

## FULL PAPER

# Evaluating spectra, thermodynamic and kinetic parameters of the complexation reaction of organic compound or chelation therapy drug with some heavy metal pollutants

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In this paper, we examined the use of chelation therapy for treating metal intoxication in humans. Chelation therapy is the use of chelating agents (complexing agents) to detoxify poisonous metals such as Nickel, Cobalt, and Lead by converting them to chemically inert form that can be excreted without further interactions with the body. The UV-Vis measurements were carried out in the water as the best media for this work. The electronic spectrum of free chelate in water solution was characterized by a single band for pyridoxine (Vitamin B6), with a single band as  $\lambda_{\text{max}}$  nm. Adding Ni (II) and Co (II) ions to the chelate solution showed an increase in absorbance with Vitamin B6 with a little shift in  $\lambda_{\text{max}}$ . This change caused the formation of the complexes. The stoichiometry of the formed complexes was investigated by the method of continuous variation, and they were found in a ratio of (1:1). The stability constants were calculated at four temperatures at the range of (298, 303, 308, 313 and 318) °K. Thermodynamic parameters like  $\Delta H^\circ$ ,  $\Delta G^\circ$ , and  $\Delta S^\circ$  were determined at five different temperatures. Chemical kinetics showed that this effect was subjected to the pseudo-first-order chelation with Ni and Co ions.

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### KEYWORDS

Chelating agents; stoichiometry; therapy drug; UV-Vis; spectrophotometric; heavy metal.

## Introduction

Contamination by heavy metals is a serious threat to aquatic ecosystems because some of these metals are potentially toxic, even at very low concentrations. The toxicity of heavy metals released by a series of productive activities is widely recognized. Metal toxicity is the toxic effect of certain metals in certain forms and doses. Toxic metals are either in form of isolated (free) metals or as metal compounds that negatively affect people's health [1].

Chelating agents are of importance in treating toxicity and overdose effects with

metals. Chelation describes a particular way that ions and molecules bind metal ions, and involves the formation or presence of two or more coordination bonds between a polydentate ligand and a single central atom. Usually, these ligands are organic compounds that consist mainly of atoms like S, N, and O function as ligand atoms called chelators [2]. Chelation therapy consists of chelating agents which remove metal ions such as lead, aluminum, mercury, arsenic, zinc, iron, copper, and calcium from the body by converting them to a chemically inert form that can be excreted through urine.

Bidentate or multidentate ligands form ring structures that include the metal ion, and

the two-ligand atoms attached to the metal [3]. A medical procedure that involves the administration of chelators to remove heavy metals from the body is called chelation therapy. Detoxification of heavy metal by the administration of chelators forms a stable complex and inhibits the toxic heavy metal species from attacking the biological targets [4]. Lead is considered one of the most hazardous and cumulative environmental pollutants that affect all biological systems through air, water, and food sources. Toxic heavy metals are known to induce a broad range of physiological, biochemical, and behavioral dysfunction in humans. Lead poisoning still remains an important health problem.

Nickel ion is an ion of a metallic character which is known as transition metallic element in the periodic table. Nickel (II) is an important oxidation state in biochemistry which can form many complexes [5]. Nickel is considered an essential element in the body because it helps in absorbing iron and prevents anemia through building strong skeleton by strengthening bones [6,7]. This prompted us to examine chelating agent, pyridoxine ( $C_8H_{11}NO_3$ ), via its interaction with Ni (II) and Co (II) ions and forming nontoxic complexes, followed by calculating their physical thermodynamic functions using spectrophotometric measurements [8].

In general, the aim of chelation treatment is to remove toxic metal ions from the vulnerable sites in the critical organs. This requires that the chemical affinity of the complexing agent for the metal ions be higher than the affinity of the metal ions for the sensitive biological molecules [9]. Accordingly, chemical assessment of the stability constants of the formed metal-complexes may give an indication of a chelating agent's efficacy [10].

### Materials and methods

The pyridoxine ligand of ( $10^{-2}$  M) was prepared by dissolving 0.205 g in 100ml

volumetric flask using distilled water as a solvent.

#### *Nickel and cobalt nitrate solutions*

A stock solution ( $10^{-2}$  M) of Nickel nitrate [ $Ni(NO_3)_2 \cdot 6H_2O$ ] M.Wt (290.81 g.mol<sup>-1</sup>), analar/England, ( $10^{-2}$  mol.L<sup>-1</sup>) was prepared by dissolving (0.290 g) in 100 ml distilled water. A stock solution of cobalt nitrate [ $Co(NO_3)_2 \cdot 6H_2O$ ] M.Wt. (291.03 g.mol<sup>-1</sup>), ( $10^{-2}$  mol.L<sup>-1</sup>) was prepared by dissolving 0.1298 g, in 100ml volumetric flask using distilled water as a solvent. All measurements were recorded by the UV-Vis Spectrophotometer: UV-1800, using a quartz cell of 1 cm path length. Pyridoxine, nickel ion (II), and Cobalt ion were calculated in a wavelength (323-318 nm) and (323-320 nm) in the presence and absence of Ni(II) and Co(II) solutions. A series of solutions of different concentrations ranging from ( $1 \times 10^{-4}$ - $5 \times 10^{-5}$ ) M were prepared by dilution from their stock solutions of pyridoxine, and the absorption spectrum were taken for them. The Stoichiometric of the formed complexes were investigated by continuous variation (Jobs-method).

