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Synthesis, Coordination behavior, pH-titration and Antimicrobial Activity Studies of Ternary Co(II) Complexes of Girard T and Glycine Oligopeptides

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The new synthesized compounds were characterized using; spectral (mass, IR, UV–Vis, XRD) and analytical (elemental, molar conductance and magnetic moment measurements) tools. The geometrical structures of Co(II) complexes were found to be in tetrahedral configuration. SEM/EDX/TEM images showed nano-sized particles and identical distribution over the complex surface. The catalytic activities of the divalent cobalt complexes have been studied in the oxidation of cyclohexane, using environmental friendly oxidant, hydrogen peroxide. Complex with rough surface has shown higher catalytic activity compared to the other complexes. The antibacterial activity of these complexes has been evaluated. Potentiometric titration technique has been used to determination of stability constants of Co (II) with girard T (GT) and glycine oligopeptides (L) complexes in aqueous solutions at 25 °C and 0.1M ionic strength. The ternary complexes of Co(II) are formed by stepwise mechanism and the concentration distribution of the complexes is evaluated.

Keywords: Synthesis, Characterization, pH-titration, Ternary complexes, *Girard T*, antimicrobial activity

1. INTRODUCTION

Girard's reagents have been for a long time used in organic chemistry for the purpose of separating carbonyl compounds from various complex mixtures in the form of water soluble hydrazones[1]. Among them, Girard-T. The interest in the complexes of these reagents and their hydrazones, which, like the other Schiff bases, contain two or more ligating atoms, is of a more recent date. In the known complexes involving hydrazones of Girard's reagents, the bidentate[2-4], or more

frequently, tridentate[5-8] character has been assigned mostly on the basis of spectral data. Girard-T complexes of divalent metal ions M(II) have been reported in solid state[9], but it's in aqueous solutions are very few . Such complexes are very interesting from both the chemical and biological point of view[10]. In this study we report the synthesis, characterization and biological activity of the ternary complexes involving Co(II), Girard T (GT) and oligopeptides (L). Solution equilibria of the systems [Co(II)–GT–L] have been studied pH-metrically at (I = 0.1M $NaClO_4$ -25°C). GT ligand and its complexes were characterized by several techniques. The antibacterial activity of the investigated complexes was tested against *E. coli, K. pneumonia, P. fluorescence* as (Gram -ve), and *B. subtilis,S. pyogenes, S. aureus* as (Gram +ve).

2. EXPERIMENTAL

2.1. Materials and reagent

All chemicals used were of guaranteed grade and used without further purification. Girard-T (GT) and $CoCl_2$. $6H_2O$ were provided by Aldrich Chem. The ligands used were diglycine, triglycine, tetraglycine, glycinamide and glutamine. These materials were obtained from Sigma Chemicals. The ionic strength (/) of the sample solutions was adjusted to 0.1 M with $NaClO_4$. Carbonate-free NaOH (titrant) was prepared and standardized against potassium hydrogen phthalate solution. All solutions were prepared in deionized water.

2.2. Synthesis

The binary complex of Co(II) with GT was prepared in a molar ratio 1:1 by adding (5 mmole) of $CoCl_2 \cdot 6H_2O$ dissolved in ethanol (~ 20 ml) to (10mmole) of Gt dissolved in (20 ml ethanol + 10 ml water). The reaction mixture was refluxed on a water bath for 2 hrs. The precipitate was obtained by filtration followed by washing with 50% ethanol-water (v/v) to remove any traces of the unreacted starting materials. Finally, the complex was washed with diethylether and then dried in oven at 100 °C for 2hrs. The ternary complexes of Co(II) with GT and oligopeptides (L)were prepared in two steps. The first step was prepared by adding (5 mmole) of [Co(II)-Gt] complex dissolved in water (~ 25ml) to (10 mmole) of oligopeptides namely (diglycine, triglycine and tetraglycine) in a molar ratio 1:2. The reaction mixture was refluxed for 2hrs. The isolated solid complexes were obtained by filtration and washed with 50% (v/v) ethanol-water. The second step was prepared in a molar ratio 1:1:1 using the same above procedure. The dried complexes were subjected to elemental and spectroscopic analysis.

Analytical data

Complex 1: [$C_9H_{20}CoN_5O_4$]: Yield-55%, dark blue, m.p. above 300ºC, **Calc**. *C, 33.65; H, 6.28; Co, 18.35; N, 21.80;* **Found** *C, 33.65; H, 6.28; Co, 18.32; N, 21.76*; Molecular Weight: 321.22[molecular ion peak m/z =321]; ^M = 6.28, μ_{eff} = 5.02 B.M.

Complex 2: [$C_{11}H_{23}CoN_6O_5$]: Yield-62%, dark blue, m.p. above 300ºC, **Calc**. *C, 34.93; H, 6.13; Co, 15.58; N, 22.22;* **Found** *C, 34.88; H, 6.11; Co, 15.54; N, 22.18*; Molecular Weight: 378.27[molecular ion peak m/z =378]; ^M = 8.26, μ_{eff} = 5.12 B.M.

Complex 3: $[C_{13}H_{26}CoN_7O_6]$: Yield-77%, dark blue, m.p. above 300ºC, **Calc**. *C, 35.87; H, 6.02; Co, 13.54; N, 22.52;* **Found** *C, 35.74; H, 5.97; Co, 13.48; N, 22.48*; Molecular Weight: 435.32[molecular ion peak m/z =435]; ^M = 12.57, μ_{eff} = 5.03 B.M.

Complex 4: $[C_7H_{18}CoN_5O_2]$: Yield-54%, dark blue, m.p. above 300ºC, **Calc**. *C, 31.95; H, 6.89; Co, 22.39; N, 26.61;* **Found** *C, 31.92; H, 6.81; Co, 22.33; N, 26.56*; Molecular Weight: 263.18[molecular ion peak m/z =263]; ^M = 12.07, μ_{eff} = 5.09 B.M.

Complex 5: $[C_{10}H_{22}CoN_5O_4]$: Yield-59%, dark blue, m.p. above 300ºC, **Calc**. *C, 35.83; H, 6.61; Co, 17.58; N, 20.89;* **Found** *C, 35.78; H, 5.98; Co, 17.55; N, 20.82*; Molecular Weight: 335.25[molecular ion peak m/z =335]; ^M = 17.26, μ_{eff} = 5.07 B.M.

2.3. Physical Measurements

The percentage of the element contents were estimate as given in the book [11]. IR spectra (KBr) were recorded on a FTIR Spectrum BX-II spectrophotometer. A Shimadzu GV-5050 mass spectrometer was used to measure the electron ionization mass spectra (EI-MS) of all compounds by Electron Spray Ionization (ESI) technique. The electronic spectra of the complexes in UV–Vis region were obtained in DMSO solutions using a Shimadzu UV-1601 spectrophotometer in the range of 200–800 nm. Magnetic susceptibility measurements were computed on a modified HertzSG8-5HJ model Gouy magnetic balance using $CuSO_4.5H_2O$ as the calibrant. Molar conductance was measure on ELICO (CM82T) conductivity bridge. XRD were recorded on XPERT PRO PAN analytical X-ray powder diffraction. Scanning electron microscopy (SEM) images were taken in Quanta FEG 250 equipment. Using Joel JSM-6390 equipment, transmittance electron microscopy (TEM) pictures were taken. Oxidative addition reactions were measure on Hewlett–Packard gas chromatography (HP 6890) having FID detector. The antimicrobial activity was carried out at Bab-Al-Sheria University Hospital at Al-Azhar Microbiology Laboratory University.

2.4. Potentiometric Procedure and Measurements

The pH-measurements were performed with a Metrohm 686 titroprocessor equipped with a 665 Dosimat (Switzerland-Herisau). The electrode was calibrated with standard buffer solutions prepared according to NBS specifications[12]. The pH meter readings were converted in to hydrogen ion concentration by titrating a standard acid solution (0.1M), the ionic strength of which was adjusted to 0.1 M ($NaClO_4$) with a standard base solution (0.1 M) at 25°C.

The acid dissociation constants of the ligands were determined potentiometrically by titrating the ligand (40 ml) solution (1.25×10^{-3} M) of constant ionic strength 0.1 M, adjusted with $NaClO_4$.

