

Kinetics and the Redox Reaction between Bis (Aspatato)(Phenylamine) Cobalt (II) Dihydrate with Nitrite Ion in Aqueous Acidic Medium

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ABSTRACT

This research focused on the kinetic studies of the redox reaction between bis (aspatato) (phenylamine) Cobalt (II) dehydrate complex and nitrite ion in aqueous acidic medium under pseudo - first order condition in excess nitrite ion, temperature= 30°C+ 0.1°C, [H] = 0.15mol/dm³, lambda max=250nm. The study aimed to investigate stoichiometry, reaction order, rate dependence on acid concentration, dielectric constant and ionic strength, as well as to elucidate the mechanism of the reaction. Experimental results revealed that the redox process had a stoichiometric ratio of 1:6, indicating that one mole of nitrite ion reacted with six mole of cobalt (II) complex. The product analysis confirmed the formation of nitric oxide (NO) and Cobalt (III) ions as the major reaction product. Kinetic analysis showed that the reaction followed first order kinetic with respect to each reactant, yielding an overall second order rate law. The rate of the reaction was found to increase with decrease in dielectric constant of the medium and with increasing ionic strength, indicating that the reaction is acid dependent and influence by the surrounding ionic environment. Test for free radical participation and intermediate complex formation where both negative, suggesting the process proceed via the outer sphere electron transfer. On the basis of these observation, a direct electron transfer mechanism was proposed for the oxidation of bis (aspatato) (phenylamine) Cobalt (II) dehydrate by nitrite ion. The study recommends further investigation of the redox behaviour of the complex using other oxoanions to establish broader mechanistic trends, as well as the application of advanced spectroscopic techniques to characterize reaction intermediates and confirmed product formation. The reaction follows the rate equation below: Rate = (a+ b [H+]) [Co³⁺] [NO₂⁻]

KEYWORDS

Aspartato, Phenylamine, Nitrite ion

I. INTRODUCTION

Redox reactions are a cornerstone of inorganic chemistry. They involve the simultaneous transfer of electrons from a donor to an acceptor atom. Various studies on the kinetics of redox reactions have been conducted by different researchers, each detailing the rate equation, the transition state in the reaction, and proposing a plausible reaction mechanism of the complex with the metal ion.

A study reported the oxidation of L-cysteine with various metal complexes. The study revealed that the different metal complexes reacted with cysteine and showed that the less polar the ligand, the more the reaction follows an outer-sphere mechanism, whereas the more polar the ligand, the greater the chances of an inner-sphere mechanism. Another study investigated the thermodynamics and kinetic reaction of acriflavine with L-cysteine in an aqueous medium. The reaction was first-order with respect to the reactant and second-order overall, and it followed an inner-sphere electron transfer.

Similarly, the kinetic and mechanistic study of neutral red with the nitrite ion was studied (Ibrahim et al., 2016). The research was conducted with the aim of elucidating the rate law and the reaction mechanism. The reaction did not reveal evidence of intermediate complex formation and displayed a negative Brønsted–Deybey salt effect. The reaction was first-order with respect to the reactant and the hydrogen ion. In the same manner, the reaction of toluidine blue with the nitrite ion has been reported. Toluidine blue was chosen for this study due to its electron donor and acceptor properties. The reaction was carried out under pseudo-first-order conditions of excess nitrite ion and has a stoichiometry of 3:1.

Nitrite ion is physiologically inorganic ion which yield bioactive NO in the blood and tissue when reduced in biological system. It also involved in neurotransmission, respiration and fighting of infections. Although, NO₂⁻ is essential in life, its over production can be deadly. Fortney has established that the toxic shocks resulting from over production of NO₂⁻ during infection can cause a fatal drop in blood pressure. Nitrite ion have been observed to reduce riboflavin, ascorbic acid and enzymes.