Jobs method was applied by placing (1 to 9) ml of ( $10^{-4}$  M) pyridoxine solution to a series of (10ml) volumetric flasks, which was followed by adding (9 to 1) ml of ( $10^{-4}$  M) Ni (II) ion, and Co(II) ion solutions[11,12]. These solutions were allowed to stand for the equilibrium time, and then we measured the absorbance against reagent blank. The results obtained were plotted against (X) mole fraction. Estimation of molar absorptive of the complexes was made by preparing a series of solution of (1:1) (pyridoxine-Ni) and (pyridoxine-Co) complexes in the range of ( $1 \times 10^{-5}$  to  $5 \times 10^{-5}$  M) concentration, and recording the absorbance spectrum for them. Then, we determined the rate constant and the order of interaction of Ni, Co and vitamin B6, at different temperatures (298, 303, 308, 313 and 318 K) in (0-110) min. The absorbance

was recorded. We determined the equilibrium constant by recording the absorption spectrum of them at different temperatures (298, 303, 308, 313 and 318 K).

## Results and discussion

### Absorption spectroscopy

The optimized solvent (water) was obtained by measuring the UV-Vis absorption spectra of pyridoxine in various mixture compositions using a 1cm path length quartz cell. The absorbance value of pyridoxine in the presence and absence of Ni(II) and Co(II) solutions was made in the range of (323-318 nm) and (323-320 nm).

When adding Ni(II) and Co(II) solutions to ( $10^{-4}$ M) chelating agent solutions, significant changes were observed in the electronic spectra as well as changes in absorbance. These two pieces of evidence indicated a complexes formation between the studied chelate (pyridoxine) and Ni(II) and Co(II) ions.

### Applicability of Beer's Law (Calibration Curve)

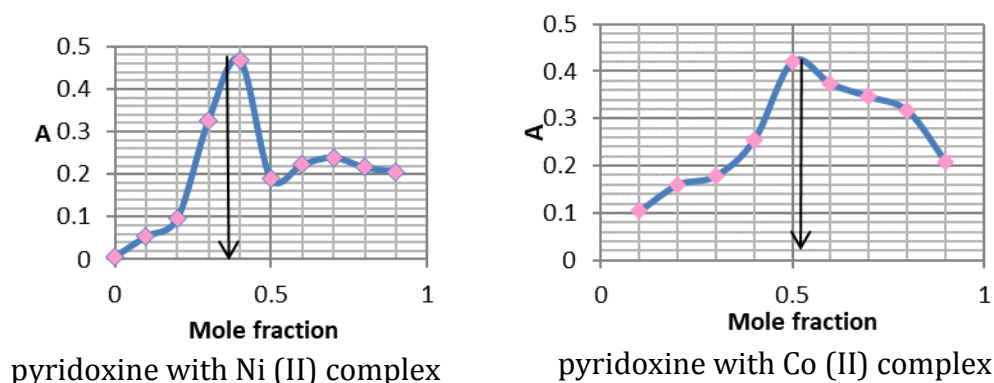
After fixing the optimum conditions, calibration graphs of the complexing agents' pyridoxine (Vitamin B6) were constructed. A series of solutions with different concentrations ranging from  $1 \times 10^{-5}$  to  $8 \times 10^{-5}$

M were prepared by dilution from the stock solutions for pyridoxine. The absorption spectrum was measured at their  $\lambda_{\max}$ .

### Stoichiometry analysis

The stoichiometry of the complexes ligand pyridoxine with Ni(II) and Co(II) ions were determined by continuous variation method (Jobs method)[11,12]. Equip-molar concentrations ( $10^{-4}$  M) of a ligand and Ni(II) and Co(II) ions were prepared, and Job's method was applied by placing 1 to 9 mL of ( $10^{-4}$  M) pyridoxine solution into a series of 10 mL volumetric flask, followed by placing 9 to 1 mL of ( $10^{-4}$  M) Ni(II). These steps were repeated for Co(II) ion solution, and the absorbance was measured at the maximum wavelength.