The starting solutions for each titration of the binary system were prepared by the successive addition of known volumes of 1.25×10^{-3} M Co(II) and GT or L solution in the 1:1 and 1:2 metal-to-ligand molar ratios. The stability constants of mixed ligand complexes were determined by titrating 40 ml of solution containing Co(II), GT and L, all of concentration (1.25×10^{-3} M) and 0.1 M $NaClO_4$.

Stability constants were calculated by the computer program HYPERQUAD [13]. Trial values of the log *β*'*s* of the ternary complexes were refined while the constants pertaining the ligand protonation and binary Co(II) complexation were held constant. For each system, the data from different titrations were treated together. Distribution diagrams for the various systems were calculated and plotted by the program HYSS[13], the computed result is more precise and reliable.

The general four component equilibrium can be written as follows (charges are omitted for simplicity).

$$l(M) + p(GT) + q(L) + r\,(H) \rightleftharpoons (M)_l\,(GT)_p\,(L)_q\,(H)_r \quad (1)$$

$$\beta_{lpqr} = \frac{[M_l (GT)_p (L)_q (H)_r]}{[M^l (GT)^p (L)^q (H)^r]} \quad (2)$$

M, GT, L, and H denote Co(II), Girard T, oligopeptides and proton, respectively.

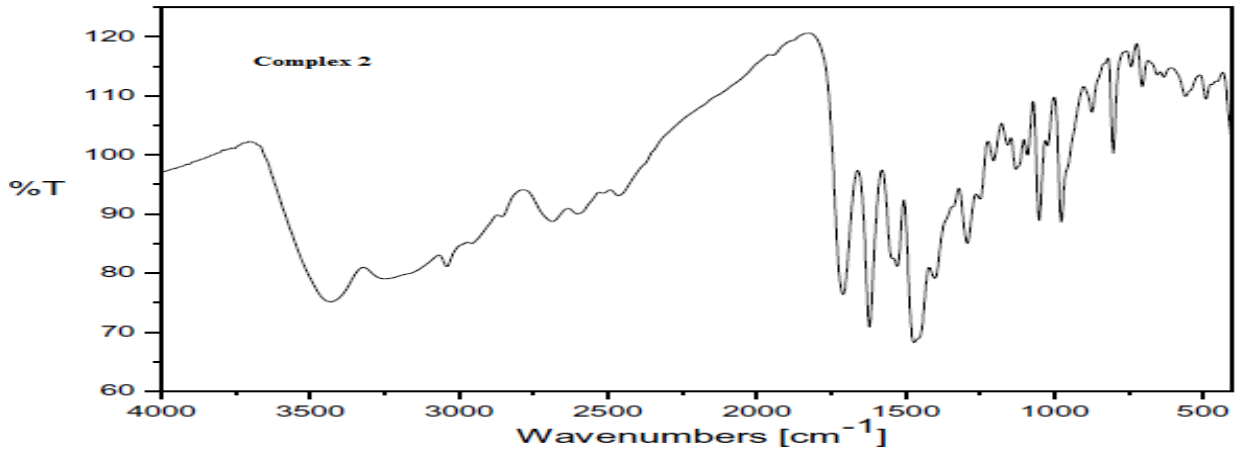
3. RESULTS AND DISCUSSION

Gerard T (GT) reacted with Co(II) in ethanol at room temperature to form a solid complexes with a characteristic color of the ligand. The complex formation of Co(II) complexes synthesized is M: GT: L=1:1:1 [L=diglycine, triglycine, tetraglycine, glycinamide and glutamine] which was indicated from the results of the chemical analysis. The molar conductivities Λ_m (Ω^{-1} cm^2 mol^{-1}) values of Gerard T and metal complexes (DMSO-d_6) with standard reference using $1x10^{-3}$ mol concentration solutions were found at 6.28- 17.26 Ω^{-1} cm^2 mol^{-1} which showed that all complexes are non-conductive in nature [15].

3.1. Spectroscopic studies

3.1.1. IR absorption spectra

The IR spectra of Gerard T and its complexes (Scheme 1; Figure 1) were recorded as KBr disks. The bands at 1722 and 1622 cm^{-1} correspond to $\nu(C=O)_{car}$ and $\nu(C=O)_{pyr}$, respectively.



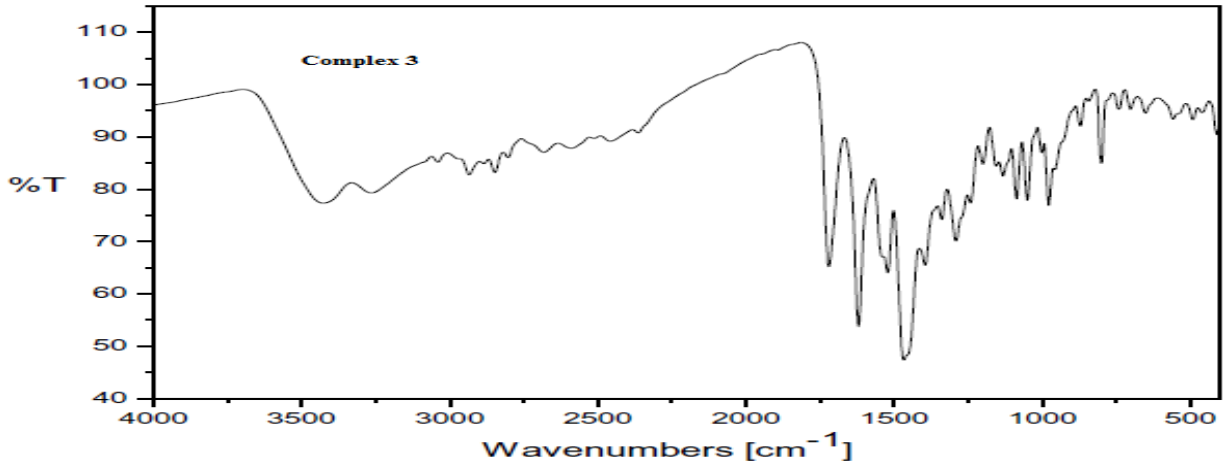
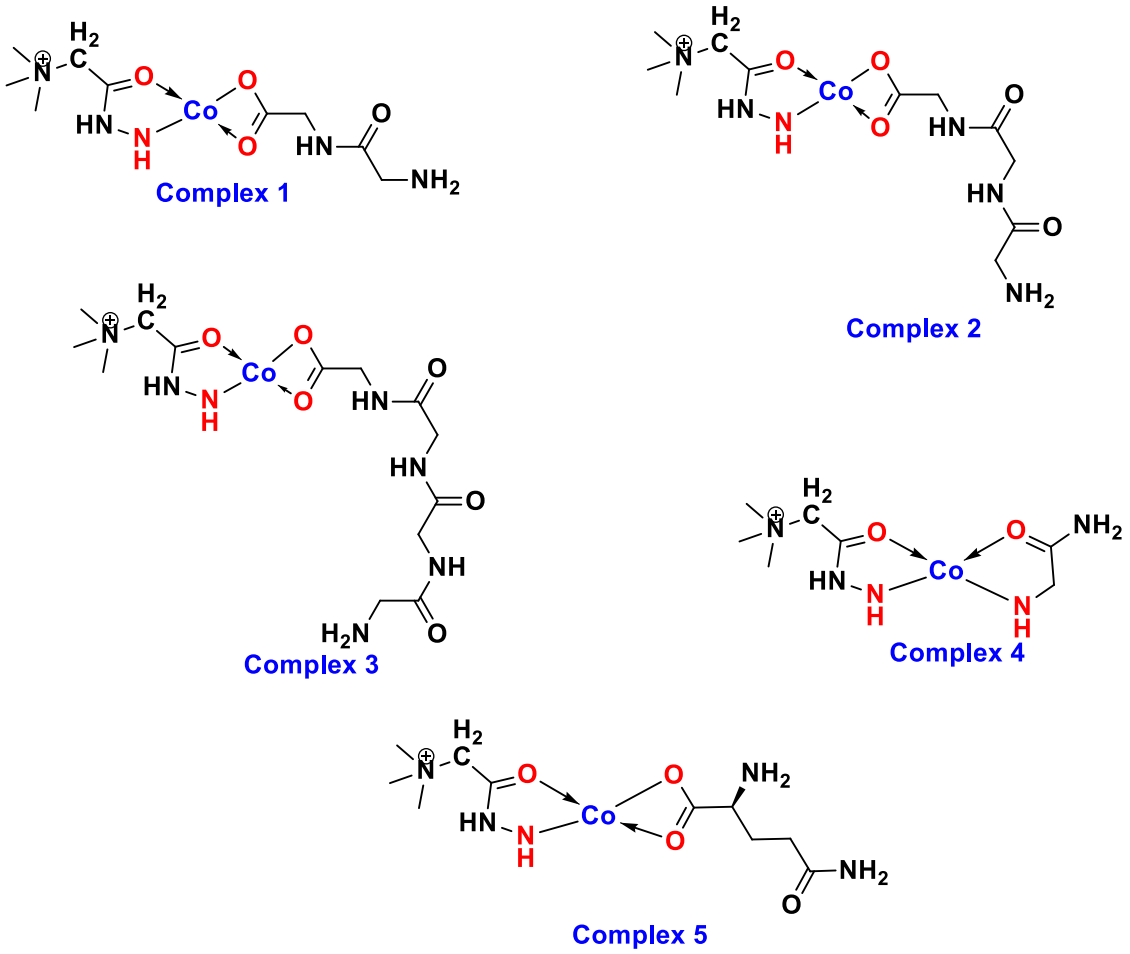


