Preparation and Characterization of Copper Iso-leucine Complex and Structure Determination by Computational Calculation

Md. Shahidul Islam[a], *Dr. Md. Abdus Salam[b],

[a] Department of Chemistry, University of Dhaka, Dhaka 1000, Bangladesh
[b] Professor, Department of Chemistry, University of Dhaka, Dhaka 1000, Bangladesh

Highlights

- This study reports a synthesis of Cu complex of Iso-leucine
- Elemental analysis of the complex shows a good agreement with the values calculated for the proposed formula
- DFT confirms square planar geometry of Cu complex of Iso-leucine
- Molecular orbital calculation relates to the stability of the complex
- UV-vis and Reflectance spectra predict characteristic MLCL and d–d transition bands

Key words

Copper nitrate, Iso-leucine, Metal-ligands, Spectroscopic analysis, Density functional theory

Abstract

A copper complex of Iso-leucine, molecular formula $Cu(C_6H_{12}NO_2)_2$, is synthesized in water-ethanol medium and characterized by elemental analysis, FTIR, UV-visible spectroscopy, thermogravimetric analysis (TGA), reflectance analysis, conductivity measurement and theoretical structure determination. Iso-leucine forms 1:2 complex with copper. The complex is soluble in methanol and decomposed before melting. The IR spectra of iso-leucine and complex are more or less similar expect in slight change in peak position and the absorption bands at 811 cm^{-1} and 593 cm^{-1} for the metal ligand bonds. The UV-visible spectra of the ligand and the complex in methanol solution are of similar pattern indicating that the structure of the ligand remains unchanged in the complex. The reflectance spectra of the ligand and the complex are similar in nature but the peak positions are different which may be due to the difference in band gap energy between the the ligand and the complex which also in the favour of the formation of the new complex. The band gap energy increases from ligand to complex so conductivity decreased. It is found that with increasing concentration molar conductance decreases for the Cu-Isoleucine complex. Therefore, it can be concluded that this complex is weak electrolyte. Optimized

structure of the synthesized $Cu(C_6H_{12}NO_2)_2$ complex is square planar calculated by DFT level of theory.

Introduction

Metals perform pivotal roles including electron transfer, catalysis, structural support, protein folding/unfolding in biological systems by interacting with amino acids [1-6]. Amino acids have diverse functional groups such as amino, carboxyl, phenolic, imidazole and phenyl which can form chelates with different metals [7].Metal chelated are used in medicines, drugs and treatment of disease[8]. Iso-leucine is one of the branched chain amino acids (Iso-leucine, Valine) and is classified as an essential amino acid. This means the body cannot manufacture iso-leucine; it must be acquired through diet or supplementation. The male adult's daily requirement is 10 mg per kg of body weight. Food sources for iso-leucine include almonds, cashews and soy protein. Iso-leucine is commonly used in parenteral and enteral nutrition. It is used in combination with the other branched chain amino acids to improve the nutritional status of patients with hepatic diseases [9].The importance and applications of transition metal–ligand complexes are widespread from synthetic chemistry to material science and biochemistry. These metals have been used for drug design and delivery [10-15], catalysis [16-19], solar cell applications [20-22] and biological imaging [23-24]. In biological systems, transition metals are involved with very specific structural and cellular functions. Despite the pivotal importance of transition metals in biological functions, very few studies are focused on interaction of these metals with amino acids employing experimental and computational methods. The crystal structure of the Copper (II) complex of L-isoleucine was determined in order to discover typical conformation of biologically important amino acid iso-leucine by Charles M. Weeks, A.Copper and Dorita A. Norton] 25.[The stability constants of Cu^{2+}, Mn^{2+} and UO_2^{2+} complexes with isoleucine were determined electrophoretic technique by Brij BhushanTewari [26].Most of the studies limited to structural features related to metal amino acid interaction. Previous investigations only considered the single amino acid binding with metals whereas metals can bind with two amino acids. In this study, the synthesis and characterization of transition metal Cu complex of iso-leucine has been reported. The computational calculation for the determination of structure of the complex has been reported.