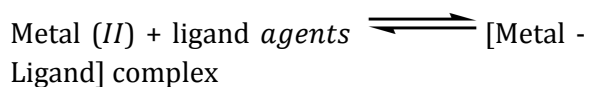
The curve displayed maxima absorbance at mole fraction  $X_{\max}$ , showing the metal ions to ligands ratio of the formed complexes. More details are shown in Figure 1, which illustrates the Jobs method plot and proves that the stoichiometric ratio of (pyridoxine-Ni) and (pyridoxine-Co) complexes at 298 °K is (1:1) as in  $n = X_{\max}/1 - X_{\max}$ . Note that  $n$  represents the coordination number of the complexes, and  $X_{\max}$  represents mole fraction corresponding to the maxima absorbance.



**FIGURE 1** Job's plot for the formation of (a) [pyridoxine -Ni] complex at  $\lambda = 323$  nm and (b) [pyridoxine -Co] complex at  $\lambda = 320$  nm, stoichiometric ratio is (1:1) at (298K)

### Stability Constant ( $K_{eq}$ )

The equilibrium constant can be calculated using the continuous variation method [13].



The reaction can best be characterized using equilibrium: (1) where  $K_{eq}$  describes the stoichiometric stability constant which describes (Ni) and (Co) metals ion, and presents the pyridoxine as (ligand) [14]. [Pyridoxine - Ni] complex equation: The Concentration of the (pyridoxine -Ni) complex at the equilibrium [15].

$$K_{eq} = \frac{[\text{metal (II) - ligand}]_{\text{complex}}}{[\text{metal (II)}]_{\text{eq}} [\text{ligand}]_{\text{eq}}} \quad (1)$$

$$K_{eq} = \frac{[A_{\text{max}} / \epsilon l]}{[C_{\text{metal}} - A_{\text{max}} / \epsilon l][C_{\text{ligand}} - A_{\text{max}} / \epsilon l]} \quad (2)$$

$A_{\text{max}}$  = the maximum absorbance of the complex;  $\epsilon$  = molar absorptivity of the complex ( $\text{L. mole}^{-1} \cdot \text{cm}^{-1}$ );  $l = 1$  path length.  $\text{cm}$ ;  $C_{\text{metal}}$  = Initial concentration of the metal ion;  $C_{\text{ligand}}$  = Initial concentration of amino acid.

$$[\text{metal (II)-ligand}]_{\text{complex}}_{\text{eq}} = \frac{\text{Absorbance}(\text{max})}{l} \quad (3)$$

$$[\text{metal (II)}]_{\text{eq}} = [\text{metal (II)}]_0 - [(\text{metal (II)-ligand})_{\text{complex}}]_{\text{eq}} \quad (4)$$

$$[\text{ligand}]_{\text{eq}} = [\text{ligand}]_0 - [(\text{metal (II)-ligand})_{\text{complex}}]_{\text{eq}} \quad (5)$$

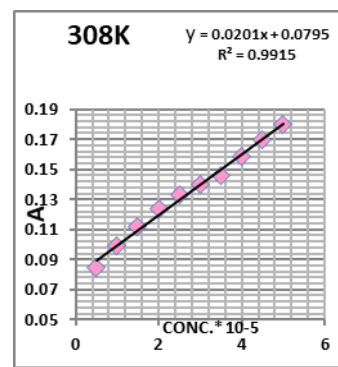
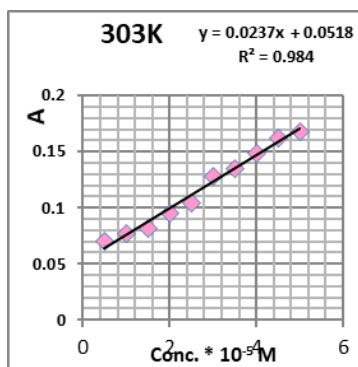
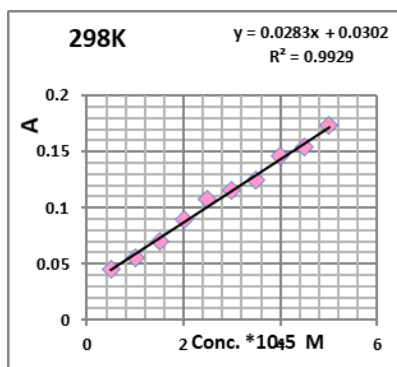
The molar absorptivity  $\epsilon$  of the complex was estimated by recording the absorbance at various concentrations of the (1:1) complexes and plotting of the absorbance of each complex against the concentration given using a intercept of the straight line with the slope equal to ( $\epsilon$ ),  $=L \cdot \text{mole}^{-1} \cdot \text{cm}^{-1}$  [16]. The values of  $k_{eq}$  obtained by the continuous variation method were determined in five temperatures (298, 303, 308, 3013 and 318K) as in Figure 2 that shows the absorbance against concentration ( $0.5 \times 10^{-5}$ – $4 \times 10^{-5}$ ) M of the (1:1) [pyridoxine-Ni] complex at temperature range of (298, 303, 308, 313 and 318) $^{\circ}\text{K}$ . Figure 3 shows the absorbance against concentration ( $0.5 \times 10^{-5}$  -  $4 \times 10^{-5}$ ) M of the (1:1) [pyridoxine-Co] complex at temperature (298, 303, 308, 313 and 318) $^{\circ}\text{K}$ . Tables 1 and 2 demonstrate the dependency of the equilibrium constant on temperature, which increases with the increase of the temperature, meaning that the stability of the [pyridoxine-Ni] and [pyridoxine- Co] complexes increases by increasing temperature.