Figure 1. Infrared spectra of (1) [Co GT-(diglycine)]; (2) [Co GT-(triglycine)] and (3) [CoGT-(tetraglycine)] complexes 1–3.

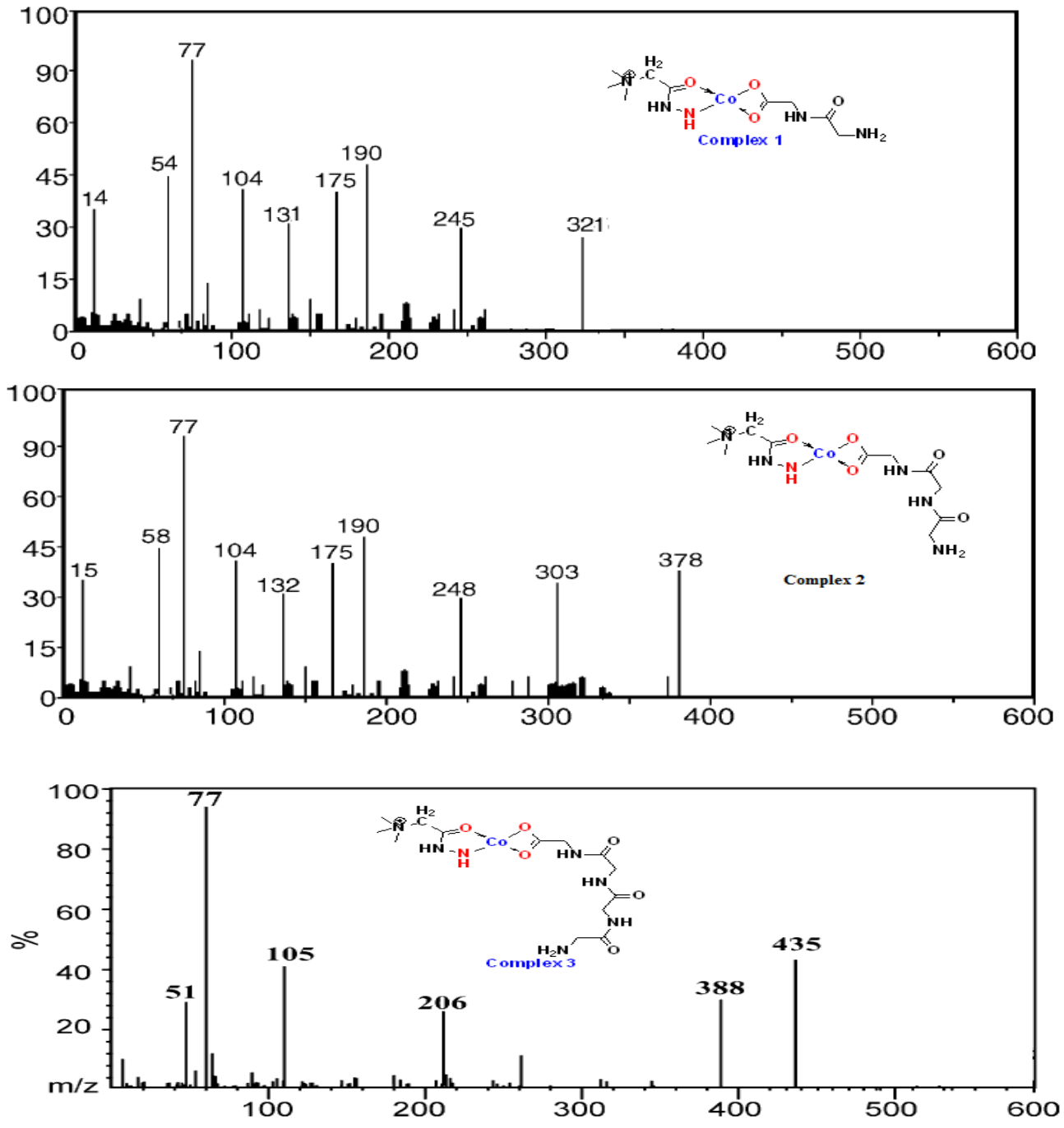


Scheme 1. The coordination mode of Co(II) complexes (1-5).

The observed band at 1722 cm^{-1} corresponding to $\nu(C{=}O)_{car}$ is disappeared in all Co(II) complexes which indicate interaction of COO^- group with metal ion. Bidentate COO^- complexes

exhibit Δv values above 200 cm^{-1} [$\Delta v=v_{as}(COO^-)-v_s(COO^-)$] [16-20]. The observed Δv.is observed between 255-215 cm^{-1}, suggesting a monodentate interaction of COO^- group. The band at 1622 cm^{-1} responsible for $\nu(C=O)_{pyr}$ in Gerard T is observed between 1595 and 1525 cm^{-1} in case of Co(II) complexes[21-23]. On the other hands, the observed medium bands between 630 – 469cm^{-1} correspond to ν(M-O), ν(M-N), respectively.

