

Preparation and Characterisation of Some Transition Metal Complexes of Niacinamide (Vitamin B₃)

Md. Mahmudul Hasan, Md. Elius Hossain, M. Ershad Halim and Md. Qamrul Ehsan*

Department of Chemistry, University of Dhaka, Dhaka-1000, Bangladesh

(received September 18, 2013; revised June 27, 2014; accepted July 9, 2014)

Abstract. Niacinamide forms metal complexes of general formula $[M(C_6H_6N_2O)_2]Cl_2$; where M = Mn(II), Co(II), Ni(II), Cu(II) and Zn(II) in the aqueous medium. The complexes were formulated by comparing the experimental and calculated data for C, H, N and metal. The prepared complexes were characterised by different physicochemical methods. The UV-vis, FTIR spectral analysis and thermo gravimetric analysis (TGA). TGA of these complexes have been discussed. Magnetic susceptibility values indicate that all complexes except Zn complex are paramagnetic in nature. The redox properties of the metal ions in the Mn, Cu and Zn complexes have been discussed from the cyclic voltammetric studies. In all cases the systems are quasi reversible.

Keywords: niacinamide, magnetic susceptibility, metal complexes, thermo gravimetric analysis

Introduction

The vitamins are a disparate group of compounds. They have little in common either chemically or in their metabolic functions. Nutritionally, they form a cohesive group of organic compounds that are required in the diet in small amounts (micrograms or milligrams per day) for the maintenance of normal health and metabolic integrity (Bender, 2003). Considering the significant role of metal ions in vast number of widely different biological processes many scientists are working in the field of interaction of metals with different vitamins. A great deal of work has been done in the field of preparation and characterisation of metal-vitamin compounds (Mamun *et al.*, 2011; Rahman *et al.*, 2011; Ehsan *et al.*, 2004; 2001; Haider *et al.*, 1988; 1987).

Niacinamide named as vitamin B₃ is one of the most important member of water-soluble vitamins (B-vitamins). Vitamin B₃ functions as coenzyme in oxidation and reduction reactions, functional part of NAD and NADP, role in intracellular calcium regulation and cell signaling. Vitamin B₃ deficiency causes pellagra, characterised by a photosensitive dermatitis, like severe sunburn, typically with a butterfly-like pattern of distribution over the face, affecting all parts of the skin that are exposed to sunlight. Similar skin lesions may also occur in areas not exposed to sunlight, but subject to pressure, such as the knees, elbows, wrists, and ankles. Advanced pellagra is also accompanied by a dementia or depressive psychosis, and

there may be diarrhoea (Bender, 2003). Studies of metal-niacinamide complexes are therefore, very important from the physiological activity point in the living system.

The niacinamide is a 3-substituted derivative of pyridine. It has three donor atoms (2N and 1O). The coordination chemistry of niacinamide is important since there are possibilities to form variety of complexes with d-block metal ions. In this communication preparation and characterisation of niacinamide complexes of first row transition metals namely; Mn, Co, Ni, Cu and Zn have been reported, all in the + 2 oxidation state.

Materials and Methods

Analytical grade reagents (BDH and Aldrich) were used in all preparative and analytical works. Micro-analysis for C, H and N were performed on an automatic micro-analyser in the Laboratory of Organic Structural Chemistry (Prof. Shinmyozu Lab.), Department of Molecular Chemistry, Graduate School of Sciences & IMCE, Kyushu University, Japan. Metal content of the complexes were quantitatively determined by complexometric method. Chloride content of all the complexes were qualitatively tested by AgNO₃ solution. The melting point of all the complexes were measured in a heating device with a thermometer, MEL-TEMP II Laboratory Devices made in USA. Infrared spectra of the complexes were recorded on a calibrated Fourier Transformation Infrared Spectrophotometer (Shimadzu FTIR IR prestige-21 S/N) in the range of 500-4500 cm⁻¹ as KBr pellets at QC Department of Beximco

*Author for correspondence; E-mail: mqehsan@yahoo.com

Pharmaceuticals, Bangladesh. The electronic spectra of niacinamide and its complexes were recorded on a Shimadzu UV-visible recording spectrophotometer (UV-160A) in the wavelength range 200-1100 nm using nujol mull technique. The thermo gravimetric analysis of the complexes was carried out with a computer controlled TA-60WS thermo gravimetric analyser and TGA-50H detector made in Japan at Centre of Excellence, Dhaka University. The magnetic properties of the complexes were studied at ambient temperature on a magnetic susceptibility balance (Magway MSB Mk1 Sherwood Scientific Ltd., Cambridge, England). The cyclic voltammogram of the complexes were studied with Epsilon, a PC controlled potentiostat; developed by Bioanalytical Systems, Inc. USA.

