
\]

It is a characteristic property of a compound and dimensionless value, ( if \( I \) and \( H \) measured in same unit ). The magnetic susceptibility may be conceptually treated as the response of a substance to induced magnetization. Ordinarily it is very small in comparision with unity except in the case of ferromagnetism and essentially independent of \( H \) for fields readily available in the laboratory. For a paramagnetic substances \( \chi \) is possitive and is negative for diamagnetic substances. Only volume
susceptibility measurement of the complex was done due to experimental limitations applying Faraday's formula\textsuperscript{64-66}.

The $\mu_{\text{eff}}$ value of the complex is calculated by using the Curie equation\textsuperscript{67}

$$\mu = 2.83 \left[ \chi_m \left( T - \Theta \right) \right]^{1/2} \quad \text{BM}$$

$(T = \text{room temp. in} \ 00K)$

Many paramagnetic co-ordination complexes exhibits the $\Theta$ value close to zero, and hence neglecting $\Theta$, when calculating the magnetic moment seldom affects the value of $\mu$.

**Experimental**

(i) Apparatus: A strong electromagnet, Model EMU-75, make Scientific Equipment Services, Roorkee, having field intensity of 11 K. Gauss ± 5% with 10 mm air gap, a sensitive single pan balancing unit and small ignition tubes.

(ii) Method: A small quantity of the complex placed in a ignition tube, and suspended from a sensitive balance, was placed in a region of a fairly strong magnetic field (7.5 k. Gauss, produced by passing current of 2.95 Amps.). The weight of complex was taken in presence and absence of magnetic field. Apparatus constant was determined using Mohr Salts. The value of $(H. \frac{d_{m}}{d_{z}})$ is obtained from the relation.

$$H. \frac{d_{m}}{d_{z}} = W_{t} - W_{0} / V \cdot \chi_{m}$$
(i) **Weight of Empty Ignition tube:**

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Weight (gm)</th>
<th>Weight (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without field</td>
<td>with field</td>
</tr>
<tr>
<td>45</td>
<td>0.8620</td>
<td>0.8620</td>
</tr>
<tr>
<td>46</td>
<td>0.8625</td>
<td>0.8625</td>
</tr>
<tr>
<td>47</td>
<td>0.8629</td>
<td>0.8629</td>
</tr>
<tr>
<td>48</td>
<td>0.8628</td>
<td>0.8628</td>
</tr>
</tbody>
</table>

(ii) **Observation for Ferrous Ammonium Sulphate:**

- **i-** Volume of FAS = 1.17608 cm³
- **ii-** $\chi_m$ of FAS = $70 \times 10^{-6}$ CGS.

<table>
<thead>
<tr>
<th>Distance (Cm)</th>
<th>Weight (gm)</th>
<th>Weight (gm)</th>
<th>Weight</th>
<th>H.d$_h$/d$_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without field</td>
<td>With field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>1.6505</td>
<td>1.7213</td>
<td>0.0708</td>
<td>859.9</td>
</tr>
<tr>
<td>42</td>
<td>1.6512</td>
<td>1.7525</td>
<td>0.1013</td>
<td>230.47</td>
</tr>
<tr>
<td>43</td>
<td>1.6520</td>
<td>1.7712</td>
<td>0.1192</td>
<td>1447.9</td>
</tr>
<tr>
<td>44</td>
<td>1.6522</td>
<td>1.7962</td>
<td>0.1440</td>
<td>1749.1</td>
</tr>
<tr>
<td>45</td>
<td>1.6523</td>
<td>1.8004</td>
<td>0.1481</td>
<td>1798.89</td>
</tr>
<tr>
<td>46</td>
<td>1.6523</td>
<td>1.8038</td>
<td>0.1515</td>
<td>1840.25</td>
</tr>
<tr>
<td>47</td>
<td>1.6524</td>
<td>1.8065</td>
<td>0.1540</td>
<td>1870.6</td>
</tr>
<tr>
<td>48</td>
<td>1.6524</td>
<td>1.8040</td>
<td>0.1521</td>
<td>1847.5</td>
</tr>
<tr>
<td>49</td>
<td>1.6510</td>
<td>1.7906</td>
<td>0.1396</td>
<td>1695.7</td>
</tr>
<tr>
<td>50</td>
<td>1.6505</td>
<td>1.7780</td>
<td>0.1275</td>
<td>1548.7</td>
</tr>
</tbody>
</table>

\[
\text{mean H.d}_h/ d_z = (1798.89 + 1840.25 + 1870.6 + 1847.5) / 4
\]

\[
\text{H.d}_h/ d_z = 1839.31
\]

(iii) $\chi$ values for copper (II) complexes calculated by using the following equation (Table 3.4)

\[
\chi = \frac{w_f - w_{no}}{V (H.d_h/ d_z)}
\]
\textbf{3.20:} Graph showing variation of \((H \cdot d_H/d_z)\) with Distance
<table>
<thead>
<tr>
<th>SNo.</th>
<th>Complex</th>
<th>Distance (cm)</th>
<th>Without field</th>
<th>With field</th>
<th>Difference</th>
<th>$\chi_g$ (g)</th>
<th>Mean $\chi_g$ (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\text{[Cu}^{\text{II}} \text{ (Met) (Pro)(H}_2\text{O})_2\text{]}$</td>
<td>45</td>
<td>1.2616</td>
<td>1.2693</td>
<td>0.0077</td>
<td>$3.5597 \times 10^{-6}$</td>
<td></td>
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<td>1.2146</td>
<td>1.2221</td>
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<td>1.1875</td>
<td>0.0067</td>
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<td>1.1891</td>
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<td>S.No.</td>
<td>Complex</td>
<td>$\mu_m$ at 25°C (μm)</td>
<td>$\chi_m$</td>
<td>Magnetic Susceptibility</td>
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<tr>
<td>1.</td>
<td>$[\text{Cu}^{II}(\text{Met})\text{(Pro)}(\text{H}_2\text{O})_2]$</td>
<td>361.88</td>
<td>4.2761 $\times 10^{-4}$</td>
<td>1.5474 $\times 10^3$</td>
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<td>2.</td>
<td>$[\text{Cu}^{II}(\text{Met})(\text{Ala})(\text{H}_2\text{O})_2]$</td>
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<td>4.5187 $\times 10^{-4}$</td>
<td>1.5171 $\times 10^3$</td>
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<td>3.</td>
<td>$[\text{Cu}^{II}(\text{Met})(\text{Ser})(\text{H}_2\text{O})_2]$</td>
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<td>5.</td>
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Result

Only volume susceptibility measurement of the complexes synthesised in the present investigation had been carried out applying Faraday's formula. The complexes are paramagnetic containing one unpaired electron. The results are summarised in table 3.5. It is clear that the value of $\chi$, $\chi_m$ and $\chi_{eff}$ confirm the presence of one unpaired electron in each case.

*****
References


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