3.1.2. Mass spectral analysis



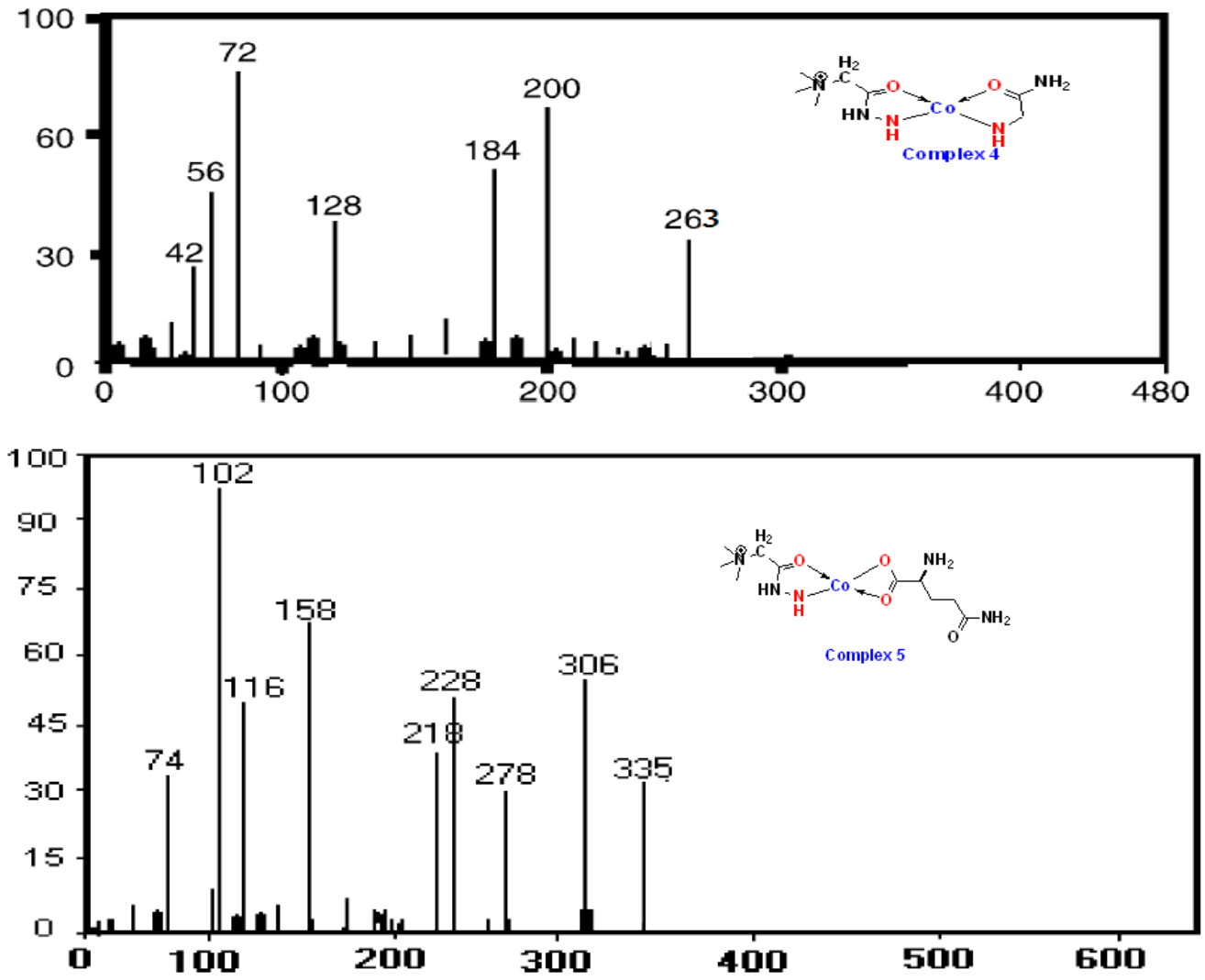


Figure 2. Electron-impact mass spectra of the complexes (1-5).

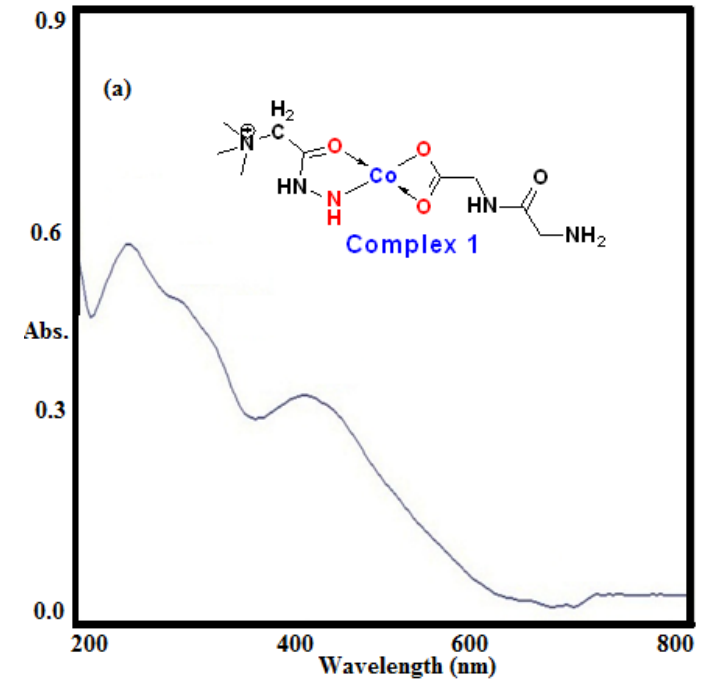
The mass spectra of Co(II) complexes (Fig. 2) have been recorded. The mass spectra give *m/z* at 321 for [Co-GT-diglycine] (1), *m/z* at 378 for [Co-GT-triglycine] (2), *m/z* at 435 [Co-GT-tetraglycine] (3), *m/z* at 263 [Co-GT-glycinamide] (4) and *m/z* at 335 [Cu-GT-glutamine] (5). These data in good guide with the molecular formula for these prepared GT complexes.

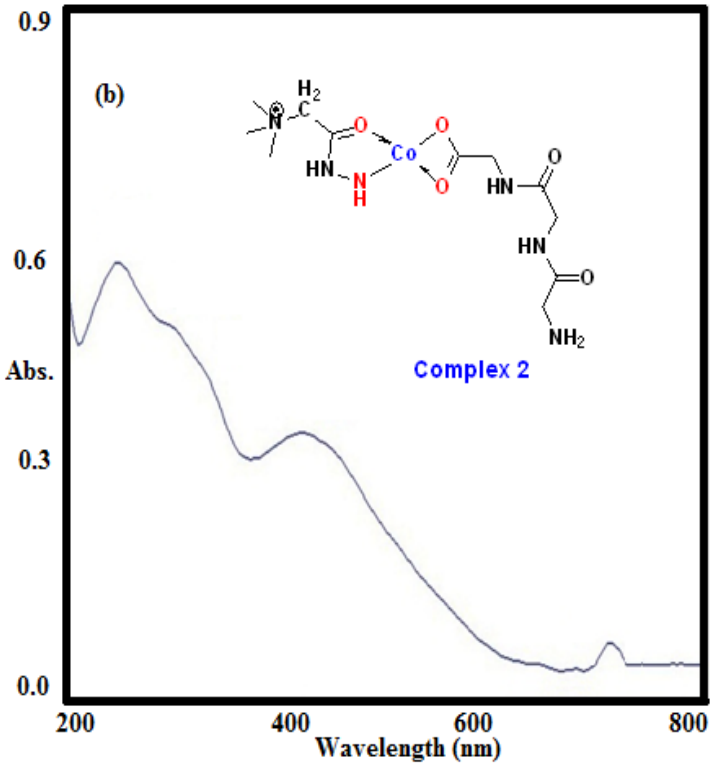
3.1.3. Magnetic moments and electronic spectra

The magnetic moments for the cobalt(II) complexes are shown in experimental part. The magnetic moments of the cobalt(II) complexes at 5.12-5.02 μB, which suggest tetrahedral geometry for cobalt(II) complexes [24,25]. For tetrahedral cobalt(II) complexes, the state acquires orbital angular momentum only indirectly through the mixing of the $^4T_2$ state by a spin–orbit coupling perturbation.

Gerard T showed bands at 47,169 and 45,454 cm^{-1} which are assigned to π-π^* transitions these bands are shifted in complexes at 49,454-33,558 cm^{-1}, also Gerard T showed another band at 2,9673 cm^{-1} which is assigned to n-π^* transitions and is shifted in Co(II) complexes at 32,467-25,906 cm^{-1}.

Gerard T complexes (Figure 3) showed new bands at 23,419-17,730 cm^{-1} which can be assigned to L→M CT [26,27], all these data are listed in Table 1.





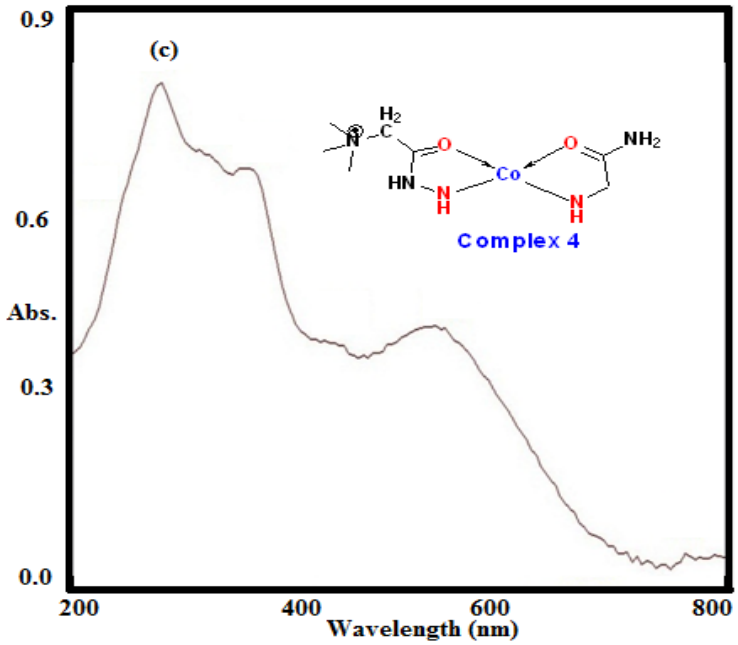


Figure 3. Electronic reflection spectra of (a) [Co-GT-diglycine], (b) [Co-GT-triglycine] and (d) [Co-GT- glycinamide] complexes.