Experimental

Materials and methods

All the chemicals were of analytical grade and used without further purification. The synthetic manipulation was carried out in the atmosphere at room temperature. L-iso-leucine (BDH Chemicals Ltd, Poole England), Copper nitrate (E. Merck of Germany), distilled water, NaHCO, $_3Na_2EDTA$, ammonium buffer, methanol, fast sulphon black F, KCl etc. were used in all preperative and analytical works.Melting

points of the studied compounds were taken in a melting points apparatus (SMP 11, Stuart, England), which have the capacity of recording the temperature up to 350 ^{o}C . Elemental analysis for C ,H ,N of the complexes was obtained from BCSIR)Bangladesh Council of Scientific and Industrial Research .(Infrared spectra of L-iso-leucine and complex of copper and L-iso-leucine were recorded on a calibrated Fourier transformation IR spectrophotometer (FTIR, 8300, Shimadzu, Japan) in the range of 400-4000 cm^{-1} using KBr pellets. The UV visible spectra of L-iso-leucine (ligand) and L-iso-leucine and copper (complex) were recorded using UV-visible spectrometer, model UV- 800, shimadzu (Japan), in the wavelength range 200-500nm using methanol as solvent. The thermograms were recorded with TGA-50, Shimadzu, Japan. Specular reflectance spectra were recorded using a double beam UV-visible spectrophotometer, (Model: UV-1800, Shimadzu, Japan) with an integrating sphere attachment DRA-CA-30I to determine the optical band gap of the samples. The conductivity of the complexes were studied with a TOA conductivity Meter CM- 55made in Japan.

Synthesis of $Cu(C_6H_{12}NO_2)_2$

The complex was prepared by mixing metal salt solution and neutralized solution of L-isoleucine. About 1 mmol L-isoleucine and 1 mmol sodium bicarbonate were dissolved in water in different beakers. These two solutions were filtered separately and mixed together. The resulted mixture was heated in a waterbath carefully and the solution was concentrated to 20 mL approximately. About 10 mmol metal salt solutions was dissolved in water in another beaker and filtered. The metal salt solution and the concentrated neutralized solution of ligand were mixed. The precipitate obtained was filtered, washed with ethanol and dried over silica gel in a desiccator. The products are stable in light and air. The metal ligand ratio in solid complexes is same as we found in solution state. The formulations of the complexes were done by comparing the experimental and calculated data of elemental analysis. The micro analytical data of C, H, N and Cu content in the prepared complexis given below:

$Cu(C_6H_{12}NO_2)_2$: Calc. (%) : C = 44.50, H = 7.47, N = 8.65, Cu = 19.49 and

Anal. Found (%) : C = 42.11, H = 7.67, N = 8.10, Cu = 17.92

Computational methods

For theoretical calculations, optimization of the equilibrium structures of Cu isoleucine complex was performed by density functional theory employing Becke's (B3)[27] exchange functional combining Lee, Yang, and Parr's (LYP) correlation functional [28]. To account the relativistic effect of transition Cu metal, calculation was conducted by Stuttgart/Dresden (SDD) effective core potential basis set [29]. Frontier molecular orbitals of these complexes were computed at B3LYP/SDD level of theory

for whole complex. All theoretical calculations were implemented by Gaussian 09 software suite [30].

Results and discussion

The formula of the Cu complex of Iso-leucine is $Cu(C_6H_{12}NO_2)_2$. It have been synthesized in aqueous medium. The complex is insoluble in most common organic solvents and water and soluble in methanol. The lattice enthalpy of the complexes may be higher than the salvation energy of the common solvents. The physical appearance of the complex is pink in color. The Melting point data of the complex demonstrates that the complex does not show the sharp melting point. The sharpness of the melting point usually depends on the purity of compound. But sometimes many compounds especially the higher molecular weight compounds decompose to its oxides or some other forms below its melting point. This temperature is known as decomposition point. The observed decomposition temperature of the complex was 265-267 ^oC.