The use of nitrites with other agents like indigo carmine is highly desirable so as to enhance its applicability in textile industry. However, most of the literature discusses the specific rate law and its equation for L-cysteine and other oxoanions, but a detailed description of the redox reaction between bis (aspartato) (phenylamine) cobalt (II) dihydrate and the nitrite ion remains limited. This research intends to fill this gap by establishing the rate law for the nitrite ion and the complex, proposing a possible reaction mechanism, and revealing whether the reaction follows an inner- or outer-sphere mechanism.

II. MATERIALS AND METHODS

A. Materials

All chemical reagents and solvents were of analytical grade (CDH, BDH, Kermel and sigma-Aldrich) and were used without further purification. Singly distilled water was used throughout for all solution preparation.

B. Stoichiometry

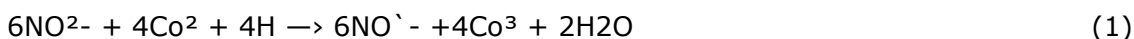
Plot of the absorbance versus mole ratio for the oxidation of Cobalt(II) Ion Concentration:

$$[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3} = 4.0 \times 10^{-3} \text{ M}$$

Hydrogen Ion (Acid) Concentration:

$$[\text{H}^+] = 0.15 \text{ mol dm}^{-3} = 0.15 \text{ M}$$

As shown in figure 1 Mol/dm^3 , $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$. The result from the plot of the spectrophotometric titration for the oxidation of the complex by nitrite ion revealed that one mole of the complex reacted with six mole of the nitrite ion as shown in the equation below:



C. Kinetic Measurement

The rate of the reaction of the redox systems were studied by monitoring the decrease in absorbance of the reacting mixture at $\lambda_{\text{max}} = 420 \text{ nm}$. All the kinetic runs were made using Jenway 6300 spectrophotometer under pseudo first-order condition of reductant concentration in at least 10 times the concentration of the oxidant at the stated temperature. Ionic strength as well as $[\text{H}^+]$ were kept constant unless otherwise stated.

Pseudo first-order plot of $\log (A_0 - A_t)$ against time was made and the slope of the plot gave the pseudo first-order rate constant, k_{obs} . The second order rate constant, K_2 , was evaluated from $k_{\text{obs}} / [\text{reductant}]$.

D. Acid Dependence

Pseudo-first and second order rate constants for the oxidation of Co^{2+} by NO_2^- in aqueous hydrochloric acid at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}(\text{NaCl})$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$.

The effect of $[\text{H}^+]$ on the reaction rate was monitored by varying the concentration of HCl within the range of $(0.4 - 2.4) \times 10^{-1} \text{ mol dm}^{-3}$, $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}(\text{NaCl})$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30.0 \pm 0.1^\circ\text{C}$. Under these conditions, the rate of the reaction increased with increase in concentration of hydrogen ion. Acid dependent rate constants are shown in Table 1 and the acid dependent rate equation is given as:

$$K_2 = A + B [\text{H}^+] \quad \text{Eqn} \quad (2)$$

E. Effect of Ionic Strength

Effect of Ionic Strength Plot of $\log K_2$ versus $\sqrt{I}$ for the oxidation of Co^{2+} by NO_2^- at $[\text{Co}^{2+}] = 4.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 420 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$. As shown in figure 2

The effect of ionic strength on the reaction rate was studied between $(1.0 - 6.0) \times 10^{-1} \text{ mol dm}^{-3}$ using various amounts of NaCl at $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30.0 \pm 0.1^\circ\text{C}$. The results as shown in Table 1 indicated that the rate of the reaction increased with increase in ionic strength. Also, the plot of $\log K_2$ against $\sqrt{I}$ was linear with a positive slope which is attributed to the fact that the redox species are of same charge

F. Effect of Added Ions

Effect of added ions on the oxidation of Co^{2+} by NO_2^- in aqueous hydrochloric acid at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}(\text{NaCl})$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$. As shown in table 2

The influence of the added ions (CH_3COO^- , NO_3^- , K^+ and Mg^{2+}) was studied by keeping the concentration of the other reactants constant while varying the concentration of the added ions. Reaction rates were observed to decrease with increase in the concentration of the added ion.