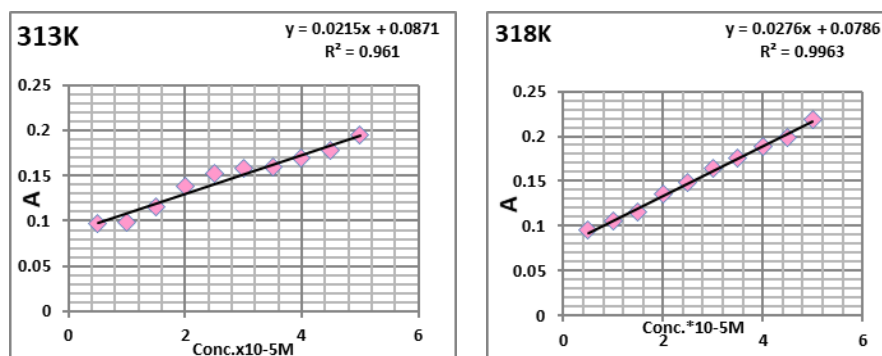
$$\epsilon [\text{Ni complex}] = 2830 \text{ L. mol}^{-1} \text{cm}^{-1}$$

$$\epsilon [\text{Co complex}] = 5230 \text{ L. mol}^{-1} \text{cm}^{-1}$$

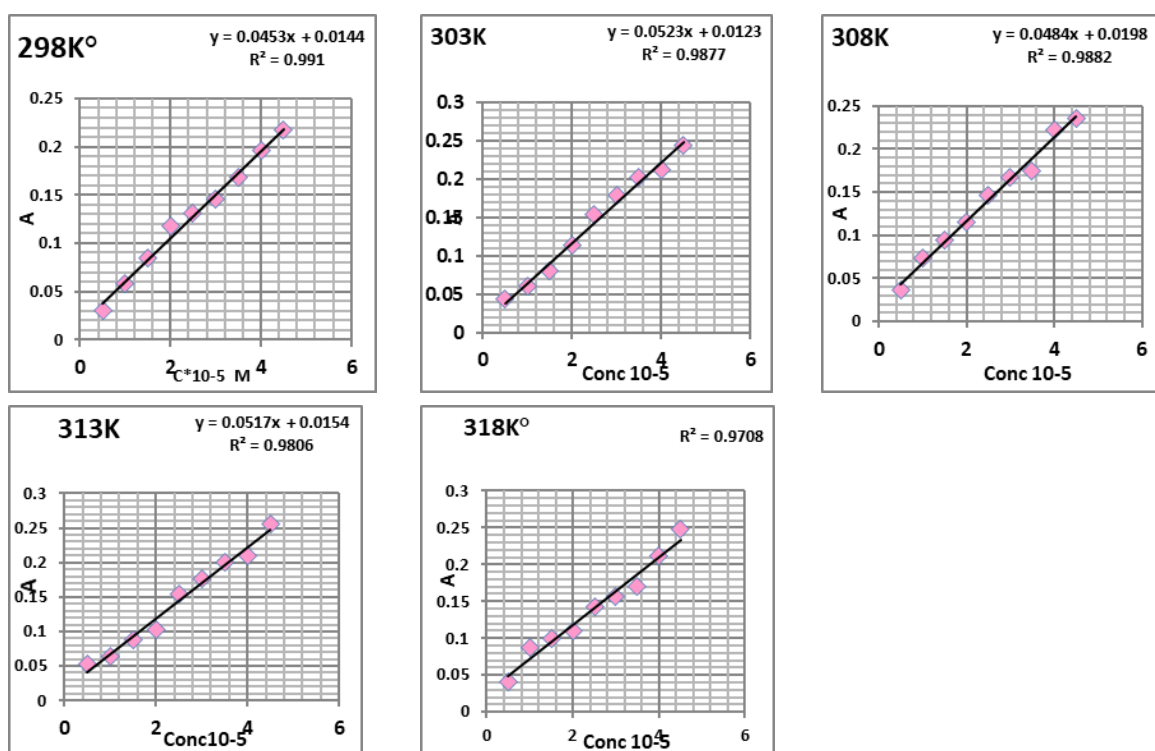
$$k_{eq} [\text{Ni complex}] = 63.1592 \times 10^4 \text{ L. mol}^{-1}$$

$$k_{eq} [\text{Co complex}] = 24.651 \times 10^3 \text{ L. mol}^{-1}$$





**FIGURE 2** The absorbance against concentration ( $0.5 \times 10^{-5}$ – $4 \times 10^{-5}$ ) M of the 1:1 [pyridoxine –Ni] complex at temperatures of (298, 303, 308, 313 and 318) °K