Vibrational frequencies

The appearance of the experimental and calculated IR frequency of the complex demonstrates that the bonding nature of the complex has similarity, with few exceptions, with other amino acids. The computed IR frequency has been visualized and confirmed by Gauss view program [31]. The characteristic experimental and calculated IR frequency of iso-leucine and the complex with tentative assignments are tabulated in Tables X and Y, respectively. Calculated IR spectra of Cu complex is depicted in Figure. In free ligand, a strong broad peak at 3464 cm^{-1} is due to N-asymmetric stretching vibration of $–NH_3^+$ group but in the complex strong peak at 3308 cm^{-1} appears due to asymmetric-H stretching vibrations of $–NH_2$ group. The corresponding calculated asymmetric -NH stretching is appeared at 3568 cm^{-1}.Experimentally, aliphatic C-H stretching vibration is observed with a medium strong sharp peak at2964 cm^{-1} which is similar to the calculated frequency 3056 cm^{-1}. Compare to the experimental medium strong intensity, the calculated intensity of aliphatic C-H stretching is rather weak. Experimental N-H bending vibration appears at 1391 cm^{-1}.The computed N-H bending vibration is relatively higher than the experimental vibrations. Very strong computed peak is appeared for C=O stretching frequency at 1657 cm^{-1} which is nearly same as the experimental frequency at1620 cm^{1}.Most of the important bands in the complex was shifted significantly compare to that of the free ligand which indicate the formation of new compound.

Table 1: Comparison of important IR frequencies of iso-leucine and its complex.

Compound	υ (-NH) str. Cm^{-1} (NH_3^+)	υ (-NH) str.(sym) cm^{-1}(-NH_2)	υ (CH) str. (aliphatic) cm^{-1}	υ (C=O) str. Cm^{-1}	υ (C-H) str. (sym) cm^{-1} (-COO-)	δ (-NH) cm^{-1}
Iso-leucine	3468	-	2969	-	1186	1513
$Cu(C_6H_{12}NO_2)_2$ (expt.)	-	3308	2964	1620	-	1391
$Cu(C_6H_{12}NO_2)_2$ (calc.)	-	3568	3056	1657	-	1688

Ultraviolet-Visible spectra

The experimental electronic absorption spectra of iso-leucine and $Cu(C_6H_{12}NO_2)_2$ complex are given in Fig . Typical carbonyls compounds undergoes an n→π* transition around 280-290 nm. Most n→π* transitions are forbidden and are of low intensity. The ligand shows a strong π→π* absorption at about 221 nm whereas the complex shows a strong π→π* absorption at about 244 nm. The complex shows weak bands at 369 nm which may be attributed to the n→π* transition whereas the ligand shows n→π* transition at 262 nm.

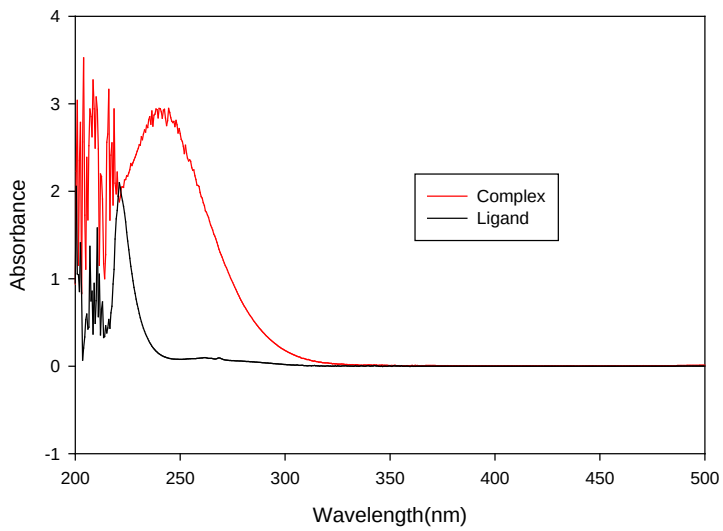

Figure 1. UV-Visible spectrum of $Cu(C_6H_{12}NO_2)_2$ complex and ligand

Thermo Gravimetric Analysis (TGA)

From thermal analysis, the nature of intermediates and final products of the thermal decomposition of coordination compounds can be obtained [32]. The thermogram of $Cu(C_6H_{12}NO_2)_2$ is shown in Fig. and the characteristic features of the decomposition of it is tabulated in Table 2. Thermogravimetric analysis revealed that the complex is accompanied by chemically bounded water or water of crystallization. The pattern of the thermograms also confirms the complexation between metals and iso-leucine.