G. Effect of Dielectric Constant

Plot of $\log K_2$ versus $1/D$ at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}(\text{NaCl})$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$. As shown in figure 3.

Keeping other parameters constant, the effect of relative permittivity (D) was studied by adding varying portions of acetone-water mixture. The results showed increase in reaction rate as dielectric constant decreased as shown in the plot of $\log k_2$ against $1/D$, implying ion-dipolar interaction in the rate determining step.

H. Michaelis-Menten Plot

Plot of $1/k_{\text{obs}}$ versus $1/[\text{NO}_2^-]$ at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}(\text{NaCl})$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$.

Michaelis-Menten type plot of $1/k_{\text{obs}}$ versus $1/[\text{NO}_2^-]$ was linear with an insignificant intercept as shown in figure 4

I. Test For Free Radicals

Addition Of Acrylamide To Partially Reacted Mixture Of The Reactants Did Not Form A Gel. This Suggests That Free Radicals Are Unimportant In The Reaction.

III. RESULT AND DISCUSSION

A. Stoichiometric Study Indicated

1:6 Mole Ratio for Co^{2+} : NO_2 System. A 1:6 Stoichiometry Was Obtained For The Co(II)/NO_2^- System, However, 1:1 Stoichiometry Has Been Reported For The Oxidation Of Ethylenediamine-N, N, N', N'-Tetraacetatocobaltate (II) By Hypochlorite Ion (Ahmed Et Al., 2018) And The Oxidation Of Aquaethylenediaminetetraacetatocobaltate (II) By N-Bromosuccinimide (Nasma And Yousif, 2010). 2:1 Stoichiometry Has Been Reported for The Oxidation Of The Ethylenediaminetetraacetatocobaltate (II) Complex By Hydrogen Peroxide (Onu Et Al., 2016). 1:1 Stoichiometry For The Redox Reaction Between Indigo Carmine And Nitrite Ion (Edokpayi Et Al., 2011), And Reduction Of Nitrite Ion By Indigo Red And Toluidine Blue (Ismail Et Al., 2016) And (Hamza Et Al., 2012) Respectively.

The Formation Of The Products (NO And Co^{3+}) Of The Redox Reaction Was Confirmed Using Freshly Prepared FeSO_4 (Umoru And Effiong) And KI (Onu Et Al., 2016) Respectively. Similar Observations Have Been Reported For The $\text{NO}_2^-/\text{Indigo Carmine}$ System (Umoru And

Effiong) And Cr (VI)/ Ethylenediaaminetetraacetatocobaltate(II) (Onu Et Al., 2016) Systems Respectively.

The Reaction Showed A First Order Dependence On Rate With Respect To The Concentration Of Each Reactants. A Similar Order Has Been Reported For The Has Been Reported For The Oxidation Of Ethylenediamine-N, N, N', N'-Tetraacetatocobaltate (II) By Silver-Activated Persulphate Ion (Onu Et Al., 2018), The Oxidation Of Ethylenediaaminetetraacetatocobaltate (II) By Cr (VI) (Onu Et Al., 2016) And For The Reduction Of NO₂⁻ By Reduction Of Nitrite Ion By Indigo Red (Ismaila Et Al., 2016) And Toluidine Blue.

As Shown In Figure 3 And Table 1, Increase In Hydrogen Ion Concentration Decreased The Reaction Rate. A Similar Observation Where Reaction Rate Increased With Increase In The Concentration Of Hydrogen Ion Has Been Reported For The Oxidation Of Aquaethylenediaminetetraacetatocobaltate (II) By N-Bromosuccinimide (Nasma And Yousif, 2010), Reduction Of Nitrite Ion By Orange II.