Preparation and formulation. All the complexes were prepared by following a general procedure. In all cases 20 mmol niacinamide and 20 mmol metal salt were dissolved separately in deionised water. These two solutions were filtered separately and mixed together. The resultant mixture was concentrated by heating carefully with moderately low flame in a Bunsen burner. Then the concentrated solution was allowed to cool at room temperature. The precipitate obtained was filtered, washed with water and dried over silica gel in a desiccator. All the complexes were stable in light and air. Preparation of the complexes are shown in scheme 1.

The formulation of the complexes was done by comparing the experimental and calculated data for elemental analysis. The micro analytical data of C, H, N and M content in the prepared complexes are given below:

A $[\text{Mn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$: calcd, (%): C, 38.91; H, 3.27; N, 15.13; Mn, 14.85.

anal Found, (%): C, 38.22; H, 3.23; N, 14.86; Mn, 12.60.

B $[\text{Co}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$: calcd, (%): C, 38.50; H, 3.23; N, 14.97; Co, 15.76.

anal Found, (%): C, 38.42; H, 3.24; N, 14.99; Co, 13.75.

C $[\text{Ni}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$: calcd, (%): C, 38.52; H, 3.24; N, 14.98; Ni, 15.70.

anal Found, (%): C, 37.62; H, 3.19; N, 14.69; Ni, 13.60.

D $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$: calcd, (%): C, 38.03; H, 3.20; N, 14.80; Cu, 16.77.

anal Found, (%): C, 37.95; H, 3.13; N, 14.78; Cu, 14.48.

E $[\text{Zn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$: calcd, (%): C, 37.85; H, 3.18; N, 14.72; Zn, 17.18.

anal Found, (%): C, 37.66; H, 3.27; N, 14.65; Zn, 14.96.

Results and Discussion

Metal complexes of niacinamide have been synthesised in the aqueous medium following a general procedure. The complexes have the general formula:

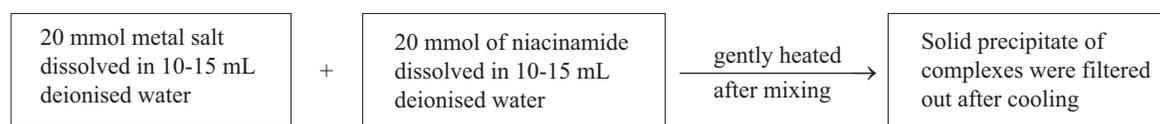
$[\text{M}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$; M = Mn(II), Co(II), Ni(II), Cu(II) and Zn(II)

The complexes are soluble in water but insoluble in most of the common organic solvents. The physical appearance of the complexes are $[\text{Mn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (light pink), $[\text{Co}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (orange), $[\text{Ni}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (yellowish green), $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (light green), $[\text{Zn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (colourless). Melting point of the complexes are more than 200 °C. The high melting point and the solubility nature of the complexes indicate that they are ionic in nature to some extent.

IR Spectral analysis. The IR spectral analysis confirm the formation as well as similar bonding nature of all the complexes. The IR absorption spectra of niacinamide and Cu-niacinamide complex are compared in Fig. 1. The tentative assignments have been done on the basis of standard references (Silverstein *et al.*, 2005, Banwell *et al.*, 2003, Pavia *et al.*, 2001) and presented in Table 1.