Table 2.Weight loss recorded at different stages of TGA analysis of iso-leucine and copper iso-leucine complex

Compounds	weight (mg)	TGA analysis		Probable findings
		Total decomposition temperature transition (^{0}C)	% weight loss	
Iso-leucine	6.7	31-139	3.44	may be moisture
		139-380	93.06	organic part may be lost
$Cu(C_6H_{12}NO_2)_2$	4.5	78-128	4.31	H_2O may be lost
		201-275	66.24	organic part may be lost

Specular reflectance spectra analysis

Specular reflectance spectra of iso-leucine and $Cu(C_6H_{12}NO_2)_2$ complex are shown in Figure 2 . From this spectral data band gap energy (Eg) for both iso-leucine and prepared complex, $Cu(C_6H_{12}NO_2)_2$ were calculated by using K–M method. For calculation of band gap energy (Eg) for both iso-leucine and prepared complex, the following Figure 3 was derived from the Figure 2 with the help of equations(1) and (2).

$$f(R) = \frac{(1-R)^2}{2R} \qquad (1)$$

$$(f(R) * h\upsilon) = B(h\upsilon - E_g)^n \qquad (2)$$

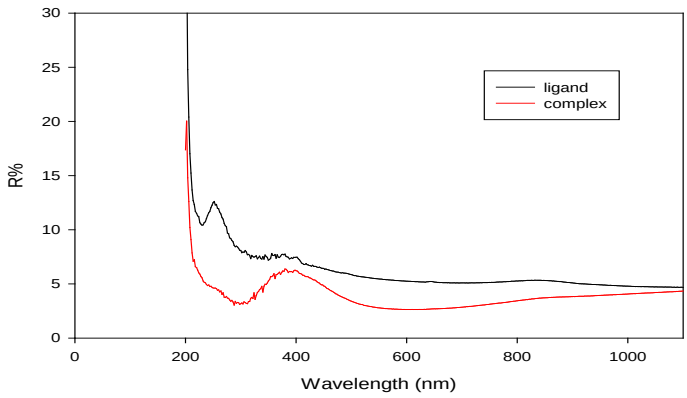

Figure 2. A plot of Reflectance vs wavelength (nm) of iso-leucine and $Cu(C_6H_{12}NO$complex

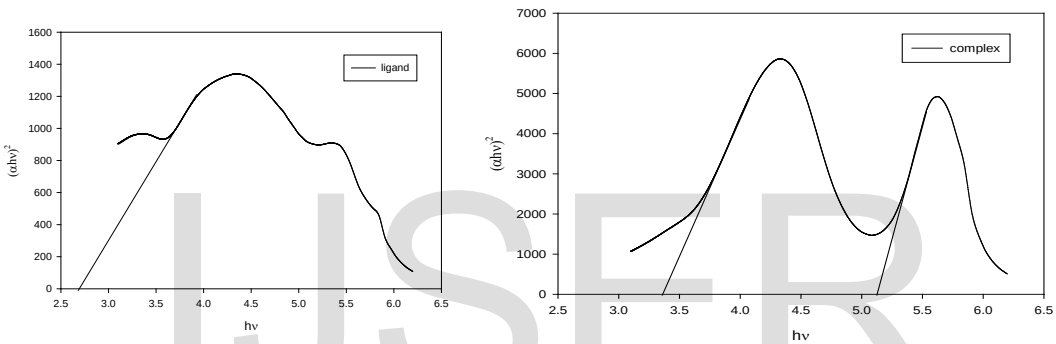

Figure 3. Determination of band gap energy from reflectance spectra: $F(R) = (\alpha h\upsilon)^2$ vs.$E=h\upsilon$ of (a) Iso-leucine and (b) $Cu(C_6H_{12}NO_2)_2$

Reflectance spectra Figure 3 of the ligand and the prepared complex also shows the difference in reflectance between them which also in the favor of the formation of the new complex and the band gap energy increases from ligand to complex so conductivity decreased.

