Supporting Information

Metalation of Glycylglycine: An Experimental Study Performed in Tandem with Theoretical Calculations

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Table S1. Experimental SLE data for the GlyGly–Copper(II) acetate system; where, weight of the reactants= x, temperature= T, and pressure= p (0.1 MPa)[a]

Mole fraction of Cu(II) acetate	Weight of Copper (II) acetate (in gm)	Weight of GlyGly (in gm)	T/^{o}C	Solid Phases
0	0.0000	0.0132	264	GlyGly
0.1	0.0018	0.0119	236	GlyGly
0.2	0.0036	0.0106	204	AB
0.3	0.0054	0.0092	212	AB
0.4	0.0073	0.0079	212	AB
0.5	0.0091	0.0066	208	AB
0.6	0.0110	0.0053	196	AB
0.7	0.0127	0.0040	160	AB
0.8	0.0145	0.0026	110	AB
0.9	0.0163	0.0013	115	Cu(II)acetate
1	0.0182	0.0000	120	Cu(II)acetate

[a]Standard uncertainties u are $u(T)$ = 1.0 ^{o}C, $u(x)$ = 0.0005 gm, $u(p)$ = 0.5 kPa; [b]AB represents the compound formed.

Table S2. Kinetic parameters for the solid-phase interactions of GlyGly and Cu(II) acetate at temperature= T, and pressure= p (0.1 MPa)[a]

T/K	k(cm/h)	n
353	(4.042 ± 0.01)	0.197 ± 0.01
363	(3.121 ± 0.02)	0.172 ± 0.01
373	(2.455 ± 0.01)	0.155 ± 0.01

k= apparent rate constant, n= another constant, [a]Standard uncertainties u are $u(T)$ = 0.2 K, $u(p)$ = 0.5 kPa;

Table S3. B3LYP/6-311++G(d,p) level calculated data on ZPVE values, total electronic energies[a], Gibbs free energies as well as ZPVE corrected values (scaled with 0.9877) of total electronic energies (E_{corr}) and Gibbs free energies (G_{corr}) of the systems studied in gas and aqueous phase.

Systems	Phases	ZPVE	Total Energy (E)	Gibbs Energy (G)	E_{corr}	G_{corr}
C5-GlyGly	Aqueous	0.137153	-492.617972	-492.516565	-492.482506	-492.381099
GlyGly	Aqueous	0.137084	- 492.615344	-492.513307	-492.4799448	-492.377909
	Gas	0.135990	-492.595268	-492.494561	-492.4609507	-492.360244
β-GlyGly	Aqueous	0.137305	-492.613935	-492.513165	-492.4783184	-492.377549
$Ni(GlyGly)_2$	Aqueous	0.254975	-2492.405353	-2492.199223	-2492.153514	-2491.947384
	Gas	0.255395	-2492.364988	-2492.157668	-2492.112735	-2491.905414
$^{t}Ni(GlyGly)_2$	Aqueous	0.252866	-2492.387588	-2492.186205	-2492.137832	-2491.936449
$Cu(GlyGly)_2$	Aqueous	0.254059	-2624.584579	-2624.380303	-2624.333645	-2624.129369
	Gas	0.253741	-2624.545441	-2624.271967	-2624.294821	-2624.091578
$*Cu(GlyGly)_2$	Aqueous	0.261286	-2623.950162	-2623.738905	-2623.692090	-2623.480833
	Gas	0.264645	-2623.889023	-2623.673811	-2623.627633	-2623.412421
$Zn(GlyGly)_2$	Aqueous	0.253887	-2763.478965	-2763.275312	-2763.228200	-2763.024548
	Gas	0.254404	-2763.433159	-2763.227107	-2763.181884	-2762.975832

[a]Energies in Hartrees; [t]Triplet; *BHandHLYP

Table S4. NPA charges calculated at B3LYP/6-311++G(d,p) level for some of the chemically significant atoms in the metal complexes. Gas phase values are given in parentheses.

Atoms	GlyGly	$Ni(GlyGly)_2$	$Cu(GlyGly)_2$	$*Cu(GlyGly)_2$	$Zn(GlyGly)_2$
M[a]	---------	1.072 (1.055)	1.343 (1.334)	1.272 (1.243)	1.650 (1.644)
N_6	-0.724 (-0.871)	-0.808 (-0.814)	-0.879 (-0.877)	-0.879 (-0.882)	-0.968 (-0.959)
O_7	-0.830 (-0.700)	-0.832 (-0.834)	-0.878 (-0.879)	-0.881 (-0.888)	-0.928 (-0.941)
C_1	0.789 (0.785)	0.808 (0.795)	0.811 (0.792)	0.872 (0.864)	0.807 (0.787)
C_2	-0.300 (-0.300)	-0.293 (-0.285)	-0.292 (-0.284)	-0.267 (-0.260)	-0.301 (-0.283)
O_8	-0.780 (-0.575)	-0.707 (-0.653)	-0.721 (-0.663)	-0.753 (-0.706)	-0.733 (-0.663)
H_a (NH_2)	0.450 (0.371)	0.419 (0.383)	0.420 (0.382)	0.407 (0.385)	0.428 (0.422)
H_b (NH_2)	0.447 (0.373)	0.420 (0.431)	0.422 (0.433)	0.425 (0.439)	0.424 (0.417)
N_3	-0.625 (-0.650)	-0.634 (-0.633)	-0.626 (-0.626)	-0.642 (-0.648)	-0.611 (-0.610)
C_4	0.668 (0.668)	0.679 (0.670)	0.676 (0.662)	0.735 (0.725)	0.666 (-0.671)
C_5	-0.250 (-0.259)	-0.262 (-0.260)	-0.262 (-0.258)	-0.230 (-0.232)	-0.257 (-0.247)

[a]M=Ni^{2+}, Cu^{2+} or Zn^{2+}; Atomic charges in a. u; *Calculated at BHandHLYP/6-311++G(d,p) level

Table S5. Calculated bond lengths (in angstrom) and bond indices of some structurally significant bonds for GlyGly and its metal complexes in gas and aqueous phase at B3LYP/6-311++G(d,p) level (gas phase values are given in parentheses)

Systems	GlyGly	$Ni(GlylGly)_2$	$Cu(GlyGly)_2$	$Zn(GlyGly)_2$	$^{w}Ni(GlylGly)_2$
C_2–C_1	1.559 (1.541)	1.549 (1.548)	1.549 (1.549)	1.549 (1.552)	1.547
C_2–N_3	1.457 (1.450)	1.460 (1.464)	1.459 (1.464)	1.450 (1.466)	1.451
N_3–C_4	1.359 (1.375)	1.366 (1.380)	1.360 (1.373)	1.350 (1.361)	1.353
N_3–H_3	1.011 (1.010)	1.011 (1.011)	1.010 (1.010)	1.010 (1.010)	1.017
C_4=O_4	1.224 (1.216)	1.226 (1.214)	1.228 (1.218)	1.234 (1.226)	1.232
C_4–C_5	1.530 (1.528)	1.527 (1.533)	1.525 (1.531)	1.524 (1.529)	1.524
C_5–N_6	1.512 (1.480)	1.503 (1.505)	1.499 (1.497)	1.499 (1.488)	1.493
C_1–O_7	1.273 (1.346)	1.297 (1.304)	1.293 (1.300)	1.286 (1.302)	1.296
C_1–O_8	1.243 (1.201)	1.229 (1.224)	1.232 (1.226)	1.233 (1.222)	1.231
N_6–H_a	1.020 (1.014)	1.018 (1.017)	1.017 (1.016)	1.017 (1.022)	1.024
M–O_7	-----	1.883 (1.868)	1.953 (1.936); *1.948 (1.919)	1.969 (1.932)	1.907
M–N_6	-----	1.975 (1.979)	2.077 (2.086); *2.070 (2.083)	2.147 (2.149)	1.969
**M–O_7	-----	0.301 (0.322)	0.165 (0.178); *0.256 (0.275)	0.133 (0.152)	-----
**M–N_6	-----	0.365 (0.352)	0.198 (0.183); *0.241 (0.233)	0.156 (0.136)	-------

*Calculated using BHandHLYP/6-311++G(d,p) method; **bond indices; $^{w}Ni(GlylGly)_2$=water complex

Table S6. Calculated bond angles (in degrees) for GlyGly and its metal complexes in gas and aqueous phase at B3LYP/6-311++G(d,p) level (gas phase values are given in parentheses)