In all the complexes a strong peak at ~ 3157 to 3203 cm^{-1} appears due to symmetric N-H stretching vibration. Asymmetric N-H stretching vibration appears at ~ 3319 to 3402 cm^{-1} . Whereas, for the ligand a strong broad peak at 3165 cm^{-1} and 3365 cm^{-1} was due to symmetric and asymmetric N-H stretching vibration of $-\text{NH}_2$ group, respectively. The change in sharpness and position of the peaks in the complexes with respect to that of ligand is due to the fact that the nitrogen participate in the coordination.

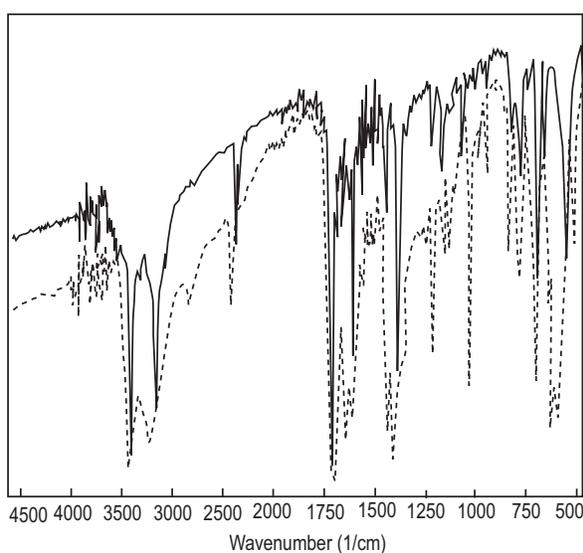
All the complexes absorb strongly at ~ 1664 to 1708 cm^{-1} due to C=O stretching vibration. Strong sharp band appear at ~ 1602 to 1624 cm^{-1} due to aromatic C=C stretching vibration. For ligand a strong peak at 1678 cm^{-1} and 1618 cm^{-1} are due to C=O and aromatic C=C stretching vibrations. At ~ 1375 to 1398 cm^{-1} all the complexes absorb



Scheme 1. Preparation of complexes.

Table 1. Comparison of IR bands of niacinamide and its complexes

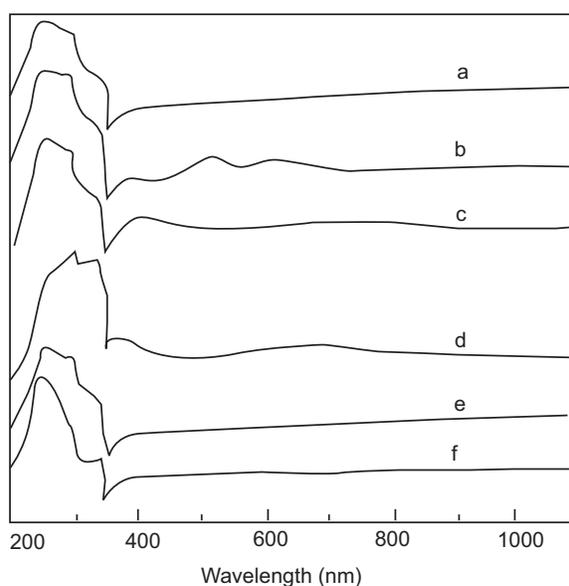
Compound	ν (NH) str. (sym) cm^{-1}	ν (NH) str. (asym) cm^{-1}	ν (CH) str. aromatic cm^{-1}	ν (C=O) str. cm^{-1}	ν (C=C) str. aromatic cm^{-1}	ν (NH) bending cm^{-1}	ν (CN) str. cm^{-1}
Niacinamide	3165	3365	2783	1678	1618	1576	1394
$[\text{Mn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	3203	3342	2365	1670	1622	1601	1375
$[\text{Co}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	3196	3319	2754	1666	1602	1568	1396
$[\text{Ni}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	3196	3367	2752	1664	1624	1605	1398
$[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	3157	3402	2360	1708	1605	-	1379
$[\text{Zn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	3184	3344	2762	1674	1603	1568	1375

**Fig. 1.** Comparison of the FTIR spectra of (a) $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ and (1) Niacinamide ($\text{C}_6\text{H}_6\text{N}_2\text{O}$) in the region 500 to 4500 cm^{-1} .

due to C-N stretching vibration. A strong sharp peak at 1394 cm^{-1} appeared due to C-N stretching vibration for ligand. A sharp peak for aromatic =C-H stretching vibration appears at 2360 to 2762 cm^{-1} in the complexes. The sharpness of the peaks due to C=O, C=C and CN bands and their displacement with respect to that of ligand confirmed the formation of the complexes.