As Shown In Figure 4 And Table 1, Reaction Rates Decreased With Increase In Ionic Strength Of The Medium. However, another Report, For the Oxidation of Ethylenediamine-N, N, N', N'-Tetraacetatocobaltate (II) By Hypochlorite Ion, Reaction Rate Increased With Increase in Ionic Strength (Ahmed Et Al., 2018)

And For the Reduction of Tartrazine by Nitrite Ion. Also, Ionic Strength Had No Effect On The Rate Of Reaction For The Reduction Of Orange II By Nitrite Ion. This Type Of Observation Is Pointing To Reactions Operating Via The Outer-Sphere Mechanistic Pathway (Lungaka Et Al., 2021, 2025). Rate Constant Increased As Medium Dielectric Constant Decreased As Shown In Figure 5. This Is Suggestive Of A Reaction That Has Outer-Sphere Characteristics.

The Effect Of Added Ions On The Rate Of The Reaction Was Studied And It Was Observed That Reaction Rate Decreased With Increase In The Added Ions. A Similar Report Has Been Documented For The Reduction Of Tartrazine By Nitrite Ion (Umoru And Effiong).

Enhancement Or Inhibition Of Reaction Rates With Increase In Added Ions Is A Characteristic Of A Reaction Occurring Through The Outer-Sphere Reaction Pathway (Lungaka Et Al., 2025). A Similar Enhancement of Reaction Rate Has Been Reported For the Redox Reaction between Ethylenediamine-N, N, N', N'-Tetraacetatocobaltate (II) and Hypochlorite Ion.

The Linearity Of The Michaelis-Menten's Plot With A Negligible Intercept Is Suggestive Of A Reaction Occurring Through The Outer-Sphere Pathway And The Absence Of Intermediate Or Precursor Complex Formation. A Similar Observation Was Reported For the Oxidation of Ethylenediamine-N, N, N', N'-Tetraacetatocobaltate (II) By Silver-Activated Persulphate Ion (Onu Et Al., 2018) and For the Reduction of Nitrite Ion by Tartrazine.

The Observation From The Free Radicals' Test Suggests That Free Radicals Did Not Participate In This Reaction As Indicated By The Negative Polymerization Test. This Is An Indication Of An Outer-Sphere Reaction Pathway In Operation (Ogori Et Al., 2017). Non-Polymerization Of Acrylamide By Cobalt (II) Complex Has Also Been Reported Elsewhere.

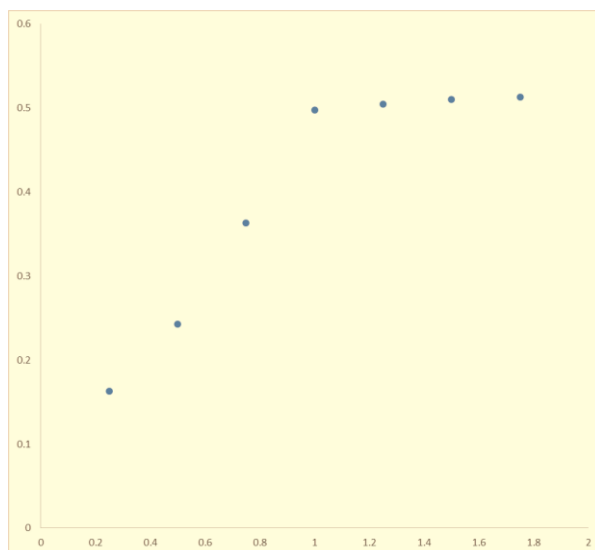


Figure 1: Stoichiometry plot of Plot of the absorbance versus mole ratio for the oxidation of Co^{2+} by NO_2^- at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol/dm}^3 (\text{NaCl})$, $[\text{H}] = 0.15$