Bond Angles	GlyGly	$Ni(GlyGly)_2$	$Cu(GlyGly)_2$	$Zn(GlyGly)_2$	$^{w}Ni(GlylGly)_2$
$C_1–C_2–N_3$	112.3 (114.7)	110.3 (109.9)	110.6 (110.4)	114.9 (110.2)	112.3
$H_3–N_3–C_4$	116.0 (116.7)	115.7 (114.1)	116.5 (115.3)	117.8 (115.1)	116.8
$N_3–C_4–C_5$	113.9 (113.4)	116.8 (117.0)	117.0 (117.2)	114.8 (117.5)	114.6
$O_4–C_4–C_5$	121.2 (122.6)	120.8 (120.4)	120.4 (120.1)	121.3 (119.2)	121.9
$C_4–C_5–N_6$	104.8 (105.2)	110.3 (111.4)	108.4 (108.8)	107.1 (105.7)	108.8
$C_2–C_1–O_7$	117.9 (118.1)	113.7 (112.7)	114.5 (113.7)	119.3 (113.7)	118.7
$O_8–C_1$-O_7	126.4 (121.4)	125.7 (125.6)	125.5 (125.7)	124.4 (126.3)	123.8
$C_2–C_1–O_8$	115.7 (120.6)	120.6 (121.7)	120.0 (120.6)	116.4 (119.9)	117.4
$H_a–N_6–C_5$	111.7 (111.7)	109.8 (110.1)	109.6 (110.3)	109.6 (112.1)	109.3
$H_b–N_6–C_5$	110.8 (110.2)	107.8 (108.3)	109.8 (111.3)	110.5 (110.3)	108.7
$H_a–N_6–H_b$	107.3 (107.1)	107.0 (108.0)	106.5 (106.9)	106.0 (106.1)	107.1

$^{w}Ni(GlylGly)_2$=water complex

Table S7. DNA binding-affinities* of the three metal-GlyGly complexes

System	Single point energies at UFF level (kcal/mol)	$E_{\text{Binding-affinity}}$ (kcal/mol)
DNA	-9082.96611048	
$Ni(GlyGly)_2$	-147.29328388	
$Zn(GlyGly)_2$	-141.62183126	
$Cu(GlyGly)_2$	-157.72699825	
DNA-$Ni(GlyGly)_2$	-9733.17368358	-502.914
DNA-$Zn(GlyGly)_2$	-9413.11386072	-188.526
DNA-$Cu(GlyGly)_2$	-9258.56574555	-17.873

*The theoretical DNA binding-affinity order of the three metal-GlyGly complexes were determined by performing single point energy calculations at UFF level[1] inbuilt in ARGUSLAB 4.0.1 program[2] on the molecular geometries of the highest ranking docked poses of the $Ni(GlyGly)_2$, $Zn(GlyGly)_2$ and $Cu(GlyGly)_2$ with the classical $d(CGCGAATTCGCG)_2$ B-DNA sequence, aqueous phase optimized structures of the three metallic complexes of GlyGly (Gaussian 09 program) and the $d(CGCGAATTCGCG)_2$ B-DNA sequence generated by AVOGADRO 1.1.1 package. The DNA binding-affinities were calculated using the equation (S1) below:

$$E_{\text{Binding-affinity}} = E_{\text{Docked pose}} - (E_{\text{DNA}} + E_{\text{Metal-dipeptide complex}}) \qquad \text{(S1)}$$

Figure S1. Experimental UV-vis spectrum of CT-DNA in aqueous phase

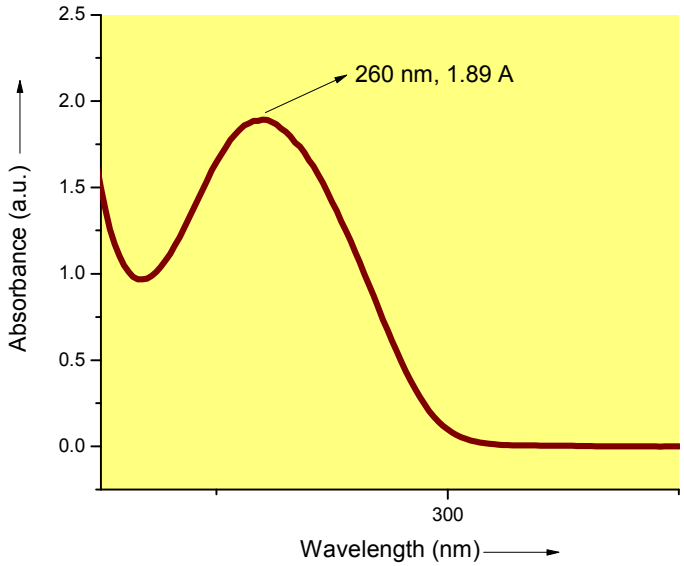


Figure S2. The 3D plots of HOMO and LUMO of GlyGly and its complexes in aqueous phase

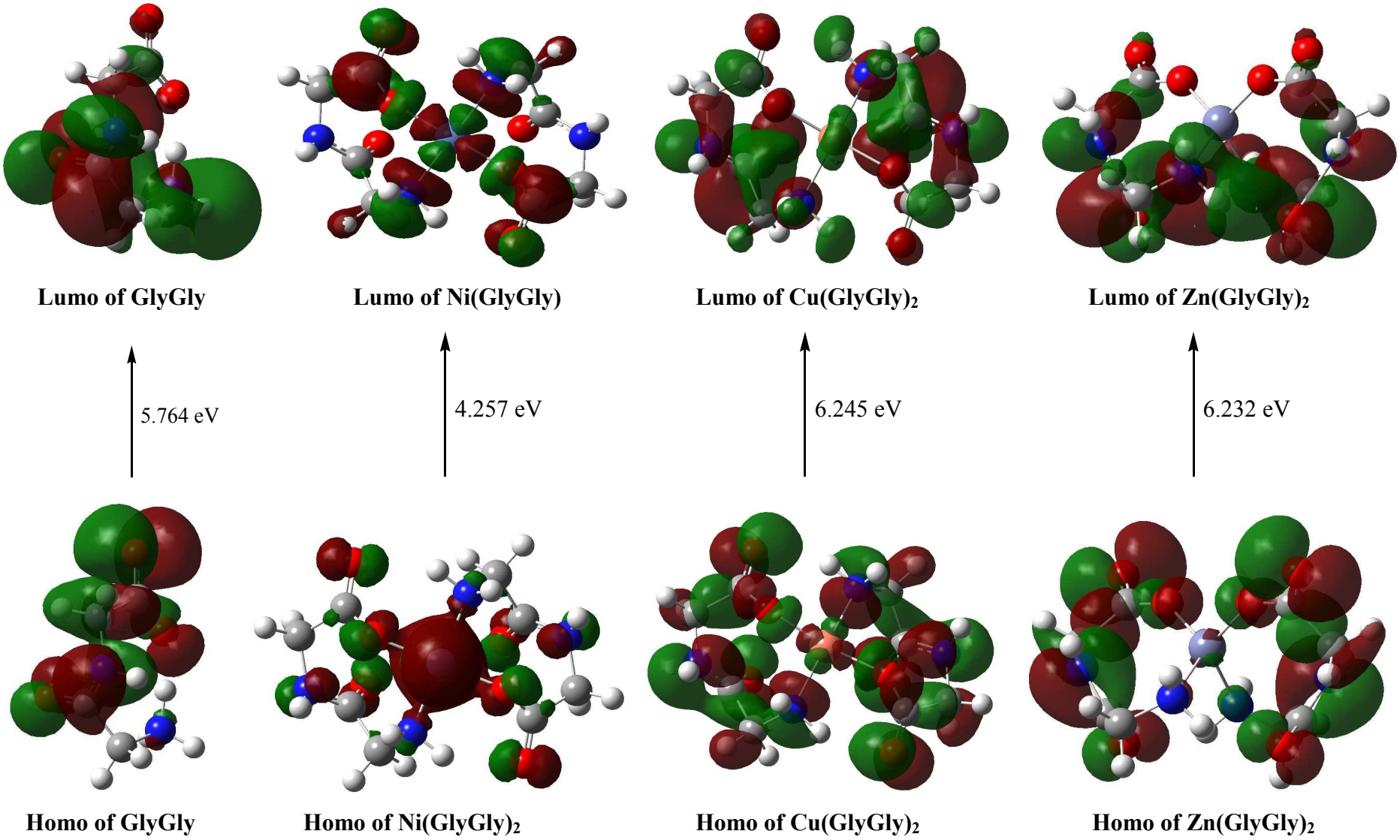
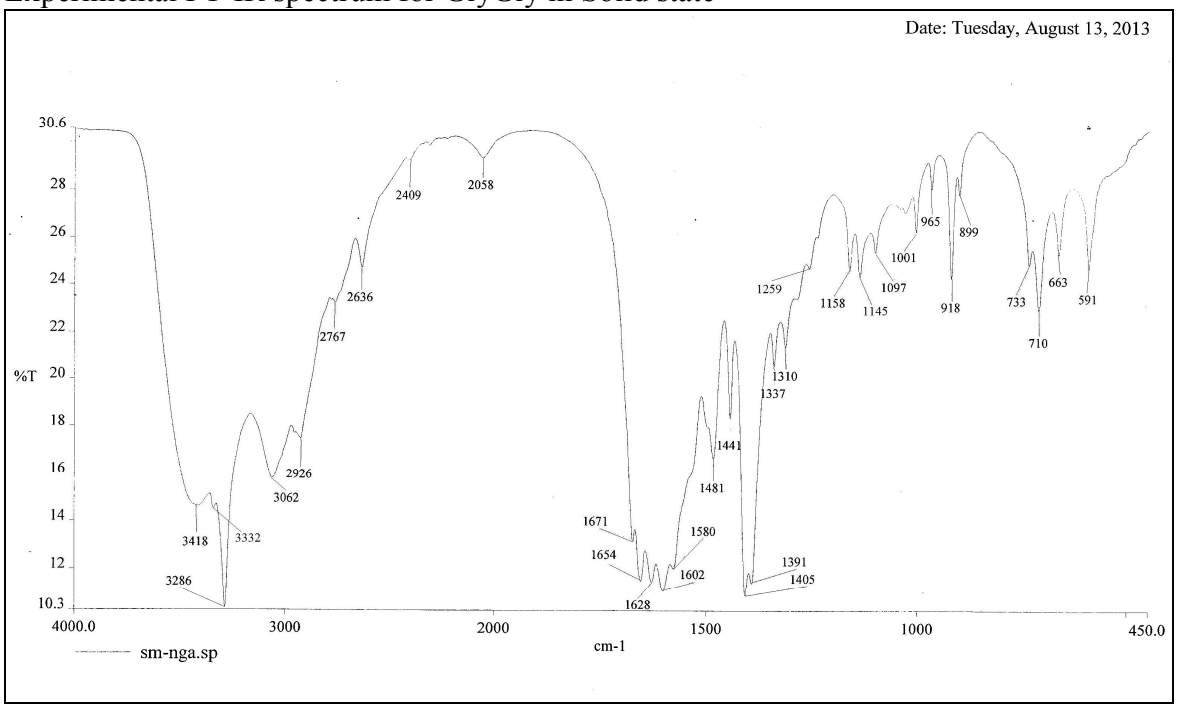