UV-vis spectral analysis. The electronic absorption spectra of the niacinamide complexes and their characteristic absorption bands with tentative assignments are presented in Fig 2 and Table 2, respectively. The assignments have been done on the basis of some standard references (Banwell *et al.*, 2003; Pavia *et al.*, 2001).

The $n \rightarrow \sigma^*$ absorption bands due to the transition of nitrogen lone pair to the anti bonding orbital of C-N bond

**Fig. 2.** The UV absorption spectrum in the region 200 to 1100 nm of (a) $[\text{Mn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (b) $[\text{Co}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (c) $[\text{Ni}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (d) $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ (e) $[\text{Zn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ and (1) niacinamide ($\text{C}_6\text{H}_6\text{N}_2\text{O}$).**Table 2.** Absorption bands of niacinamide and its complexes

Compound	Absorption bands λ_{max} (nm)			
	$d \rightarrow d^*$	$n \rightarrow \pi^*$	$n \rightarrow \sigma^*$	$\pi \rightarrow \pi^*$
Niacinamide ($\text{C}_6\text{H}_6\text{N}_2\text{O}$)	-	343	300	250
$[\text{Mn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	-	340	298	263
$[\text{Co}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	520, 620	342	299	263
$[\text{Ni}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	700	340	299	265
$[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	650	341	299	262
$[\text{Zn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$	-	338	299	255

Table 3. Weight loss at different stages of TG analysis of niacinamide and metal-niacinamide complexes

Compound	Sample weight (mg)	TG analysis		Comments
		Transition temp. (°C)	% Wt. loss	
[Cu(C ₆ H ₆ N ₂ O) ₂]Cl ₂	10.373	32-60	6	The weight loss may be due to loss of adhere water
		60-250	No loss	No chemically bound water
		250-350	57	The weight loss may be due to loss of CO ₂ , HCl, NH ₃ , H ₂
		350-580	5	It may be due to loss of CH ₄
		580-580 (10 min.)	6	The rest of the organic part may be lost
			Residue = 26%	

Table 4. Magnetic properties of the complexes of niacinamide

Compound	χ_A (cgs) x 10 ⁻³	μ_{eff} BM (at 300K)		No. of unpaired electron	Config. g.	Inference
		Found	Theo.			
[Mn(C ₆ H ₆ N ₂ O) ₂]Cl ₂	10.63	5.50	5.7-6.0	5	d ⁵	Paramagnetic
[Co(C ₆ H ₆ N ₂ O) ₂]Cl ₂	11.47	5.20	4.3-5.2	3	d ⁷	Paramagnetic
[Ni(C ₆ H ₆ N ₂ O) ₂]Cl ₂	3.598	2.94	3.0-3.3	2	d ⁸	Paramagnetic
[Cu(C ₆ H ₆ N ₂ O) ₂]Cl ₂	1.09	1.62	1.7-2.2	1	d ⁹	Paramagnetic
[Zn(C ₆ H ₆ N ₂ O) ₂]Cl ₂	-ve	0*	-	0	d ¹⁰	Diamagnetic

* = The negative value of χ_A indicates that the tube and sample have a net diamagnetism. In that case μ_{eff} can be considered as zero.

appeared at 299 nm instead of 300 nm in niacinamide. The bands due to $\pi \rightarrow \pi^*$ transition in the metal complexes at ~ 255-263 nm are somewhat broad and seem to be overlapped with the $n \rightarrow \sigma^*$ bands. The $n \rightarrow \pi^*$ transition bands in the complexes are observed in the region 338-340 nm whereas the ligand absorb at 343 nm. The broad bands for the coloured complexes in the range of 520-700 nm were clearly due to the d-d transitions which is absent for the complex with d¹⁰ system.