B. Kinetic Measurement

Pseudo first-order plot of $\log (A_0 - A_t)$ against time was made and the slope of the plot gave the pseudo first-order rate constant, k_{obs} . The second order rate constant, K_2 , was evaluated from $k_{\text{obs}} / [\text{reductant}]$ (Ogori et al., 2021). The reaction followed first order kinetic with respect to the concentration of each of the reactant, giving an overall order of two. The rate equation is given by:

$$\frac{-d[\text{Co(II)}]}{dt} = K_2 [\text{Co}^{2+}] [\text{NO}_2^-] \text{ eqn} \quad (3)$$

C. Acid dependence

Table1: Pseudo-first and second order rate constants for the oxidation of Co^{2+} by NO_2^- in aqueous hydrochloric acid at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3} (\text{NaCl})$, $[\text{H}] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ \text{C}$.

$10^1 [\text{NO}_2^-]$ mol dm^{-3}	$10^1 [\text{H}^+]$ mol dm^{-3}	$I, 10^1$ mol dm^{-3} (NaCl)	$10^3 k_{\text{obs}}$ s^{-1}	$10^2 k_2$ $\text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$
0.4	1.5	6.0	2.16	5.40
0.6	1.5	6.0	4.42	5.50
0.8	1.5	6.0	5.45	5.50
1.0	1.5	6.0	6.42	5.40
1.2	1.5	6.0	7.55	5.40
1.4	1.5	6.0	9.63	5.40
0.4	0.4	6.0	1.60	4.00
0.4	0.8	6.0	3.80	4.75
0.4	1.5	6.0	9.50	6.33
0.4	2.0	6.0	14.25	7.13

0.4	2.4	6.0	18.90	7.88
0.4	1.5	0.8	1.30	1.63
0.4	1.5	1.6	2.70	1.69
0.4	1.5	2.4	5.50	2.30
0.4	1.5	3.2	9.05	2.83
0.4	1.5	6.0	18.37	3.06

D. Effect of Ionic Strength

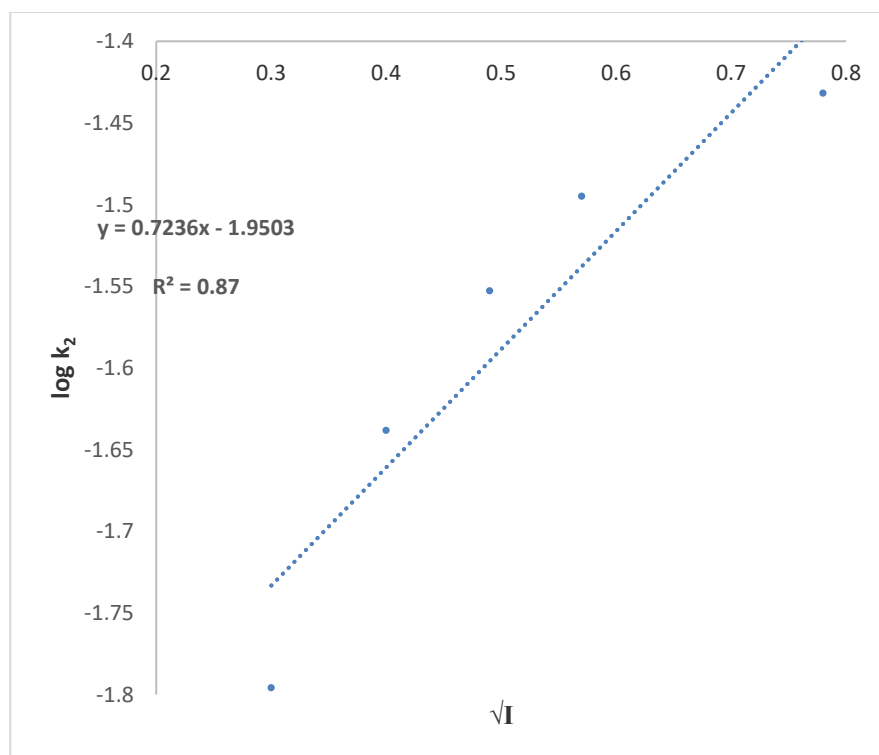


Figure 2: Effect of Ionic Strength Plot of $\log k_2$ versus $\sqrt{I}$ for the oxidation of Co^{2+} by NO_2^- at $[\text{Co}^{2+}] = 4.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 420 \text{ nm}$ and $T = 30 \pm 0.1^\circ\text{C}$.