Figure S3. Experimental FT-IR spectra for GlyGly and its metal complexes

Experimental FT-IR spectrum for GlyGly in Solid state



Experimental FT-IR spectrum for $Ni(GlyGly)_2$ complex (solid state technique)

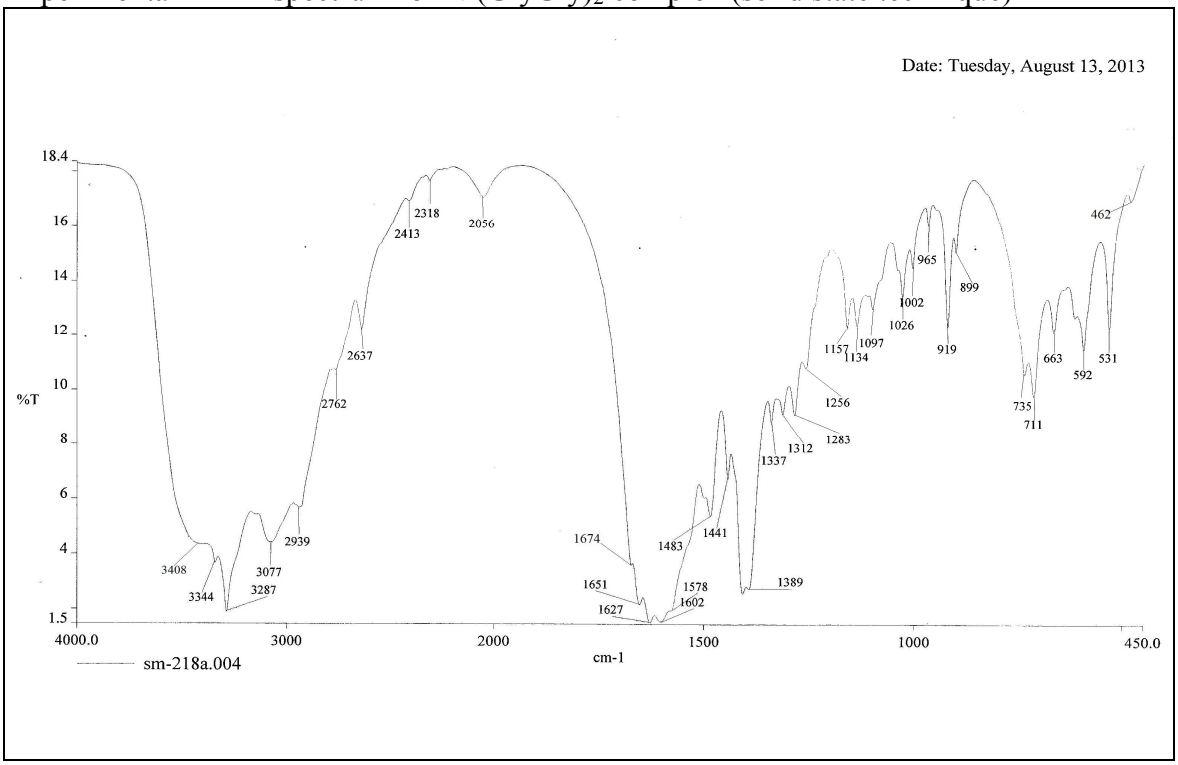
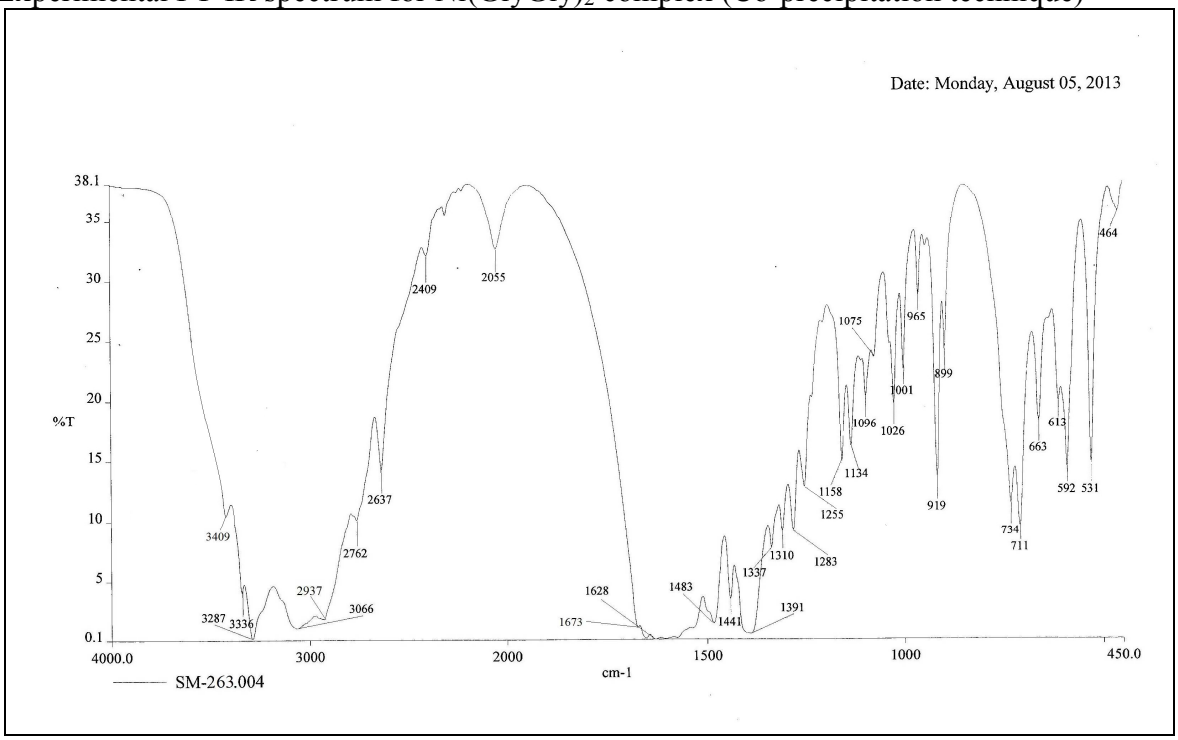


Figure S3. Continued……..