**FIGURE 3** The absorbance against concentration ( $0.5 \times 10^{-5}$ – $4 \times 10^{-5}$ ) M of the 1:1 [pyridoxine-Co] complex at temperatures of (298, 303, 308, 313 and 318) °K.

**TABLE 1** The dependency of the equilibrium constant on temperature which increases with the increase of the temperature, which means that the stability of the [pyridoxine-Ni] complex increases with the increase of the temperature

Temp.K	$1/T \times 10^{-3} K^{-1}$	$\epsilon \times 10^3$	$K_{eq} \times 10^4$	$K_{eq} \text{ Ln}$	$R^2$
298	3.355	2.830	4.0456	10.608	0.9929
303	3.300	2.370	8.3584	11.334	0.984
308	3.250	2.010	24.4751	12.408	0.9915
313	3.195	2.150	52.0736	13.163	0.961
318	3.145	2.760	63.1592	13.356	0.9963

**TABLE 2** The dependency of the equilibrium constant on temperature which increases with the increase of the temperature, meaning that the stability of the [pyridoxine-Co] complex increases by the increase of the temperature

T	1/T x10 <sup>-3</sup> K <sup>-1</sup>	$\epsilon \times 10^3$	Keq x10 <sup>4</sup>	LnKeq	R <sup>2</sup>
298K	3.355	4.530	17675.276	9.7799	0.991
303K	3.300	5.230	17007.299	9.74139	0.9877
308K	3.250	4.840	18341.518	9.8169	0.9735
313K	3.195	5.170	19423.303	9.87422	0.9806
318K	3.145	4.640	24651.720	10.11260	0.9708

### Thermodynamic parameters

The standard enthalpy changes  $\Delta H^0$ , the standard entropy changes  $\Delta S^0$  and the standard free energy changes  $\Delta G^0$  [17] have been reported for the complexation (metal (II) - ligand) in Tables 3 and 4.

$$\Delta G^0 = -RT \ln K_{eq} \quad (1)$$

Where, Keq is the equilibrium constant, T (K) is the temperature and R shows the global constant (J mol<sup>-1</sup> K<sup>-1</sup>).

$$\ln K_{eq} = -\Delta G^0 / RT \quad (2)$$

Both Keq and  $\Delta G^0$  are temperature-dependent amounts. Differentiating equation (2) versus (1/T) gives:

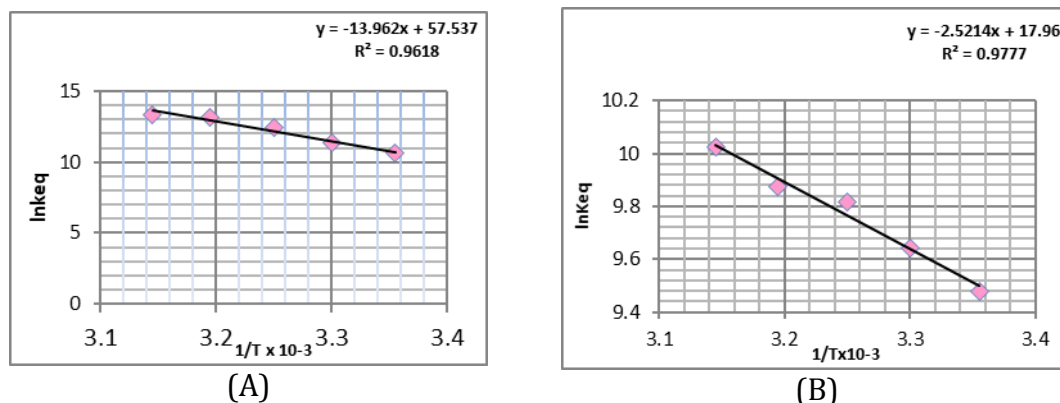
$$\ln K_{eq} = -\Delta H^0 / RT + \Delta S^0 / R \quad (3)$$

$$\text{Intercept} = \Delta S^0 / R \quad (4)$$

The evaluation of changes in entropy ( $\Delta S^0$ ) is done by the following equation (4)