Table 1. UV-Vis. Spectra of Gerard T ligand and its Co(II) complexes (1-5).

Assignments (cm^{-1})	GT	GT complexes				
		Complex 1	Complex 2	Complex 3	Complex 4	Complex 5
π- π* transitions	47,169	47,348	49,454	35,697	33,558	41,259
n- π* transitions	2,9673	32,467	29,476	25,587	30,308	28,287
Ligand-metal charge transfer	-	23,419, 18,747	21,478 17,730	23,009, 17,030	23,204, 17,775	22,978, 17,989

3.1.4. X-ray diffraction and TEM micrographs

Single crystals of the complexes could not be prepared to get the XRD and hence the powder diffraction data were obtained for structural characterization. Structure determination by X-ray powder diffraction data has gone through a recent surge since it has become important to get to the structural information of materials, which do not yield good quality single crystals. The indexing procedures were performed using (CCP4, UK) CRYSFIRE program [28-30] giving tetragonal crystal system for [Co-GT-diglycine] (Fig. 4a) having M(9) = 13, F(6) = 7, cubic crystal system for [Co-GT-triglycine] (Fig. 4b) having M(6) = 12, F(6) = 6 and tetragonal crystal system for [Co-GT-tetraglycine] (Fig. 4c) having M(6) = 18, F(6) = 7, as the best solutions. Their cell parameters are shown in Table 2.

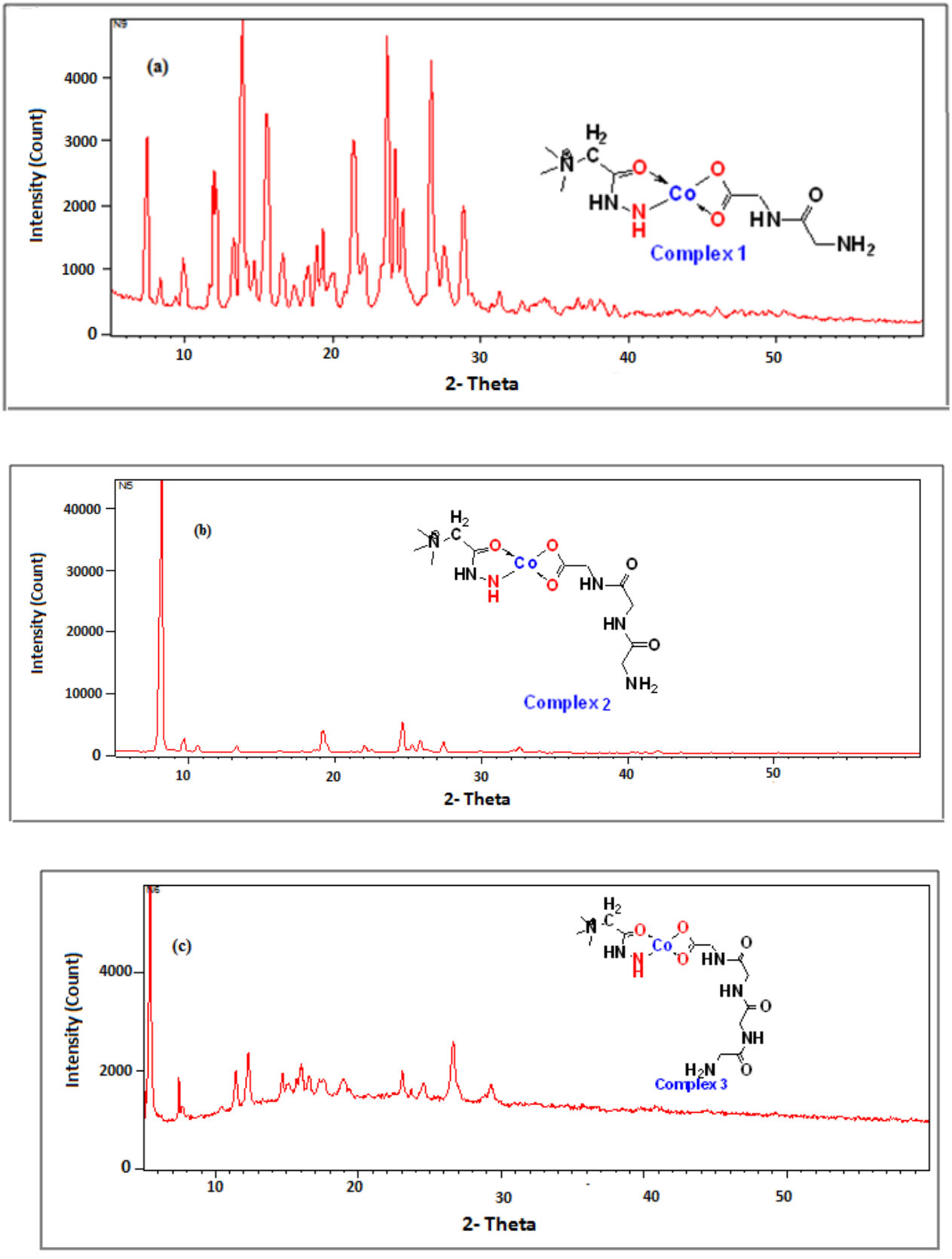


Figure 4. Powder XRD spectra of (a) [Co-GT-diglycine], (b) [Co-GT-triglycine] and (c) [Co-GT-tetraglycine] complexes (1-3).

Table 2. Crystallographic data for the Schiff base complexes [Co-GT-diglycine], [Co-GT-triglycine] and [Co-GT-tetraglycine].

Data	[Co-GT-diglycine]	[Co-GT-triglycine]	[Co-GT-tetraglycine]
Empirical formula	$CoC_9H_{20}N_5O_4$	$CoC_{11}H_{23}N_6O_5$	$CoC_{13}H_{26}N_7O_6$
Formula weight(g/mol)	321.22	378.27	435.32
Wavelength(Å)	1.49997	1.49988	1.51999
Crystal system	Tetragonal	Cubic	Triclinic
Space group	P4/m	P4/m	P4/m
Unit cell dimensions(Å)			
a(Å)	8.200349	16.1053	7.301454
b(Å)	8.200416	16.1052	7. 301454
c(°)	16.02300	16.1052	7. 301454
α(°)	90	90	90
β(°)	90	90	90
γ(°)	90	90	90
Volume ($Å^3$)	1010.54	5187.25	758.69
(Calc.) density (g/cm^{-3})	1.92575	1.23	1.94
2θ range	13.47–55.84	16.24–63.96	12.98–67.84
Limiting indices	0≤h≤2, 0≤k≤2, 1≤2≤8	3≤*h*≤12, 1≤*k*≤7, 3≤*l*≤12	3≤*h*≤7, 2≤*k*≤7, 0≤*l*≤3
Z	3	8	7
*R*f	0.0000824	0.000038	0.0000689
Temperature (K)	298	298	298