Experimental FT-IR spectrum for $Ni(GlyGly)_2$ complex (Co-precipitation technique)



Experimental FT-IR spectrum for $Cu(GlyGly)_2$ complex (solid state technique)

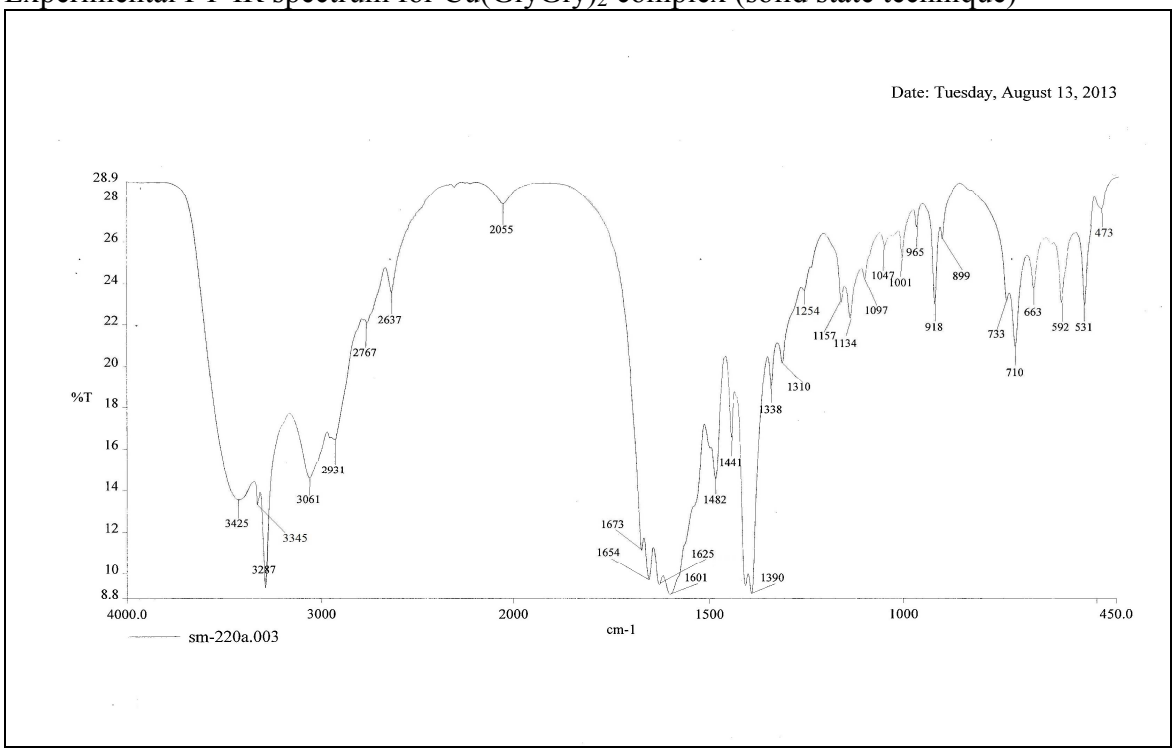
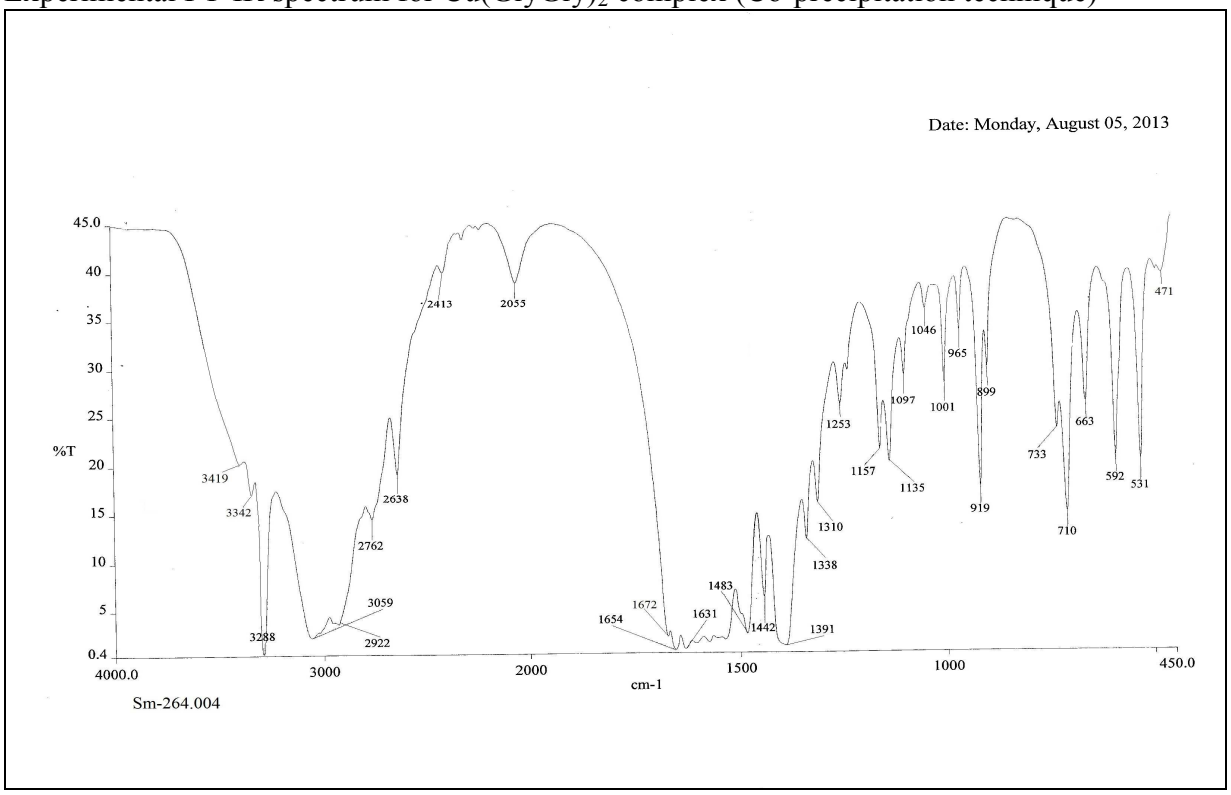


Figure S3. Continued……..

Experimental FT-IR spectrum for $Cu(GlyGly)_2$ complex (Co-precipitation technique)



Experimental FT-IR spectrum for $Zn(GlyGly)_2$ complex (solid state technique)