The presence of $\pi \rightarrow \pi^*$, $n \rightarrow \pi^*$ and $n \rightarrow \sigma^*$ bands in all the complexes indicate the presence of the functional groups of the parent ligand (e.g. -C=O, -NH₂). Shifting of the absorption bands in the complexes and appearing of a new band for d-d transitions also indicate the probability of forming M←L coordination bonds in the complexes. Again the positions of the absorption bands also indicate the similar bonding pattern of the complexes.

Thermo gravimetric analysis. Thermo gravimetric TG curves of the complexes and the ligand are compared in Fig. 3 and the characteristic features of decomposition of [Cu(C₆H₆N₂O)₂]Cl₂ are tabulated in Table 3.

Thermo gravimetric analysis (TGA) reveals that niacinamide and its complexes are not accompanied by any chemically bonded water or water of crystallization. The

pattern of the thermo grams also confirm the complexation between metal and niacinamide.

Magnetic properties. Magnetic moments of all the complexes were measured using a manual magnetic susceptibility balance. The measured values agree with the divalent oxidation state of the metals (Table 4).

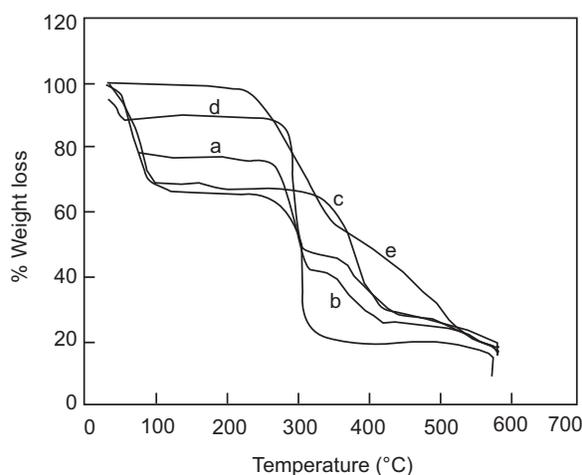


Fig. 3. TG curves of (a) [Mn(C₆H₆N₂O)₂]Cl₂ (b) [Co(C₆H₆N₂O)₂]Cl₂ (c) [Ni(C₆H₆N₂O)₂]Cl₂ (d) [Cu(C₆H₆N₂O)₂]Cl₂ (e) [Zn(C₆H₆N₂O)₂]Cl₂ (1) Niacinamide (C₆H₆N₂O).

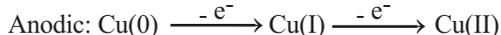
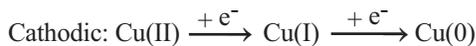
The μ_{eff} values of the complexes demonstrate that all the complexes are sufficiently pure. The complexes of Mn(II), Co(II), Ni(II) and Cu(II) are high spin paramagnetic as suggested by their measured and standard magnetic moment values (Mamun *et al.*, 2011, Rahman *et al* 2011). The $[\text{Zn}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ complex is diamagnetic as the complex is d^{10} system. The deviation of magnetic moment value of copper ion may be due to some experimental errors.

Cyclic voltammetric studies. The redox behaviour of Mn(II), Cu(II) and Zn(II) in the coordinated and uncoordinated states were examined using cyclic voltammetric technique. All the solutions in the present study were prepared in freshly prepared KCl solution. The surface of the working electrode was polished with powdered alumina and rinsed thoroughly with deionised water before doing the experiments. The solution system was deoxygenated by purging with N_2 gas and was homogenised by stirring with a magnetic stirrer. The cyclic voltammograms of the solution were recorded with respect to saturated Ag/AgCl reference electrode.

CV studies of redox behaviour of Cu(II) in CuCl_2 and $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$. The redox behaviour of Cu(II) in CuCl_2 and $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ were observed in 0.1M KCl using cyclic voltammetric technique on glassy carbon electrode within the potential window 1200-1300 mV at room temperature. The voltammogram of the complex is compared with that of the free metal and niacinamide in Fig. 4.