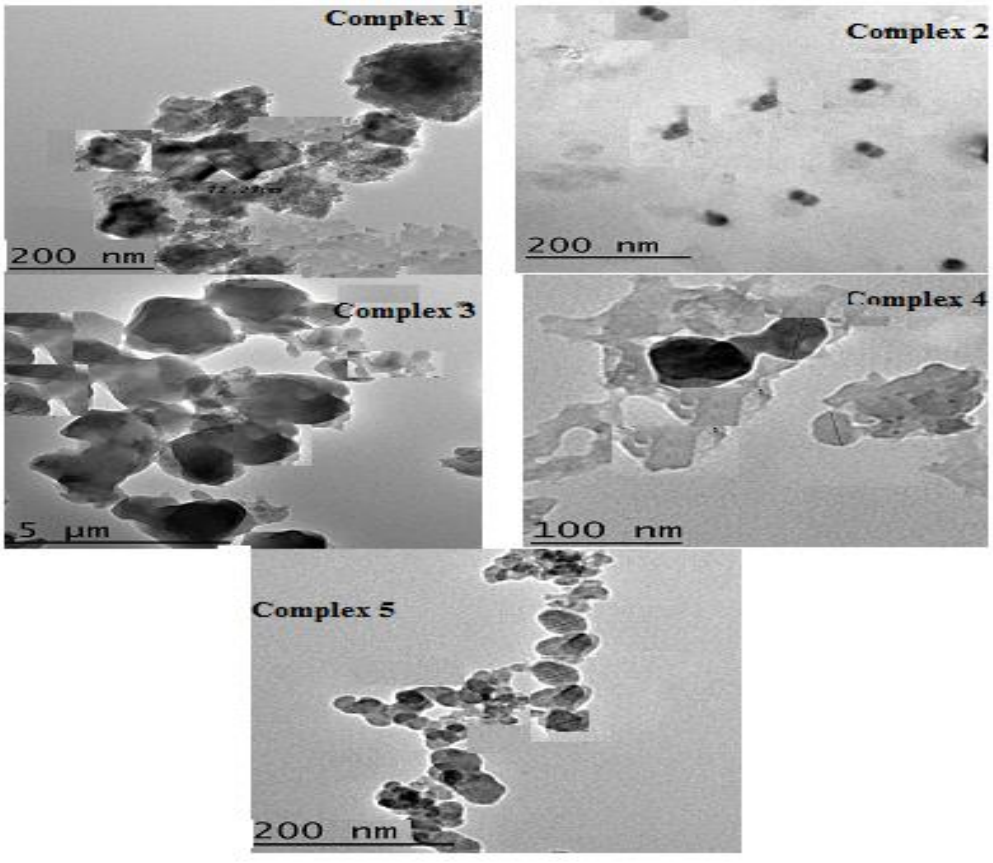


Figure 5. TEM images for Co(II) complexes (1-5).

Although, the amorphous attitude reflects the infinite small size for the aggregates which may be found comfortably in nanometer range this verified through TEM analysis. TEM is a broad implemented method used to discuss the particle shape and size for solid matrix. High settlements images were observed (Fig. 5). The micrographs introduce diverse particle shapes in nano-crystalline matrixes. The rocky shape is the main feature for free ligand and complex (5). This attitude proposes the adaptable accumulation for the particles. Micrographs of complexes (3 and 4) represent their nanometer features by a clear cubic like crystal shapes. Micrographs of complexes (1and 2) display clear homogenous matrixes with a distinct isolation for spherical particles in nanometer range. This attitude point to essential rule for the presence of metal ions on yielding nanometer particles [31]. The highly symmetric spherical anions occluded in complexation sphere may lead to the spherical feature appeared in images. Also, may be expressed by the distinct accumulation of several individual particles in polycrystalline nature. The dark areas in micrographs, may point to the aggregation of condensed fine particles. The nanometer sizes may enhance the biological activity with regard to bulk analogue. This property may simplify the permeability through infected cell membrane.

3.1.5. SEM and EDX spectra

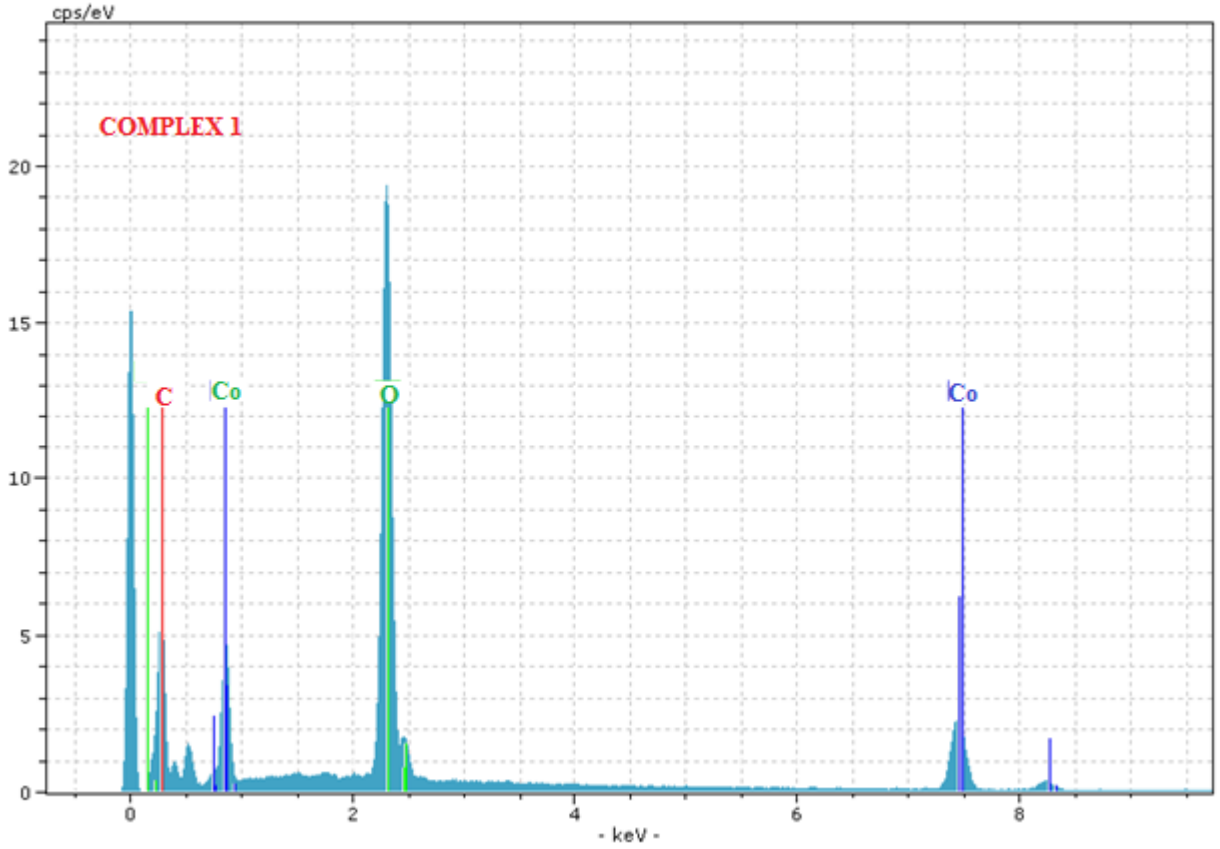


Figure 6. SEM and EDX spectrum of [Co-GT-diglycine] complex.

A representative scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDX) analysis results of the residue obtained from thermal decomposition of Co(II) complexes (1-5) are shown in Fig. 6. The [Co-GT-diglycine] complex shows bar like structure. The EDX spectra show that the residues majorly consist of metal (cobalt) and oxygen with some traces of sulfur.

3.1.6. Catalytic activity

The catalytic activity of cyclohexane oxidation was performed over the five synthesized complexes at room temperature (RT) and 70 ºC for 8 and 12 h. The complexes have not showed any conversion of cyclohexane to cyclohexanol and cyclohexanone at RT. Though all synthesized complexes have not yielded any product at RT, cyclohexane conversion can be achieved at particular temperature which is almost close to the boiling point of the reactant. The cyclohexane boiling point is ~79 ºC and thus the reaction temperature fixed at 70 ºC.

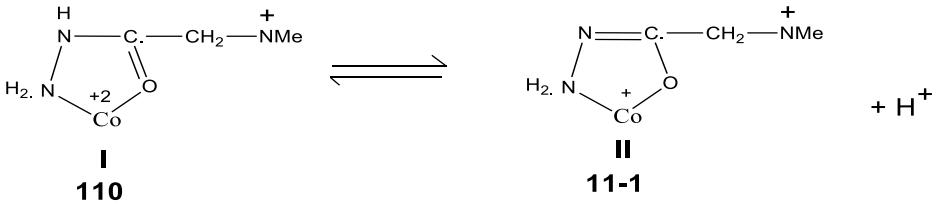
3.2. pH titrations

The acid dissociation constants of the glycine oligopeptides ligands and the formation constants of their binary complexes were previously reported [32]. We have redetermined these constants under

the prevailing experimental conditions as those utilized for determining the stability constants of the mixed-ligand complexes. In Table 3 and 4 are tabulated the values of the stability constants for the ternary species, together with the proton-association constants of the ligands and the stability constants of the binary complexes, most of which are taken from the formation and decay process of the 110 species.