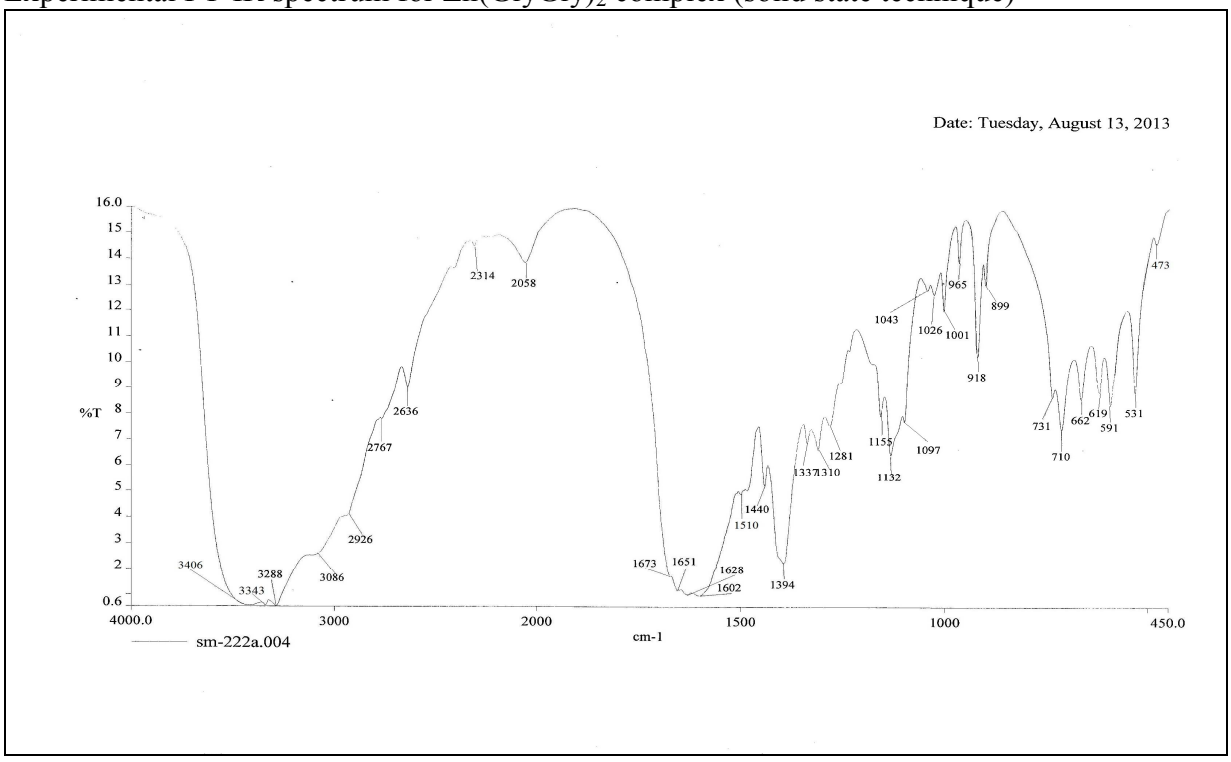


Figure S3. Continued……..

Experimental FT-IR spectrum for $Zn(GlyGly)_2$ complex (Co-precipitation technique)

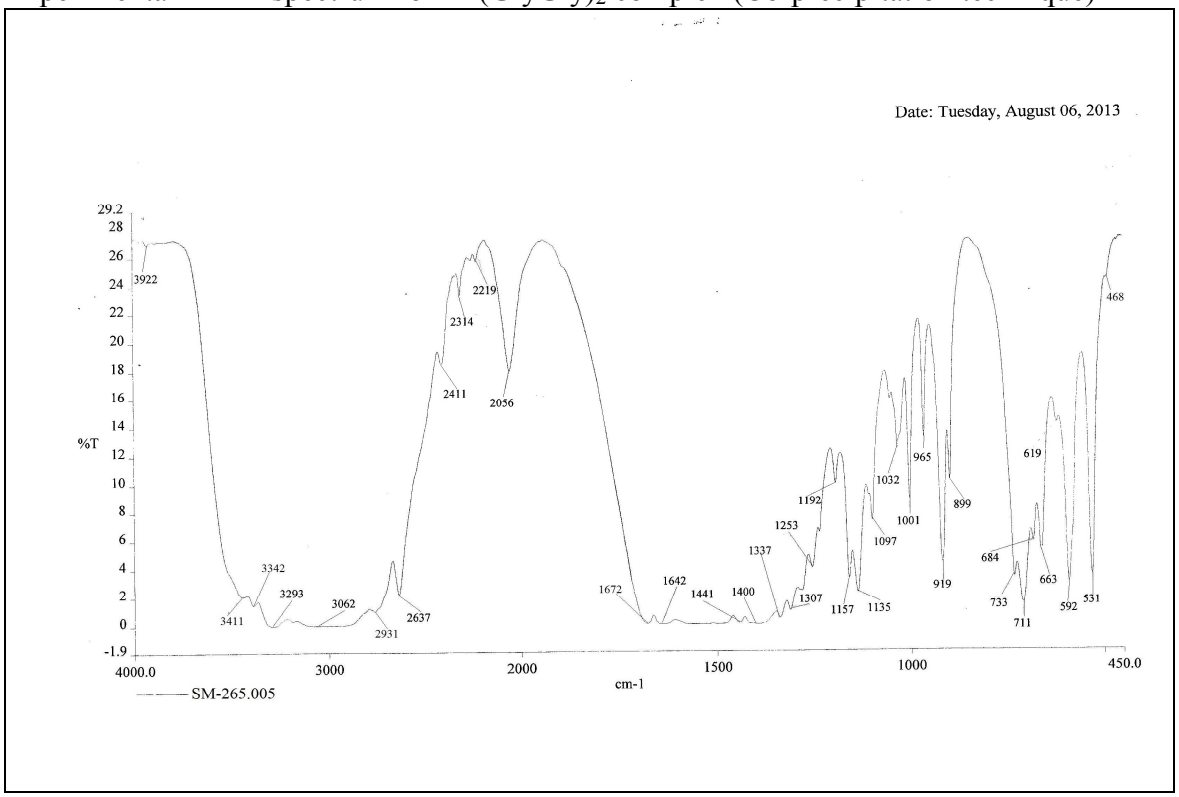
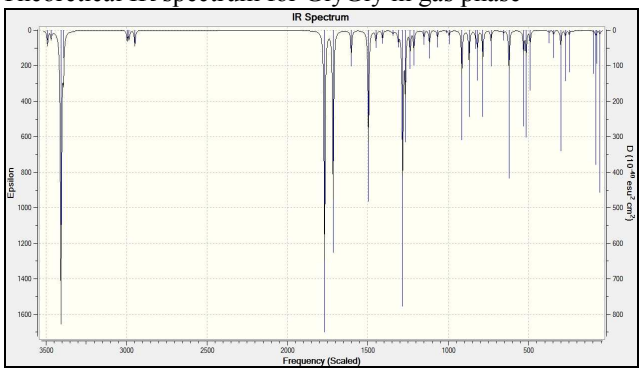
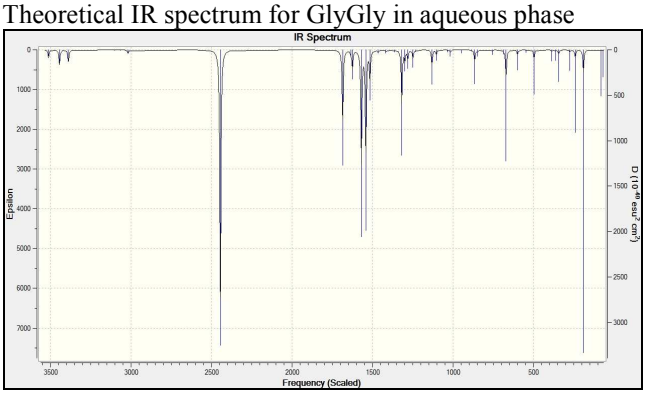


Figure S4. Theoretical IR spectra for GlyGly and its metal complexes in gas and in aqueous phases

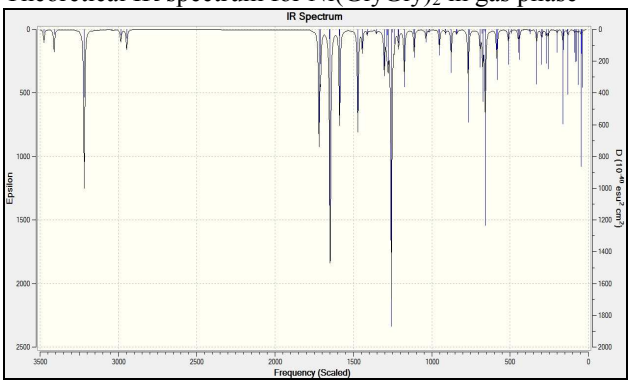
Theoretical IR spectrum for GlyGly in gas phase



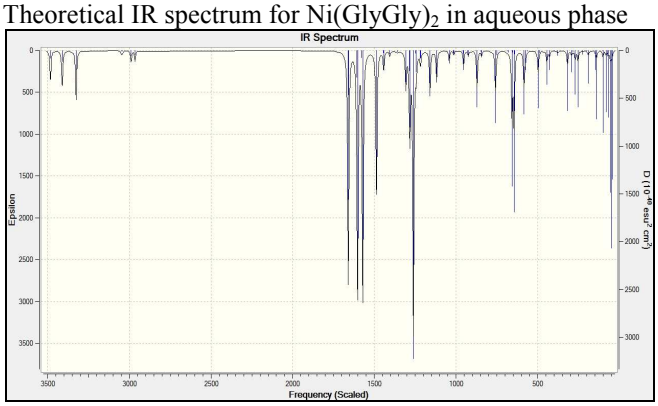
Theoretical IR spectrum for GlyGly in aqueous phase