The CV of Cu(II) in CuCl_2 shows two cathodic peaks at potential 45.4 mV and -212.2 mV, and two anodic peaks at potential 241.0 mV and 88.4 mV, respectively. In the metal complex, there were two cathodic peaks at potential 121.8 mV, and -188.4 mV, and two anodic peaks at potentials 174.2 mV, and 55.0 mV, respectively. The voltammograms indicate that there were two one-electron transfer processes i.e.,

The peak positions deviated noticeably in the complex system compared to that of free metal. However, the peak currents for both the anodic and cathodic peaks in the voltammogram of the complex are remarkably lower than that of metal salt.



Scan rate variation. The cyclic voltammograms of 1 mM $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ at different scan rates are shown in Fig. 5. The current potential data, peak potential separation

and peak current ratio of the voltammograms are recorded in Table 5.

The voltammograms of the metal complex at different scan rates expressed that with the increase of scan rate the peak currents for both cathodic and anodic peaks increases. Both the cathodic peaks shifted towards negative while the anodic peaks shifted towards positive direction with the increase of scan rate. The peak separation for the first pair of cathodic and anodic peaks increases with the increase of scan rate.

Randless-sevcick plot. A plot of peak current (first pair of peak) vs SQRT of scan rate (Fig. 6) for the metal complex showed that with the increase of scan rate peak, current for both cathodic and anodic peaks increases.

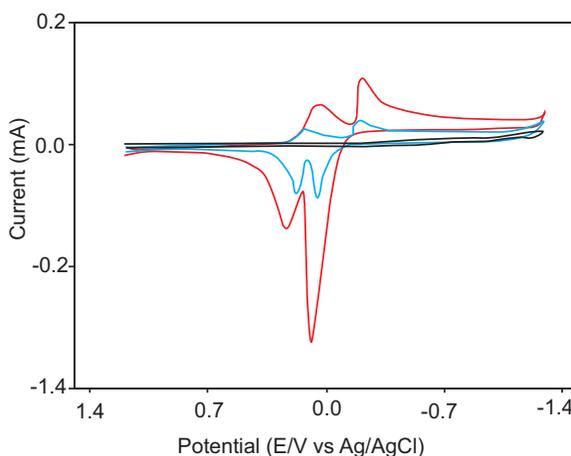


Fig. 4. CVs 1mM CuCl_2 , 1mM $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ and 1mM niacinamide in 0.1M KCl at 100 mV/s.

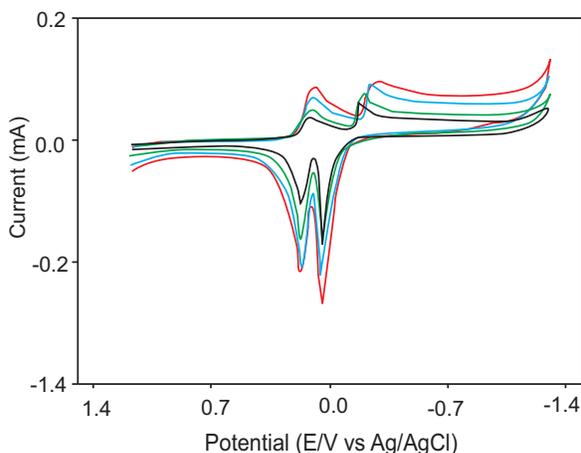
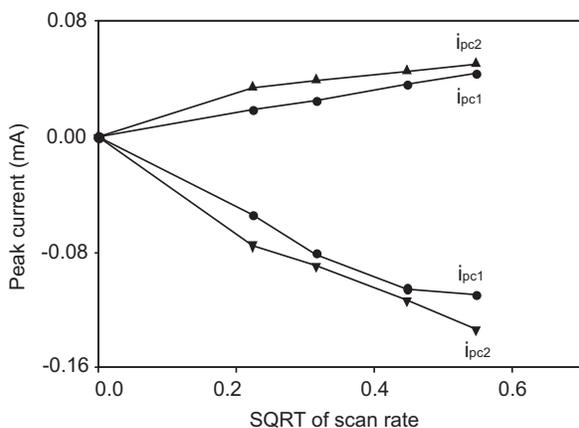


Fig. 5. CVs of 1mM $[\text{Cu}(\text{C}_6\text{H}_6\text{N}_2\text{O})_2]\text{Cl}_2$ in 0.1M KCl at 300, 200, 100 and 50 mV/s.