Conductivity measurement

A solution will conduct electricity if it contains ions that are free to move. The ionic solids possess that property when they are in the solution. These solids are called electrolytes and the power of electrolytes to conduct electrical current is termed conductivity. Conductivity is concentration dependent but the measured values for different solutions are not easy to compare directly. For this reason, a quantity called the molar conductivity (or sometimes equivalent conductivity). It measures the

efficiency with which a given electrolyte conducts electricity in solution.From the definition molar conductivity is given by

$$m_{.} = \kappa \times 1000/\ C$$

Where κ is the measured conductivity and M is the number of moles of the electrolytes present in 1000 cm^3 of the solution. The experimental results for specific conductance and molar conductance are listed in Tables 3.

Table 3. Determination of conductance of $Cu(C_6H_{12}NO_2)_2$ at different concentration

Molar concentration C (M) X 10^5	√C	Conductance of methanol σ_E(S) x 10^6	Observed conductance σ_C(S) x 10^6	Corrected conductance $\sigma = (\sigma_C - \sigma_E)$ x 10^6	Specific conductance $K = C_K$ x σ (Scm^{-1}) x 10^6	Molar conductance $\Lambda_m = \frac{1000K}{C}$
0.0309	0.0556		146	143.63	294.3752	48.34
0.0189	0.0430		94.4	92.03	95.7112	51.74
0.6180	0.0249	2.37	36.2	33.83	35.1132	56.93
0.3090	0.0176		19,72	17.35	18.0440	58.39
3.0900	0.0056		6,73	4.36	4.5344	146.74

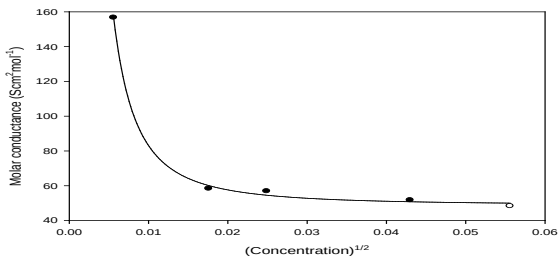

Figure 4. A plot of molar conductance vs $(concentration)^{1/2}$ of $Cu(C_6H_{12}NO_2)_2$

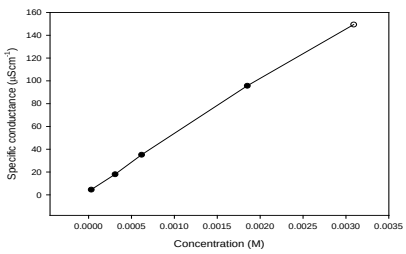

Figure 5. A plot of specific conductance vs concentration of $Cu(C_6H_{12}NO_2)_2$

It is found that with increasing concentration molar conductance decreases for the Cu-isoleucine complex. Therefore, it can be concluded that the complex is a weak electrolyte.

Structure Determination

The optimized structure of the Cu-isoleucine complex was shown in the Figure 6.The bond distance and angle of this complex were summarized in the Table 4 and 5.

Table 4: Bond distances of $Cu(C_6H_{12}NO_2)_2$

Assignment	Bond distance (Å)
Cu(1)-O(43)	1.906
Cu(1)-O(22)	1.906
Cu(1)-N(39)	2.015
Cu(1)-N(19)	2.016
C(24)-O(43)	1.341
C(24)-O(23)	1.248
C(24)-C(25)	1.571
C(25)-N(39)	1.511
C(3)-O(22)	1.341
C(3)-O(2)	1.248
C(3)-C(4)	1.570
C(4)-N(19)	1.511

Table 5: Bond angles of $Cu(C_6H_{12}NO_2)_2$

Assignment	Bond angle
N(19)-Cu(1)-O(43)	95.3
N(39)-Cu(1)-O(43)	84.6
N(39)-Cu(1)-O(22)	95.3
N(19)-Cu(1)-O(22)	84.8
Cu(1)-N(19)-C(4)	107.8
Cu(1)-N(39)-C(25)	107.7
Cu(1)-O(43)-C(24)	116.9