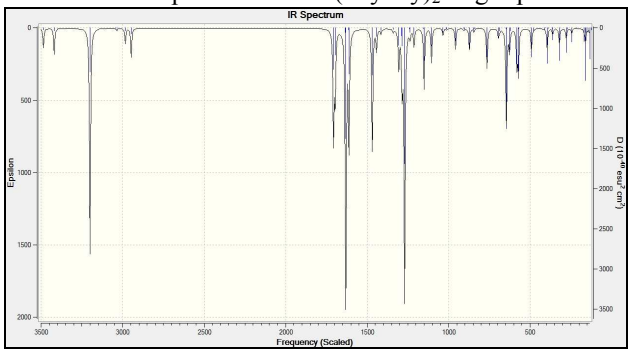
Theoretical IR spectrum for $Ni(GlyGly)_2$ in gas phase



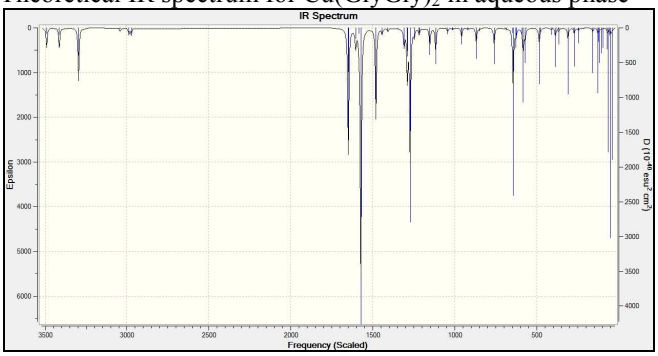
Theoretical IR spectrum for $Ni(GlyGly)_2$ in aqueous phase



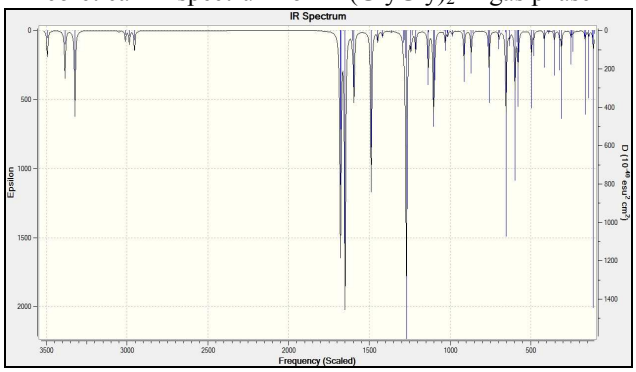
Theoretical IR spectrum for $Cu(GlyGly)_2$ in gas phase



Theoretical IR spectrum for $Cu(GlyGly)_2$ in aqueous phase



Theoretical IR spectrum for $Zn(GlyGly)_2$ in gas phase



Theoretical IR spectrum for $Zn(GlyGly)_2$ in aqueous phase

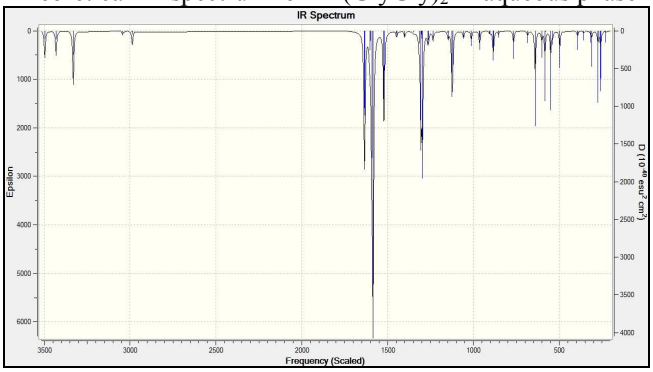
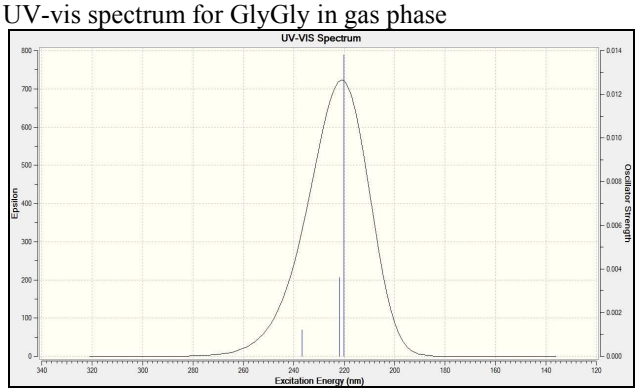
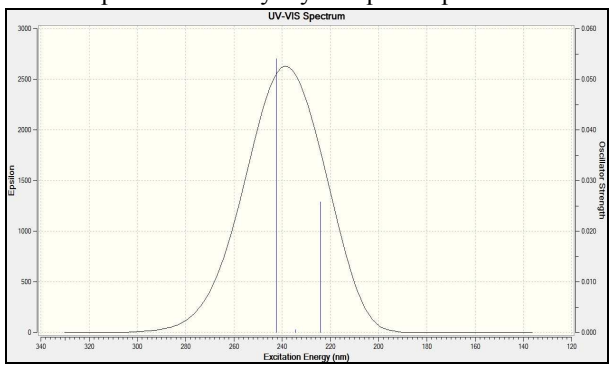


Figure S5. Theoretical UV-vis spectra of GlyGly and its metal complexes in gas and aqueous phase

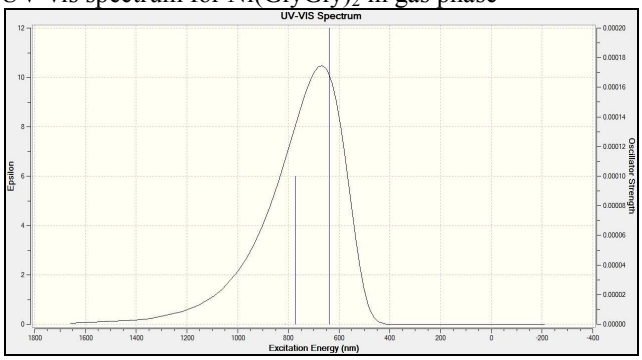
UV-vis spectrum for GlyGly in gas phase



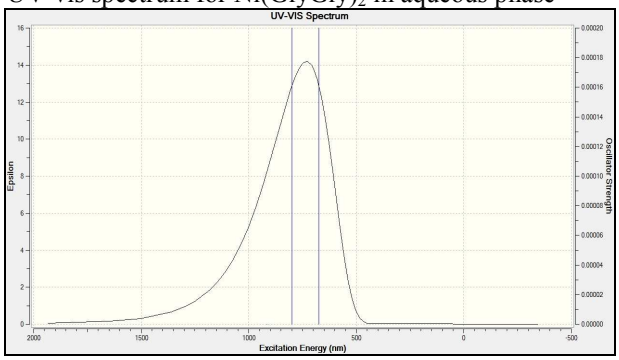
UV-vis spectrum for GlyGly in aqueous phase



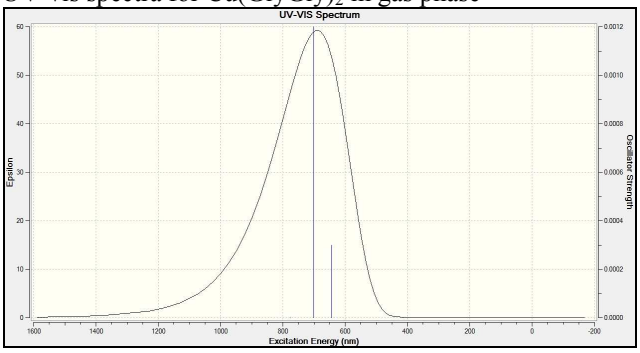
UV-vis spectrum for $Ni(GlyGly)_2$ in gas phase



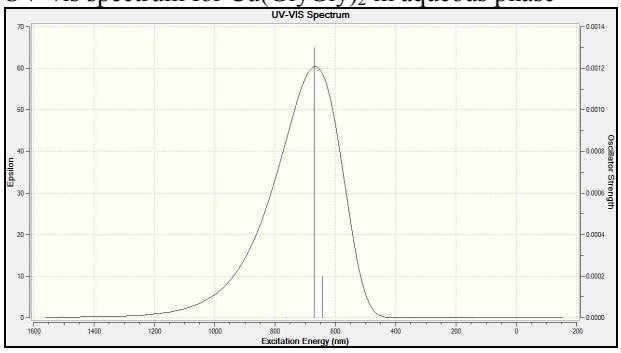
UV-vis spectrum for $Ni(GlyGly)_2$ in aqueous phase