The calculated acid dissociation constants expressed as pK_a values are amounting to 9.71 and 2.80. The highest pK_a value might be due to the dissociation of the proton in the methylene group located between a carbonyl and a quaternary ammonium group in view of the electron attracting effect of the quaternary ammonium group [33]. On the other hand, the lowest pK_a value may plausibly correspond to the protonated amino group.

The potentiometric data of the Co(II)-GT system provide a good fit assuming the formation of the species 110, 120 and 11-1 species. The stability constants of their complexes are given in Table 3. Previous studies[33] on related systems favoured the occurrence of structure (I) for 110 complex and reported the following scheme for acid dissociation from 110 complex yielding structure (II) which is referred to as 11-1 (Scheme 2).



Scheme 2. Binary complex of the Girard-T

The potentiometric data of the [Co(GT)]-L system were fitted by various models. The most acceptable model was found to be consistent with the formation of the complexes with stoichiometric coefficients 110 and 11-1according to eq. (3) and (4).

$$Co(GT) + L \rightleftharpoons [Co(GT)(L)] \quad (3)$$

$$[Co(GT)\,L] \rightleftharpoons [Co(GT)\,L\,H_{-1}] + H^+ \quad (4)$$

Charges are omitted for simplicity

In the 110 case, the peptide is bound through the amino and carbonyl oxygen groups. On increasing the pH, the coordination sites should switch from the carbonyl oxygen to the amide nitrogen. Such a change in coordination centres is now well documented [34,35].The pK_a values are calculated by the following equation:

$$pK_a = log\ \beta_{110} - log\ \beta_{11\text{-}1} \quad (3)$$

The p*K*a values of the amide group incorporated in the Co(GT) complex are in the range of 1.8– 4.86.The p*K*a of the glutamine complex is exceptionally higher than those for the other peptide complexes. This is ascribed to the formation of a seven-membered chelate ring which is more strained and therefore less favoured. While the glycinamide complex is lower than the p*K*a values of other peptides. This signifies that the more bulky substituent group on the peptide may serve to hinder the structural change in going from the protonated to deprotonated complexes. Therefore, under

physiological conditions (pH≈7.4) glutamine would coordinate in its protonated form, whereas glycinamide would preferably coordinate in the deprotonated form.

Table 3. The acid dissociation constants of the ligands and the formation constants of the binary complexes in the Co(II)- *GT* or oligopeptides systems at 25°C and 0.1 M ionic strength.

System	***l***	***p***	***q*** [a]	***logB*** [b]
Girard-T (GT)	0	1	1	9.71(0.006)
	0	1	2	12.51(0.01)
	1	1	0	10.62(0.01)
	1	2	0	14.92(0.05)
	1	1	-1	1.94(0.05)
Diglycine	0	1	1	3.21(0.05)
	0	1	2	8.13(0.03)
	1	1	0	5.70(0.02)
	1	1	-1	0.65(0.03)
	1	1	-2	- 4.66(0.03)
Triglycine	0	1	1	3.27 (0.03)
	0	1	2	7.96 (0.02)
	1	1	0	5.22 (0.00)
	1	1	-1	0.65 (0.04)
	1	1	-2	-7.32 (0.03)
Tetraglycine	0	1	1	3.24 (0.03)
	0	1	2	7.97 (0.01)
	1	1	0	5.33(0.04)
	1	1	-1	-1.32(0.02)
	1	1	-2	- 7.32(0.01)
Glutamine	0	1	1	8.95(0.01)
	1	1	0	8.50(0.01)
	1	1	-1	-1.58(0.02)
Glycinamide	0	1	1	7.61(0.01)
	1	1	0	4.89(0.01)
	1	1	-1	-2.22(0.02)
	1	1	-2	-6.50(0.01)

[a] l, p and q are the stoichiometric coefficient corresponding to Co(II), GT or peptides (L) and H^+, respectively. [b] standard deviations are given in parentheses.

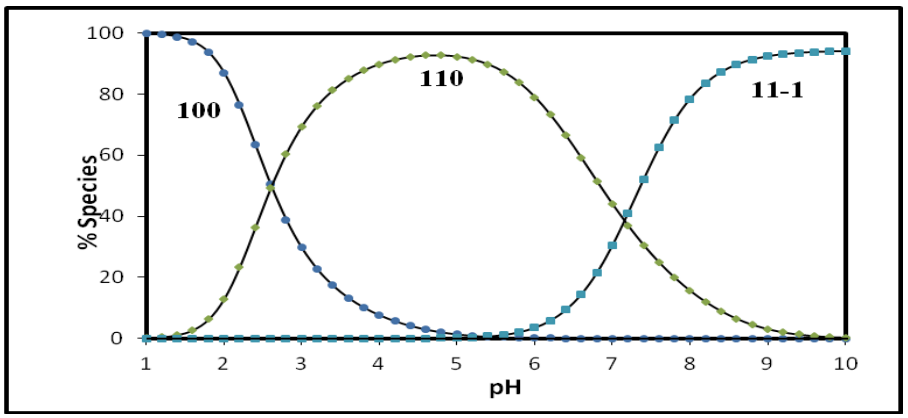


Figure 7. Concentration distribution of various species as a function of pH in the Co(GT)-glycylglycine system.

The distribution diagram of the diglycine complex is given in Fig. 7. The mixed ligand species 110 starts to form at pH~1.4 and, with increasing pH, its concentration increases reaching a maximum of 93% at pH = 4.8. A further increase of pH is accompanied by a decrease in the 110 complex concentration and an increase in [Cu(GT)LH_{-1}] (111-1) complex formation.

Table 4. Stability constants of the ternary species in the Co(GT)-glycine oligopeptides systems at 25°C and 0.1 M ionic strength.

System	***l***	***p***	***q*** [a]	***logB*** [b]	p*K*a
Diglycine	1	1	0	4.50(0.01)	1.98
	1	1	-1	2.52(0.02)	
Triglycine	1	1	0	4.31(0.01)	2.42
	1	1	-1	1.89(0.02)	
Tetraglycine	1	1	0	4.23(0.04)	2.21
	1	1	-1	2.02(0.03)	
Glutamin	1	1	0	7.52(0.01)	4.86
	1	1	-1	2.66(0.03)	
Glycinamide	1	1	0	3.78(0.02)	1.80
	1	1	-1	1.98(0.03)	

[a] l, p and q are the stoichiometric coefficient corresponding to Co(II), GT, peptides (L) and H^+, respectively .[b] standard deviations are given in parentheses.

3.3. Antibacterial activities

The susceptibility of certain strains of bacterium towards ligand and its complexes was judged by measuring size of the inhibition zone diameter, because[36]. Antibacterial activites of GT ligand and its Co(II) complexes have been carried out with three Gram-positive bacteria such as *B. subtilis*, *S. pyogenes* and *S. aureus* and three Gram-negative species *E. coli*, *K. pneumoniae* and *P. fluorescence*.

The tests solutions were prepared in DMSO-d_6 and the results are presented in Table 5. A comparative study of ligand and their metal complexes showed that the [Co(GT)-glutamine] complex exhibit higher antibacterial activity against three types of Gram-positive bacteria and two types of Gram-negative bacteria and no activity observed for *P. aeruginosa*, while the other complexes showed an excellent activity against all microorganisms.

Chelation considerably reduced the polarity of the metal ion because of the partial sharing of its positive charge with the donor groups and possible π-electron delocalization over the chelate ring [37]. Such chelation increased the lipophilic character of the central metal ion, which subsequently favors the permeation through the lipid layer of cell membrane. This increased lipophilicity enhances the penetration of the complexes into the lipid membranes and blocks the metal binding sites in enzymes of microorganisms [38].