Cu(1)-O(22)-C(3)	116.9

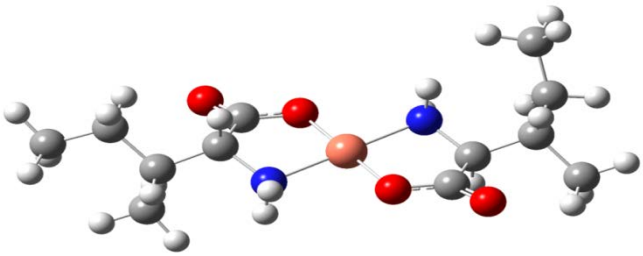

Figure 6. Optimized structure of square planar of the prepared complex calculated at DFT level of theory.

Table 6: Energies (eV) of HOMO and LUMO orbitals of Cu-iso-leucine complex

Molecular orbitals	Energy(eV)
HOMO-3	-7.38
HOMO-2	-7.19
HOMO-1	-6.86
HOMO	-6.44
LUMO	-0.89
LUMO+1	-0.49
LUMO+2	-0.14
LUMO+3	-0.21
HOMO-LUMO gap	5.55

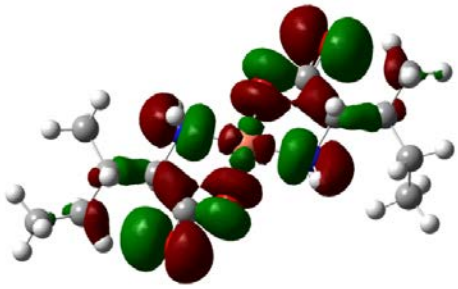

Figure 7. Selected frontier molecular orbital (HOMO) of prepare $Cu(C_6H_{12}NO_2)_2$ complex calculated at B3LYP/SDD level of theory.

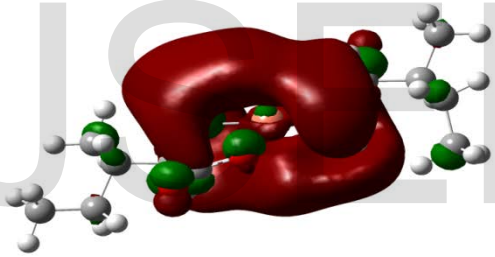

Figure 8. Selected frontier molecular orbital (LUMO) of prepared $Cu(C_6H_{12}NO_2)_2$ complex calculated at B3LYP/SDD level of theory

Theoretical calculation revealed that copper metal formed complexation with one oxygen of COO^- group and one nitrogen of $-NH_2$ group of a ligand. Two iso-leucine ligands are chelated with one copper. The two Cu(1)–O(43)and Cu(1)-O(22)bond distances remain nearly same at 1.906 Å. Interestingly, the N(39)-Cu(1)-O(43)and N(19)-Cu(1)-O(22)angles detected similar to 85˚ whereas N(39)-Cu(1)-O(22)and N(19)-Cu(1)-O(43)angles identified to 95˚. The two C-O bond distances are remained nearly same as 1.3 Å. The two C-N bond distance is obtained same 1.511Å. DFT calculation unveiled that this complex adopted square planar structure. Molecular orbital calculation of this complex performed by B3LYP/SDD level theory. Energies

of the HOMOs and LUMOs orbitals are presented in the Table 6. Frontier orbitals results revealed that the electron density of the HOMO (highly occupied molecular orbital) remains on the d-orbitals of Cu and p orbitals of oxygen and nitrogen of the ligand (Figure 7). However, lowest unoccupied molecular orbital is very diffuse in nature and observed on the delocalized p-orbitals of COO^- and $-NH_2$ groups of the ligand. The HOMO-LUMO gap of this Cu-isoleucine complex is relatively. Kinetic and chemical stability of a molecule can be foreseen from the energy gap between HOMO and LUMO orbitals. Higher HOMO-LUMO gap shows additional kinetic stability, however, in turn it indicates little chemical reactivity. In high gap complex, it is energetically unfavorable to uplift an electron from HOMO to LUMO orbital [33] and to excite a chemical interaction or reaction. The high HOMO-LUMO gap indicated that this complex is kinetically more stable but chemically less reactive.