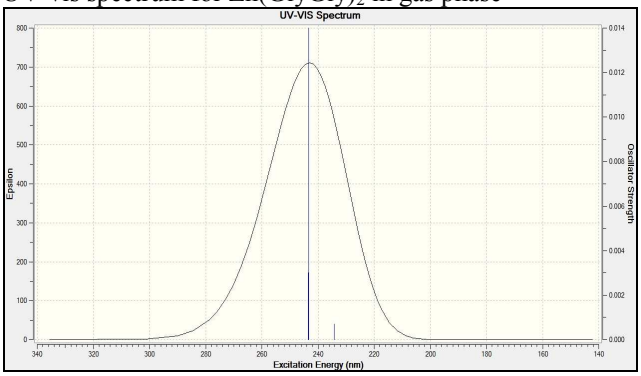
UV-vis spectra for $Cu(GlyGly)_2$ in gas phase



UV-vis spectrum for $Cu(GlyGly)_2$ in aqueous phase



UV-vis spectrum for $Zn(GlyGly)_2$ in gas phase



UV-vis spectrum for $Zn(GlyGly)_2$ in aqueous phase

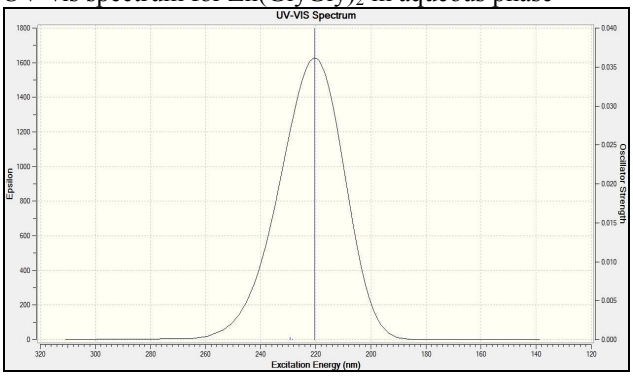
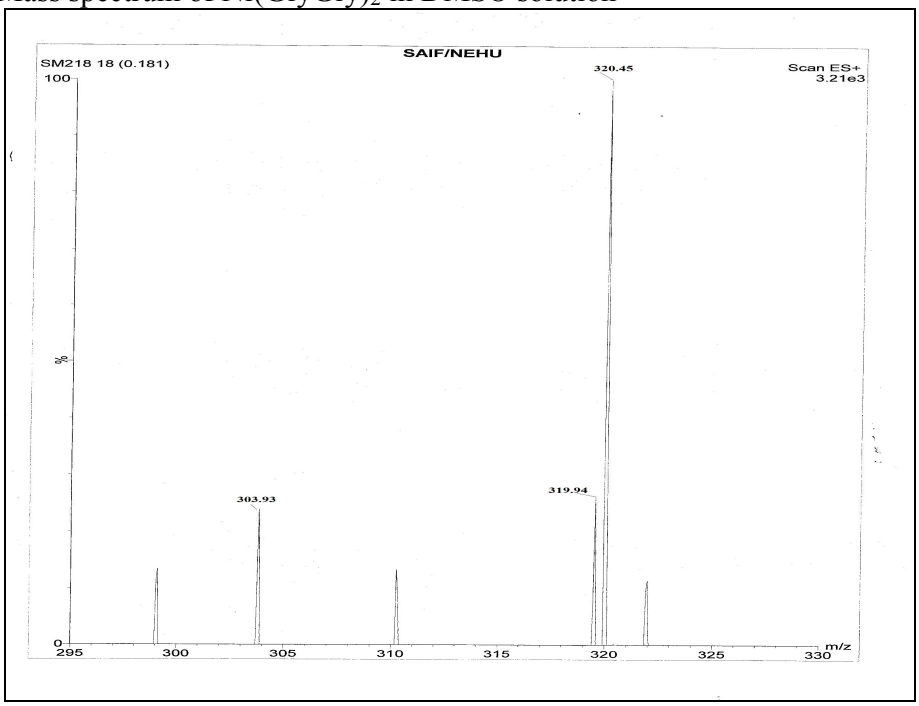


Figure S6. Mass spectra of the metal complexes prepared by solid state technique

Mass spectrum of $Ni(GlyGly)_2$ in DMSO solution



Mass spectrum of $Cu(GlyGly)_2$ in DMSO solution

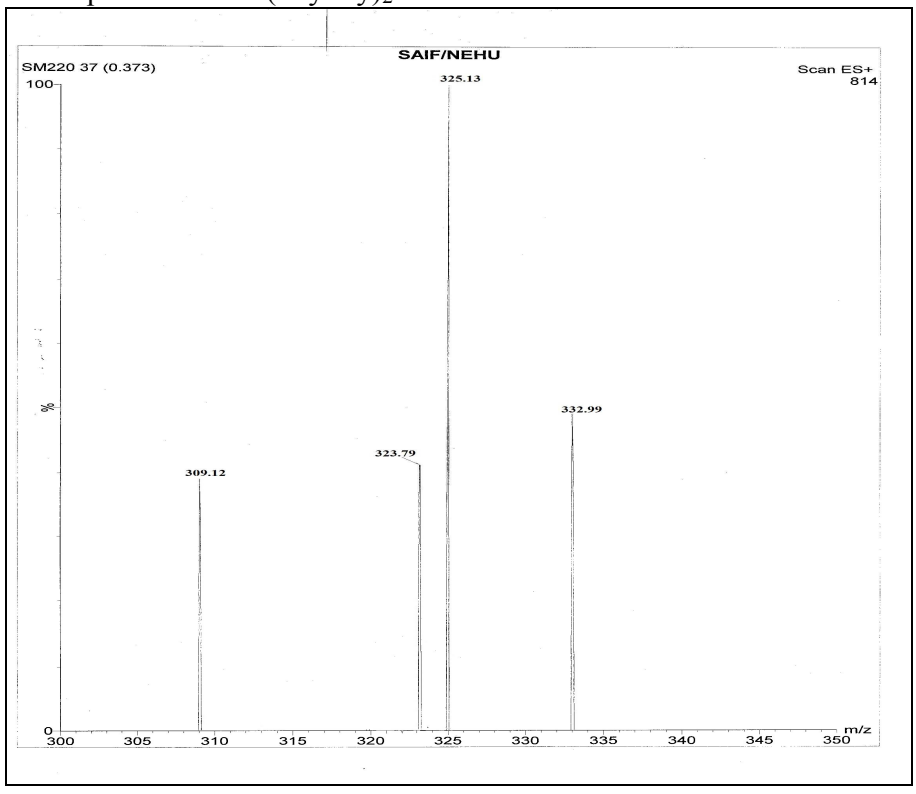


Figure S6. Continued……..