Table 5. Current- Potential data, peak potential separation, peak current ratio of the voltammogram of 1 mM [Cu(C₆H₆N₂O)₂]Cl₂ in 0.1 M KCl at different scan rates

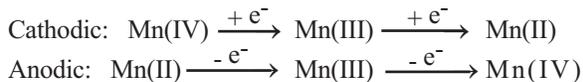
v V s ⁻¹	$v^{1/2}$ V s ⁻¹	E_{pc1} Volt (+)	E_{pc2} Volt (-)	E_{pa1} Volt (+)	E_{pa2} Volt (+)	i_{pc1} mA (+)	i_{pc2} mA (+)	i_{pa1} mA (-)	i_{pa2} mA (-)	ΔE_p Volt	i_{pa1}/i_{pc1}
0.05	0.2236	0.1218	0.1693	0.1742	0.0502	0.0187	0.0341	0.054	0.075	0.0475	2.8877
0.10	0.3162	0.1218	0.1884	0.1742	0.0550	0.0251	0.0393	0.081	0.089	0.0666	3.2271
0.20	0.4472	0.1074	0.2361	0.1742	0.0597	0.0363	0.0457	0.105	0.113	0.1287	2.8926
0.30	0.5477	0.0979	0.2838	0.1742	0.0597	0.0441	0.0504	0.109	0.133	0.1859	2.4716

v = scan rate; $v^{1/2}$ = SQRT of scan rate; E_{pc1} = cathodic peak potential for 1st peak; E_{pc2} = cathodic peak potential for 2nd peak; E_{pa1} = anodic peak potential for 1st peak; E_{pa2} = anodic peak potential for 2nd peak; i_{pc1} = cathodic peak current for 1st peak; i_{pc2} = cathodic peak current for 2nd peak; i_{pa1} = anodic peak current for 1st peak; i_{pa2} = anodic peak current for 2nd peak, ΔE_p = peak potential separation for 1st pair of peak; i_{pa1}/i_{pc1} = peak current ratio for 1st pair of peak

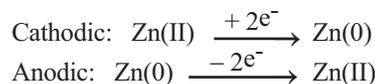
**Fig. 6.** Variation of peak current with SQRT of scan rate.

The shifting of the peaks in the complex compared to that of free metal confirmed the complexation of Cu(II) with niacinamide. The peak potential separation increases with scan rate due to slow electron transfer kinetics or ohmic potential (iR) drop. The linear increase of peak current with SQRT of scan rate revealed that the electrode process is diffusion controlled. The values of peak current ratio indicate that the process is quasi reversible (Akhtar *et al.*, 2008; Shaikh *et al.*, 2006; Wang 2006; Bard and Faulkner 2001; Brett and Brett, 1993).

Redox behaviour of the complexes [Mn(C₆H₆N₂O)₂]Cl₂ and [Zn(C₆H₆N₂O)₂]Cl₂ were also studied. The Mn-complex showed two pair of redox signals. The probable electron transfer processes are:



The CV of [Zn(C₆H₆N₂O)₂]Cl₂ showed one pair of redox signals. The probable electron transfer processes are:



The Mn and Zn complexes behaved almost similarly to that of the Cu-complex. In both the cases the electron transfer processes were diffusion controlled and quasi reversible.

Conclusion

- Niacinamide forms coordination complexes with Mn(II), Co(II), Ni(II), Cu(II) and Zn(II) in 2:1 ratio.
- Weight losing pattern of all the complexes are similar indicating similar structure of the complexes.
- All except Zn(II) produces paramagnetic complexes with the ligand.
- The redox properties of the metal ions changes appreciably on complexation with niacinamide

Acknowledgement

The authors would like to acknowledge the support from Prof. Shinmyozu of the Laboratory of Organic Structural Chemistry, Department of Molecular Chemistry, Graduate School of Sciences & IMCE, Kyushu University, Japan, for supplying the elemental analysis data of the samples.