Conclusion

In this study, a copper complex has been synthesized and characterized by the reaction between Cu(II) nitrate and iso-leucine. In this complex the molar ratio of the metal and ligand (Iso-leucine) is 1:2. The results of the elemental analysis of the complex showed good agreement with the values calculated for the proposed formula. Based on the analytical data, the proposed formula of the complex is $Cu(C_6H_{12}NO_2)_2$. UV-vis and reflectance spectra of the ligand and the complex are similar in nature but the peak positions are different which may be due to the difference in band gap energy between the ligand and the complex which is also in the favor of the formation of the new complex. Theoretical calculation revealed that copper metal formed complexation with one oxygen of COO^- group and one nitrogen of $-NH_2$ group of a ligand. Two iso-leucine ligands are chelated with one copper. Optimized structure of the synthesized $Cu(C_6H_{12}NO_2)_2$ complex is square planar calculated by DFT level of theory.

References

[1] A. S. Binolfi, E. E. Rodriguez, D. Valensin, N. D'Amelio, E. Ippoliti, G. Obal, R Duran, A. Magistrato, O. Pritsch, M. Zweckstetter, G. Valensin, P. Carloni, L. Quintanar, C. Griesinger, C. O. Fernández, Bioinorganic chemistry of Parkinson's disease: structural determinants for the copper-mediated amyloid formation of alpha-synuclein, Inorg. Chem. 49 (2010) 10668–10679.

[2] R. Spezia, G. Tournois, J. Tortajada, T. Cartailler, M.-P. Gaigeot, Toward a DFT based molecular dynamics description of Co(ii) binding in sulfur-rich peptides Phys. Chem. Chem. Phys. 8 (2006) 2040–2050

[3] C.Huber, G.Wächtershäuser, Peptides by activation of amino acids with CO on (Ni, Fe) S surfaces: implications for the origin of life, Science 281 (1998) 670 672

[4] H.Yamazaki, Y.-F. Ueng, T. Shimada, F.P. Guengerich, Roles of divalent metal ions in oxidations catalyzed by recombinant cytochrome P450 3A4 and replacement of NADPH-Cytochrome P450 reductase with other flavoproteins, ferredoxin, and oxygen surrogates, Biochemistry 34 (1995) 8380–8389

[5] H.Yamazaki, Y.-F. Ueng, T. Shimada, F.P. Guengerich, Roles of divalent metal ions in oxidations catalyzed by recombinant cytochrome P450 3A4 and replacement of NADPH-Cytochrome P450 reductase with other flavoproteins, ferredoxin, and oxygen surrogates, Biochemistry 34 (1995) 8380–8389

[6] A. Ganesan, J. Dreyer, F. Wang, J. Akola, J. Larrucea, Density functional study of Cu^{2+}-phenylalanine complex under micro-solvation environment, J. Mol. Graph. Model. 45 (2013) 180–191.

[7] O. Yamauchi, A. Odani, M. Takani, Metal-amino acid chemistry. Weak interactions and related functions of side chain groups, J. Chem. Soc., Dalton Trans. (2002) 3411–3421

[8] J. D. Lee; *Concise inorganic chemistry*, Backwell Science (5thedition), 1996

[9] J. J. Fiol, A. Terr6n, A. M. Calafat, V. Moreno, M. Aguilo, X. Solans, J, (IPCS, 1991).Inorg. Biochem., 35, 191,1984

[10] B. Rosenberg, L. Van Camp, T. Krigas, Inhibition of cell division in Escherichia coli by electrolysis products from a platinum electrode, Nature 205 (1965) 698–699.

[11] W. Liu, R. Gust, Metal N-heterocyclic carbene complexes as potential antitumor metallodrugs, Chem. Soc. Rev. 42 (2013) 755–773.