Mass spectrum of $Zn(GlyGly)_2$ in DMSO solution

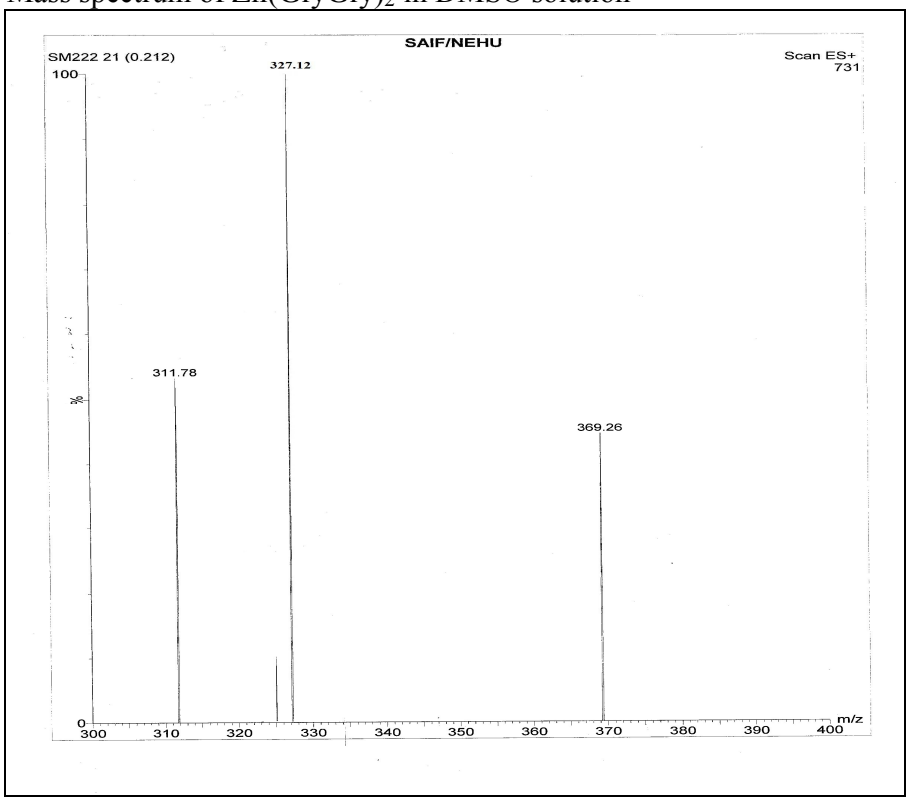
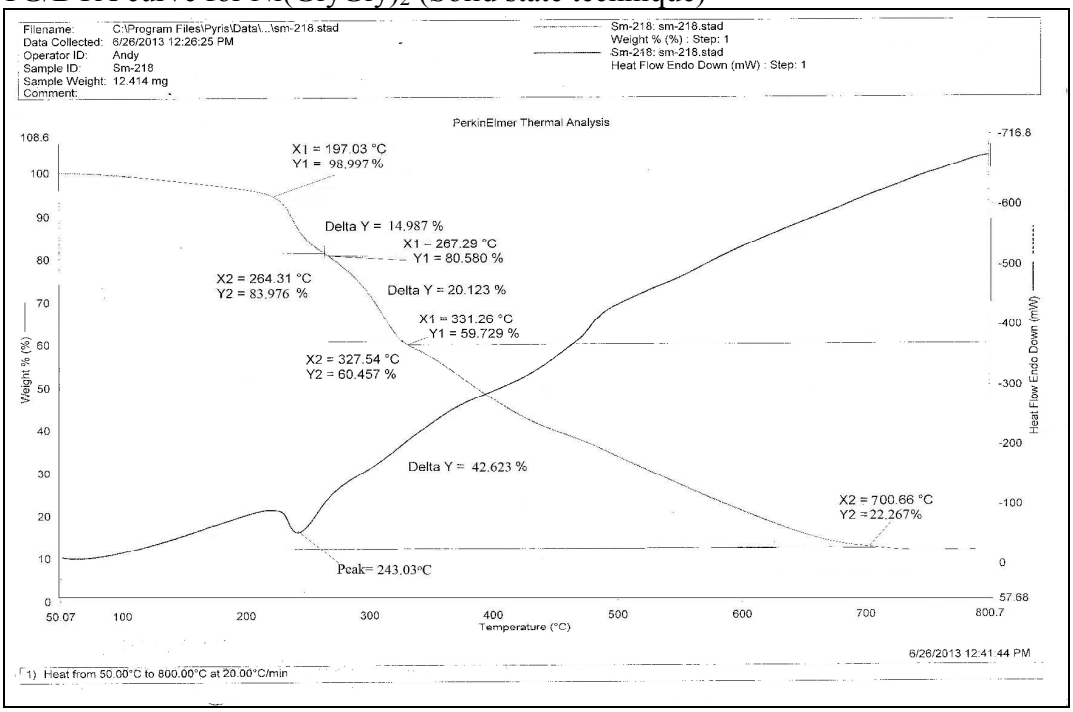


Figure S7. Experimental TG/DTA curves of the metal complexes prepared in solid state

TG/DTA curve for $Ni(GlyGly)_2$ (Solid state technique)



TG/DTA curve for $Cu(GlyGly)_2$ (Solid state technique)

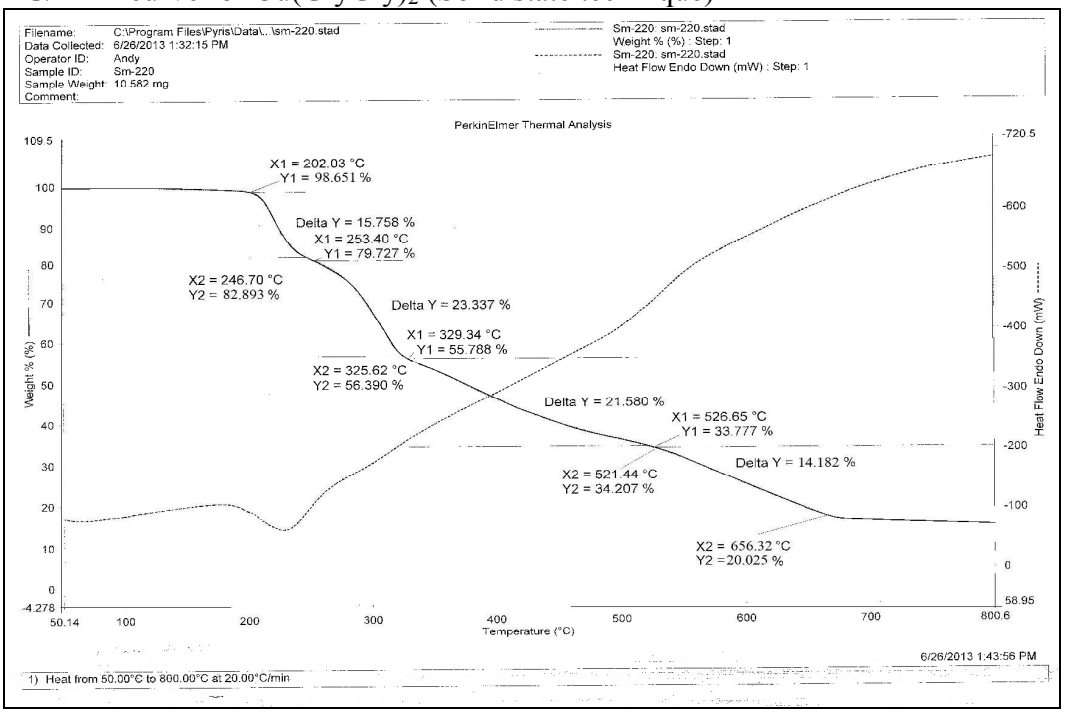
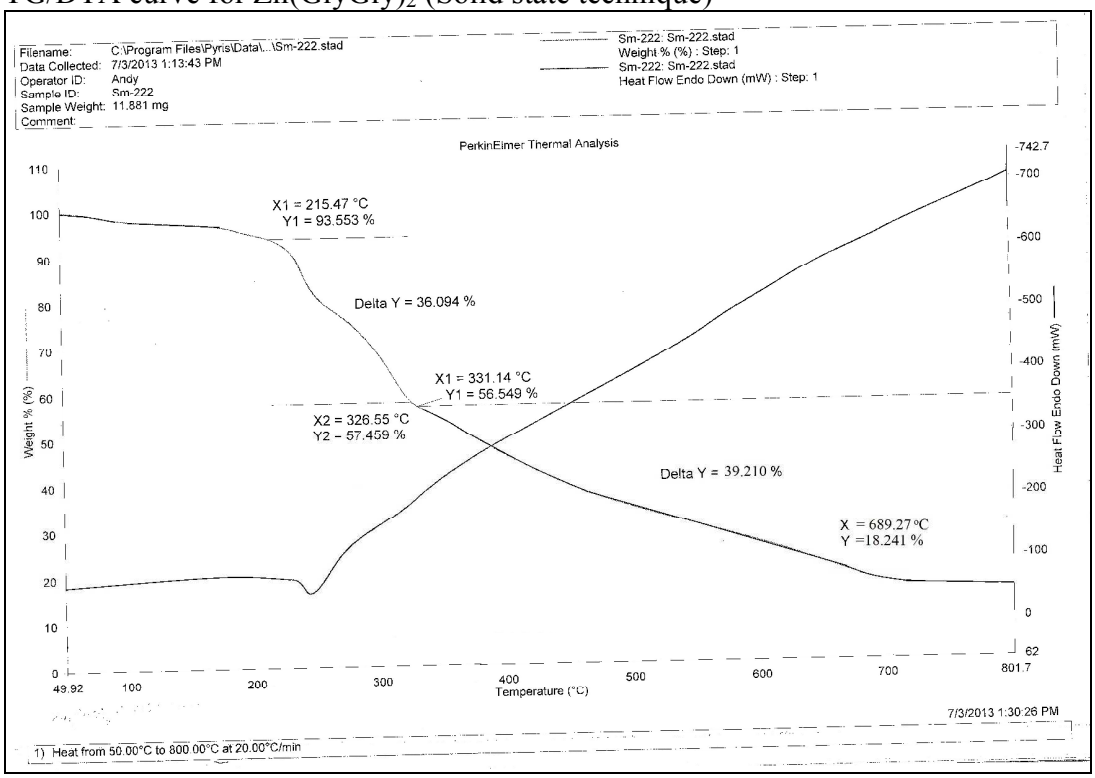


Figure S7. Continued……..

TG/DTA curve for $Zn(GlyGly)_2$ (Solid state technique)



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