References

- Akhtar, H.M.N., Shaikh, A.A., Ehsan, M.Q. 2008. Cyclic voltammetric study of the redox behavior of Fe(II)/Fe(III) systems forming during the oxidation of Fe(II) complexes with saccharin and 1,10- phenanthroline. *Russian Journal of Electrochemistry*, **44**: 1403-1408.

- Banwell, C.N., McCash, E.M. 1995. *Fundamentals of Molecular Spectroscopy*, pp. 84-88, 189-192, 4th edition, McGraw-Hill International Limited, UK.
- Bard, A.J., Faulkner, L.R. 2001. *Electrochemical Methods Fundamentals and Applications*, pp. 228-255, 2nd edition, John Wiley & sons, Inc., New York, USA.
- Bender, D.A. 2003. *Nutritional Biochemistry of the Vitamins*, 512 pp., 2nd edition, Cambridge University Press, UK.
- Brett, C.M.A., Brett, A.M.O. 1993. *Electrochemistry Principles, Methods and Applications*, pp. 174-191, Oxford University Press, New York, USA.
- Ehsan, M.Q., Begum, S.M., Islam, S.M.S. 2004. Preparation and characterization of pyridoxine complexes of Fe(III), Mo(VI), Cd(II), Hg(II) and U(VI). *Journal Saudi Chemical Society*, **8**: 251-256.
- Ehsan, M.Q., Khatun, S., Quyser, M.A. 2001. Preparation and characterisation of pyridoxine complexes of Mn(II), Co(II), Ni(II), Cu(II) and Zn(II). *Journal Saudi Chemical Society*, **5**: 59-65.
- Haider, S.Z., Malik, K.M.A., Khan, M.S., Bakshi, P.K., Bhuiyan, A.A., Hursthouse, M.B. 1988. Preparation, characterization and properties of some metal-thiamine compounds of general formula $(C_{12}H_{17}N_4OS)MCl_3 \cdot 0.5 H_2O$ [M = Co(II), Zn(II) and Cd(II)]. *Journal of Bangladesh Academy of Sciences*, **12**: 197-206.
- Haider, S.Z., Malik, K.M.A., Bakshi, P.K., Bhuiyan, A.A., Khan, M.S., Hursthouse, M.B. 1987. Preparation, characterization and properties of the metal-thiamine compounds $(C_{12}H_{18}N_4OS)CuCl_4$ and $(C_{12}H_{18}N_4OS)MCl_4 \cdot H_2O$ [M = Co(II), Zn(II), Cd(II) and Hg(II)]. *Journal of Bangladesh Academy of Sciences*, **11**: 117-127.
- Mamun, M.A., Ahmed, O., Bakshi, P.K., Yamauchi, S., Ehsan, M.Q. 2011. Synthesis and characterization of some metal complexes of cystine: $[Mn(C_6H_{10}N_2O_4S_2)]$; where M = Mn(II), Co(II), Ni(II), Cu(II), Zn(II), Cd(II), Hg(II) and Pb(II). *Russian Journal of Inorganic Chemistry*, **56**: 1972-1980.
- Pavia, D.L., Lampman, G.M., Kriz, G.S. 2001. *Introduction to Spectroscopy*, pp. 26, 28, 357-386, 3rd edition, Harcourt College Publisher, Fort Worth, New York, USA.
- Rahman, K.L., Mamun, M.A., Ehsan, M.Q. 2011. Preparation of metal Niacin complexes and characterization using spectroscopic and electrochemical techniques. *Russian Journal of Inorganic Chemistry*, **56**: 1436-1442.
- Shaikh, A., Begum, M., Khan, A.H., Ehsan, M.Q. 2006. Cyclic voltammetric studies of the redox behavior of iron(III)-vitamin B6 complex at carbon paste electrode. *Russian Journal of Electrochemistry*, **42**: 620-625.
- Silverstein, R.M., Webster, F.X., Kiemle, D.J. 2005. *Spectrometric Identification of Organic Compounds*, pp. 75-108, 7th edition, John Wiley & Sons, Inc., New York, USA.
- Wang, J. 2006. *Analytical Electrochemistry*, pp. 29-40, 3rd edition, John Wiley & Sons, Inc., New York, USA.