$$\Delta G^0 = \Delta H^0 - T \Delta S^0 \quad (5)$$

The standard enthalpy changes were calculated by substituting the value of the slope of the plot (log Keq vs 1/T) in the Van't Hoff equation (6), as depicted in Figure 4. [18]. Gibbs's free energy is very important in deciding the direction of the process and position of equilibrium. The negative values of Gibbs free energy for these interactions indicate the spontaneous process in the direction of equilibrium and increase with the increase in temperature. The enthalpy of interaction has a positive value indicating that the formation of [pyridoxine-Ni] and [pyridoxine-Co] complexes are endothermic [19]. The positive value of enthalpy and entropy change also refer to the type of interaction between ligand - Ni (II) and Co(II) ions, which are electrostatic in nature as shown in Tables 3 and 4. The positive values of entropy ( $\Delta S^0$ ) occur because water molecules arranged around the ligand, Ni(II) and Co(II) ions became more random [20].



**FIGURE 4** Van't Hoff plot for interaction of (A) (pyridoxine -Ni) complex(B) (pyridoxine-Co) complex

**TABLE 3** Thermodynamic parameters for [pyridoxine-Ni] complex at different temperatures

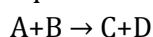
T(K)	1/T x10 <sup>-3</sup>	Keq x10 <sup>4</sup>	lnKeq	J.mol <sup>-1</sup> G°x10 <sup>4</sup> Δ	ΔH°(J.mol <sup>-1</sup> )	ΔS°(J.mol <sup>-1</sup> )
298	3.355	4.0456	10.608	-14.2442	116.086	478.386
303	3.300	8.3584	11.334	-14.4834		
308	3.250	24.4751	12.408	-14.4950		
313	3.195	52.0736	13.163	-14.9618		
318	3.145	63.1592	13.356	-15.2010		

**TABLE 4** Thermodynamic parameters for [pyridoxine -Co] complex at different temperatures

T(K)	1/T x10 <sup>-3</sup>	Keqx10 <sup>4</sup>	lnKeq	ΔG° x10 <sup>4</sup> (J.mol <sup>-1</sup> )	ΔH°(J.mol <sup>-1</sup> )	ΔS°(J.mol <sup>-1</sup> )
298K	3.355	1.3093	9.4799	-4.4476	20.963	149.319
303	3.300	1.5388	9.64139	-4.5226		
308	3.250	1.8341	9.8169	5.9829-		
313K	3.195	1.9423	9.87422	-4.6715		
318K	3.145	2.2606	10.026	-4.7462		

### Interaction kinetics

In order to investigate the interaction kinetic of Ni(II) and Co(II) ions with pyridoxine, the absorbance of (1:1) complexes were followed with time at a certain wave length. The first order rate equation and the second order rate equation were applied.



k: is the rate constant for the reaction which is independent on the concentration but depends on the temperature.

#### First order reaction

As for the first order rate law for the consumptive of a reaction A, The first order rate equation (7) and the second order rate equation (8) were applied.

$$A = -k t + \ln A_0 \quad (7)$$

First order equation

#### Second order reaction

As for the second-order rate law, we have:

$$(1/A) - (1/A_0) = k T \quad (8)$$

Second order equation

A = absorbance at time t.

A<sub>0</sub> = absorbance at time zero.

k = rate constant.

A = Absorbance of complex [Ni(II)-ligand] with deferent times.

A<sub>0</sub> = Absorbance of complex [Ni(II)-ligand] in time zero.

Tables 5 and 6 show the absorption of complexation of Ni(II) and Co(II) with pyridoxine, at (0-110) min and 318nm for the former and (0-70) min and 323 nm for the latter complex. The first complex with Ni was stable for about 0-110 minutes, while the second complex of Co was stable for about (0-70) minutes. This can be seen through the constant absorbance. The application of the first order of the reaction is shown in Figures 6 and 7 as well as in Tables 5 and 6 which illustrate the first order rate constant for the two complexes. The interaction between [pyridoxine-Nickel] and [pyridoxine-Co] complexes follows the first order with flowing rate constant.