[12] F. Arjmand, S. Parveen, S. Parveen, M. Afzal, Chemistry & biology interface, Chem. Biol. 3 (2013) 137–145.

[13] F. Cisnetti, A. Gautier, Metal/N-heterocyclic carbene complexes: opportunities for the development of anticancer metallodrugs, Angew. Chem. Int. Ed. 52 (2013) 11976–11978.

[14] D. Castanotto, J.J. Rossi, The promises and pitfalls of RNA-interference-based therapeutics, Nature 457 (2009) 426–433

[15] J. Zhuang, C.-H. Kuo, L.-Y.Chou, D.-Y.Liu, E. Weerapana, C.-K.Tsung.

Optimized metal-organic-framework nanospheres for drug delivery: evaluation

Of small molecule encapsulation, ACS Nano (2014)

[16] Z. Du, Z. Shao, Combining transition metal catalysis and organocatalysis – an update, Chem. Soc. Rev. 42 (2013) 1337–1378.

[17] Z.J. Wang, K.N. Clary, R.G. Bergman, K.N. Raymond, F.D. Toste, A supramolecular approach to combining enzymatic and transition metal catalysis, Nat. Chem. 5 (2013) 100–103.

[18] C.K. Prier, D.A. Rankin, D.W. MacMillan, Visible light photo redox catalysis with transition metal complexes: applications in organic synthesis, Chem. Rev. 113 (2013) 5322–5363

[19] Y. Brunsch, A. Behr, Temperature-controlled catalyst recycling in homogeneous transition-metal catalysis: minimization of catalyst leaching, Angew. Chem. Int. Ed. 52 (2013) 1586–1589.

[20] A. Yella, H.-W. Lee, H.N. Tsao, C. Yi, A.K. Chandiran, M.K. Nazeeruddin, E.W.-G.Diau, C.-Y.Yeh, S.M. Zakeeruddin, M. Grätzel, Porphyrin-sensitized solar cells with cobalt (II/III)-based redox electrolyte exceed 12 percent efficiency, Science 334 (2011) 629–634

[21] B. O'regan, M. Grfitzeli, A low-cost, high-efficiency solar cell based on dye sensitized, Nature 353 (1991) 737–740.

[22] M. A. Halim, Harnessing sun's energy with quantum dots based next generation solar cell, Nanomaterials 3 (2012) 22–47.

[23] E. Baggaley, J.A. Weinstein, J. Williams, Lighting the way to see inside the live cell with luminescent transition metal complexes, Coord. Chem. Rev. 256 (2012) 1762–1785

[24] Q. Zhao, C. Huang, F. Li, Phosphorescent heavy-metal complexes for bioimaging, Chem. Soc. Rev. 40 (2011) 2508–2524.

[25] Nelson, D. L.; Cox, M. M. "Lehninger, Principles of Biochemistry" (3rd Edition) Worth Publishing: New York, 2000.

[26] Brij Bhushan Tewari, Department of Chemistry, Facultry of Natural Sciences, University of Guyana.

[27] Becke, J. Chem. Phys. 98, 1372-77, A.D.1993.

[28] Lee, C., Yang, W., Parr, R.G., Phys. Rev. Sect B 37, 785–789, 1988.

[29] Andrae, D., Häussermann, U., Dolg, M., Stoll, H., Preuss, H., 1990. Theor. Chim, Acta 77, 123–141, 1990.

[30] M. J. Frisch et al., Gaussian 09, Revis. A. 02, 2009.

[31] T.A.K.R.D. Dennington II, J.M. Millam, GaussView 5.0, Wallingford, CT, 2009.

[32] A.M. Khedr, H.M. Marwani, Synthesis, spectral, thermal analyses and molecular modeling of bioactive Cu(II)-complexes with 1,3,4-hiadiazole Schiff base derivatives. Their catalytic effect on the cathodic reduction of oxygen, Int. J. Electrochem. Sci. 7 (2012).

[33] MM Hoque, MA Halim, MM Rahman,MI Hossain, MW Khan, J MolStruct 1054–1055:367–374, 2013.