Table 5. Size of inhibition zone (mm) formed at different concentrations (12.5, 25, 50 and 100 μg/ml in DMSO solvent) against various Bacteria and fungi

Compounds	Microbial Bacteria species					
	E. coli	*K. pneumoniae*	*P. fluorescence*	*B. subtilis*	*S. pyogenes*	*S. aureus*
GT ligand	12.1 ± 0.8	14.4 ± 0.2	13.7 ± 0.5	14.2 ±0.4	19.6 ±0.3	17.3 ±0.7
[Co(GT)diglycine]	15.1 ±0.04	18.4^{+1} ±0.03	16.7^{+1} ±0.03	26.1^{+2} ±0.01	23.2^{+1} ±0.05	19.9^{+1} ±0.05
[Co(GT)triglycine]	19.4^{+1} ±0.05	19.2^{+1} ±0.01	20.4^{+2} ±0.07	28.1^{+2} ±0.01	25.4^{+1} ±0.03	23.8^{+1} ±0.1
[Co(GT)tetraglycine]	13.6^{NS} ±0.03	15.4^{NS} ±0.08	15.6^{+1} ±0.1	22.2^{+1} ±0.08	20.2^{+1} ±0.04	19.3^{+1} ±0.09
[Co(GT)glutamine]	22.0^{+2} ±0.3	21.4^{+2} ±0.09	NA	30.1^{+3} ±0.09	$29,4^{+3}$ ±0.09	27.3^{+2} ±0.2
[Co(GT)glycinamide]	15.1 ±0.04	16.2 ±0.09	21.4^{+2} ±0.09	30.1^{+3} ±0.09	$29,4^{+3}$ ±0.09	27.3^{+2} ±0.2
$CoCl_2.6H_2O$	0	0	0	0	0	0
Control (DMSO)	0	0	0	0	0	0
Penicillin G	15.1 ±0.07	16.2 ±0.09	17.0 ±0.05	21.5 ±0.06	20.3 ±0.2	19.4 ±0.08
Streptomycin	16.6 ±0.04	17.6 ±0.09	15.3 ±0.08	17.1 ±0.04	21.3 ±0.2	18.1 ±0.08

NA: No activity, data are expressed in the form of mean ± SD.Statistical significance P^{NS} P not significant, P >0.05; P^{+1} P significant, P<0.05; P^{+2} P highly significant, P<0.01; P^{+3} P very highly significant, P <0.001; student's *t*-test (Paired).

4. CONCLUSION

The present investigation describes the formation equilibria of Co(II) complexes involving Girard-T (GT) as primary ligand and glycine oligopeptides as secondary ligands in aqueous media by using potentiometric titration method at (I = 0.1M $NaClO_4$ -25°C). The complexation behavior of Co(II) with (GT) and oligopeptides shows the formation of ternary complexes in a stepwise manner in aqueous media. Co(II) complexes with Girard-T (GT) derived from glycine oligopeptides have been synthesized and characterized on the basis of elemental analysis, molar conductance, magnetic moment and spectral data. All complexes show tetrahedral geometry. Antimicrobial studies of the ligand and complexes have also been evaluated which indicate that activity increases on chelation. On considering the structural formula of the compounds that exhibited antimicrobial activity, it can be concluded that substituted ligands and cobalt moiety may play a role in the antimicrobial activity.

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References

1. A. Girard, G. Sandulesco, *Helv. Chim. Acta*, *19* (1936) 1095-1107.
2. M.E.M. Emam, M.A.H. Hafez, M.N.H. Moussa, *J. Therm. Anal*., 37 (1991) 1005-1011.
3. M.M. Mostafa, M.A. Khattab, K.M. Ibrahim, *Transition Met. Chem*., *8* (1983)212-214.
4. M.M. Mostafa, S.M. Hassan, G.M. Ibrahim, *J. Inorg. Nucl. Chem*., *42* (1980) 285-291.
5. S.M. Al-Ashqar, M.M. Mostafa, *Spectrochim. Acta* Part A *71* (2008) 1321-1326.
6. R.M. AbouSekkina, R.M. Salem, *J. Therm. Anal*. *48* (1997) 841-849.
7. R.M. El-Bahnasawy, *J. Therm. Anal*., *45* (1995)1547-1556.
8. Leovac, V.M. Mészáros-Szécsényi, K. Vojinović-Ješić, L. j. S. Češjević, V. I. Markov, S. Wadsten, T. *J. Therm. Anal. Calorim*., *86* (2006) 379-403.
9. M. Masui, H. Ohmori, *J. Chem. Soc. A* (1969) 153-156
10. A. M. A. El-Sokkary, M. M. El-Naggar, A. F. Abdel-Aziz, *Appl. Organomet. Chem*., *24* (2010) 439- 445.
11. Vogel: Text book of Quantitative Chemical Analysis, 5th Edition, Chapter 15(1989) 555, Longman, UK.
12. P. Gans, A. Sabatini, A. Vacca, Investigation of equilibria in solution. Determination of equilibrium constants with the HYPERQUAD suite of programs, *Talant*, , *43* (1996) 1739–1753.
13. P. Gans P, A. Ienco, D. Peters, A. Sabatini, A. Vacca,,Hyperquad simulation and speciation (HySS): a utility program for the investigation of equilibria involving soluble and partially soluble species, *Coordination Chemistry Reviews*, *184* (1999) 311–318.
14. D.J. Beecher, A.C. Wong, *Appl. Environ. Microbiol. 60* (1994) 1646-1651.
15. W.J. Geary, *Coord. Chem. Rev*. *7* (1971) 81–122.
16. S.A. Sadeek, S.M. Abd El-Hamid, M.M. El-Aasser, *Monatsh Chem. 146* (2015)1967-1982.
17. N. Sultana, M.S. Arayne, S.B.S. Rizvi, U. Haroon, M.A. Mesaik, *Med. Chem. Res. 22*(2012)1371-1377.
18. I. Turel, *Coord. Chem. Rev*. *232* (2002) 27-47.
19. G. Pasomas, *J. Inorg. Biochem. 102* (2008)1798-1811.
20. G. Pasomas, A. Tarushi, E.K. Efthimiadou, *Polyhedron 27* (2008) 133-138.
21. S.A. Sadeek, S.M. Abd El-Hamid, *J. Therm. Anal. Calorim*. *124* (2016) 547-562.
22. M. Sakai, A. Hara, S. Anjo, M. Nakamura, *J. Pharm. Biomed. Anal. 18* (1999)1057–1067.

23. S. Sagdinc, S. Bayar, *J. Mol. Struct. 691* (2004) 107–113.
24. B.N. Figgs, Introduction to Ligand Fields, Interscience, New York, 1966.
25. A.M.A. Alaghaz, A.G.Al-Sehemi, T.M. EL-Gogary, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 95* (2012) 414-422.
26. S. Sagdinc, S. Bayar, *J. Mol. Struct. 691*(2004) 107–113.
27. I. Turel, I. Leban, P. Bukovec, M.Barbo, *Acta Cryatallogr. C. 53* (1997) 942-943.
28. B.D. Cullity, Elements of Xeray Diffraction, AddisoneWesley Publishing Company, USA, 1958.
29. H.P. Klug, L.E. Alexander, Xeray Diffraction Procedures for Polycrystalline and Amorphous Materials, Wiley, New York, 1974.
30. R. Shirley, The CRYSFIRE powder indexing system, <http://www.ccp14.ac.uk/tutorial/crys/obtain.htm>.
31. M.M. Mostafa, S.M. Hassan, G.M. Ibrahim, *J .Iong. Nucl. Chem*. *42* (1980) 282-285.
32. I. Savago, A. Kiss, E. Farkas, D.Sanna, P.Marras, G.Micerain, *J. Inorg. Biochem.65* (1997)103-108.
33. P.G. Daniele, O. Zerbinati, V. Zelano, , G. Ostacoli, *J. Chem. Soc., Dalton Trans*. *10* (1991)2711-2715.
34. W. Rehman, M.K. Baloch, A. Badshah, *J. Med. Chem. 43* (2008) 2380-2385.
35. M. Tumer, H. Koksal, M.K. Sener, *Trans. Met. Chem. 24* (1999) 414-420.
36. I. Muhammad, I. Javed, I. Shahid, Nazia, I. *Turk. J. Biol. 31* (2007) 67-72.
37. N. Raman, A. Kulandaisamy, A. Shunmugasundaram, and K. Jeyasubramanian, *Transition Metal Chemistry*, *26* (2001) 131–135.
38. R. S. Srivastava, *Inorganica Chimica Acta, 56* (1981) 65–67.