k = 1.161x 10<sup>-2</sup> min<sup>-1</sup> for [pyridoxine-Nickel] complex

k = 3.3x10<sup>-3</sup> min<sup>-1</sup> for [pyridoxine-cobalt] complex

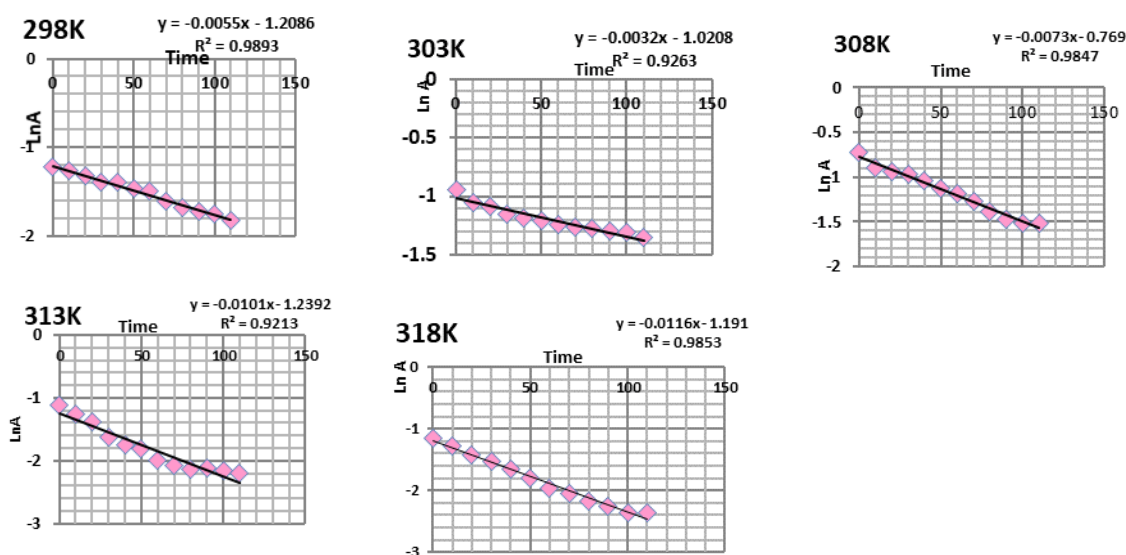
A plot of (lnA) against time (t) is presented in Figures 5 and 6 by the application of

equation (7). Straight lines were obtained which indicate the first order interaction between Ni(II) and Co(II) ions with pyridoxine

with a rate constant illustrated in Tables 7 and 8 calculated from the slope of the straight line [22].

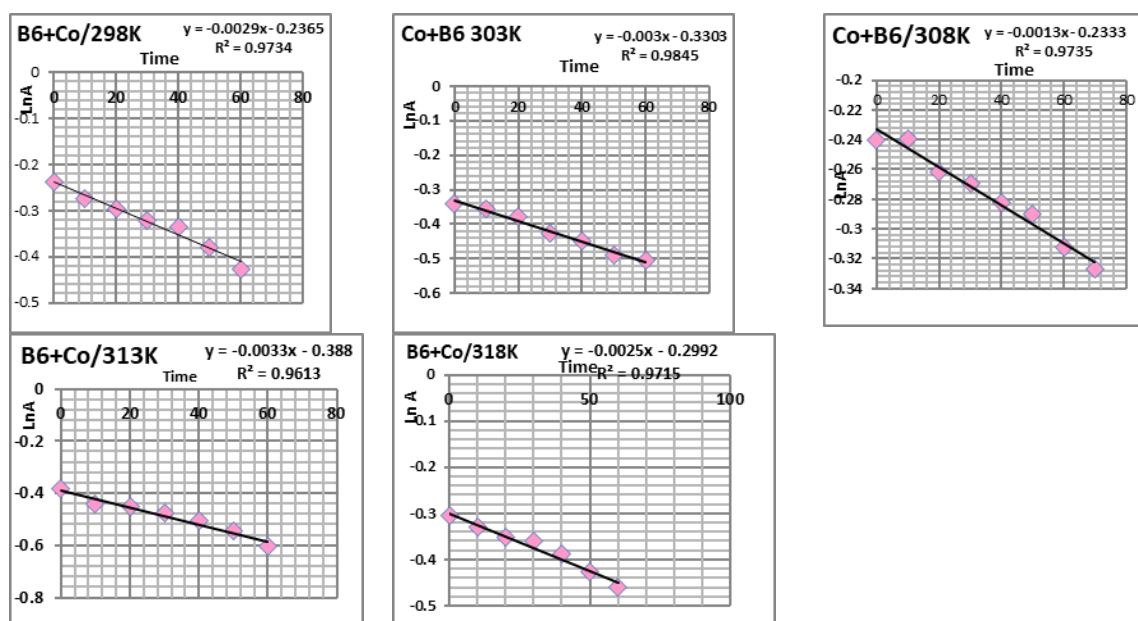
**TABLE 5** Data for application the first order equation for (1:1) [pyridoxine -Ni] complex at temperatures 298, 303, 308, 313 and 318 K

Time	298K		303K		308K		313K		318K	
	A	LnA	A	LnA	A	LnA	A	LnA	A	LnA
0	0.294	-1.224	0.3881	-0.946	0.4819	-0.730	0.329	-1.111	0.316	-1.152
10	0.281	-1.269	0.3498	-1.050	0.41	-0.891	0.285	-1.255	0.28	-1.273
20	0.266	-1.324	0.3381	-1.084	0.393	-0.933	0.254	-1.370	0.239	-1.431
30	0.25	-1.386	0.3148	-1.155	0.379	-0.970	0.198	-1.619	0.219	-1.518
40	0.247	-1.398	0.3050	-1.187	0.352	-1.044	0.175	-1.742	0.191	-1.655
50	0.23	-1.469	0.2997	-1.205	0.326	-1.120	0.1654	-1.799	0.166	-1.795
60	0.223	-1.500	0.2900	-1.238	0.305	-1.187	0.1370	-1.987	0.139	-1.973
70	0.200	-1.609	0.2820	-1.266	0.280	-1.273	0.1265	-2.067	0.128	-2.055
80	0.1863	-1.680	0.2784	-1.280	0.251	-1.382	0.1190	-2.128	0.115	-2.162
90	0.1793	-1.718	0.2743	-1.294	0.230	-1.469	0.1198	-2.122	0.105	-2.253
100	0.1740	-1.748	0.2693	-1.312	0.220	-1.514	0.1157	-2.156	0.095	-2.353
110	0.1614	-1.823	0.2593	-1.351	0.220	-1.514	0.1122	-2.187	0.095	-2.353



**FIGURE 5** The application of the first order reaction for the [pyridoxine -Ni] complex at temperatures 298, 303, 308, 313 and 318 K





**FIGURE 6** The application of the first-order reaction for the [pyridoxine-Co] complex at temperatures 298, 303, 308, 313 and 318 K

**TABLE 6** Data for application the first order equation for (1:1) [(pyridoxine-Ni) complex, at 298 K

Time	298K		303K		308K		313K		318K	
	A	LnA	A	LnA	A	LnA	A	LnA	A	LnA
0	0.789	-0.237	0.712	-0.339	0.726	-0.320	0.681	-0.384	0.738	-0.303
10	0.761	-0.273	0.701	-0.355	0.715	-0.335	0.643	-0.441	0.719	-0.329
20	0.743	-0.297	0.686	-0.377	0.702	-0.353	0.637	-0.451	0.704	-0.351
30	0.725	-0.322	0.654	-0.424	0.687	-0.375	0.622	-0.474	0.697	-0.361
40	0.716	-0.334	0.639	-0.447	0.664	-0.409	0.604	-0.504	0.679	-0.387
50	0.684	-0.379	0.614	-0.487	0.619	-0.479	0.58	-0.544	0.652	-0.427
60	0.653	-0.426	0.603	-0.505	0.614	-0.487	0.547	-0.603	0.631	-0.460

**TABLE 7** The calculated First order rate constant and second order rate constant for (1:1) [pyridoxine-Ni] complex at temperatures 298, 303, 308, 313 and 318 K

Temperatures (°K)	(k) First-order rat constant (min-1)	(k) second-order rat constant (M.min)-1
298	$5.5 \times 10^{-3}$	$2.55 \times 10^{-2}$
303	$3.2 \times 10^{-3}$	$1.03 \times 10^{-2}$
308	$7.3 \times 10^{-3}$	$2.37 \times 10^{-2}$
313	$1.01 \times 10^{-2}$	$5.8 \times 10^{-2}$
318	$1.161 \times 10^{-2}$	$7.3 \times 10^{-2}$

**TABLE 8** The calculated First order rate constant and second order rate constant for (1:1) [pyridoxine-Co] complex at temperatures 298, 303, 308, 313 and 318 K

Temperatures (°K)	(k) First-order rat constant (min <sup>-1</sup> )	(k) second-order rat constant (M.min) <sup>-1</sup>
298	2.9x10 <sup>-3</sup>	2.1 x10 <sup>-3</sup>
303	3x10 <sup>-3</sup>	1.8x10 <sup>-3</sup>
308	1.3x10 <sup>-3</sup>	1.6x10 <sup>-3</sup>
313	3.3x10 <sup>-3</sup>	4.5x10 <sup>-3</sup>
318	2.5x10 <sup>-3</sup>	5.5x10 <sup>-3</sup>

## Conclusion

Metal toxicity remains a significant health-related concern. Elimination of metal ions can be achieved by proper chelation agents. It seems that chelating agents used in combination with Vitamin B6 can be considered as a standard strategy in the treatment of heavy metal toxicity.

The complexes of the vitamin B6 with heavy metal Ni(II) and Co(II) ions showed a high tendency to Nickel(II) and Cobalt(II) ions. This was obvious from the values of their equilibrium constant with the comparison with Vitamin B6 which was considered as a good complexing agent used. The thermodynamic parameter showed that this complexation is spontaneous; the enthalpy of interaction has a positive value indicating that the formation of [pyridoxine-Ni] and [pyridoxine-Co] complexes are endothermic, with an electrostatic interaction and an increase in the order of orientation rate of complexation follows the first-order reaction kinetics confined by the straight line and a high rate constant.

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