E. Effect of Added Ions

Table 2: Effect Of Added Ions On The Oxidation Of Co^{2+} By NO_2^- In Aqueous Hydrochloric Acid At $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ Mol Dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ Mol Dm}^{-3}$, $I = 0.6 \text{ Mol Dm}^{-3}(\text{NaCl})$, $[\text{H}] = 0.15 \text{ Mol Dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ Nm}$ And $T = 30 \pm 0.1^\circ\text{C}$.

X	$10^1[\text{X}], \text{mol dm}^{-3}$	$10^3 k_{\text{obs}}, \text{s}^{-1}$	$10^2 k_2, \text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$
CH_3COO^-	0.8	3.00	3.75
	1.6	2.50	1.56
	2.4	2.10	0.88
	3.2	1.75	0.55
	4.0	1.20	0.30
NO_3^-	0.8	5.00	6.25

	1.6	4.70	2.94
	2.4	4.20	1.75
	3.2	3.60	1.13
	4.0	2.50	0.63
Mg ²⁺	0.8	8.50	10.63
	1.6	6.80	4.25
	2.4	5.50	2.29
	3.2	4.20	1.31
	4.0	2.90	0.73
K ⁺	0.8	4.22	5.25
	1.6	3.60	2.25
	2.4	2.90	1.21
	3.2	2.00	0.63
	4.0	1.45	0.36

F. Effect of Dielectric Constant

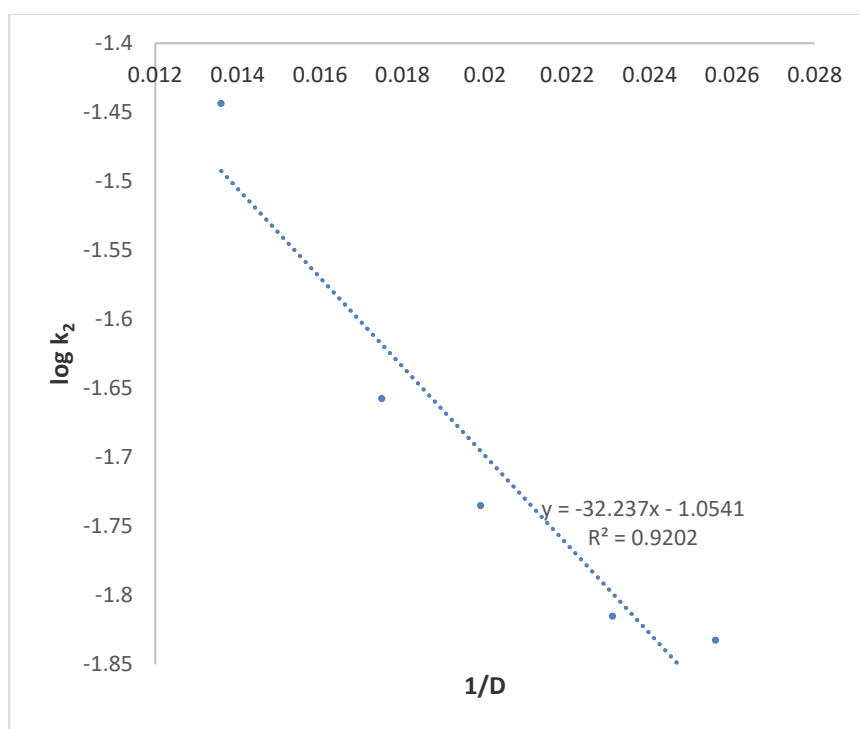


Figure 3: Plot of $\log K_2$ versus $1/D$ at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $[\text{NO}_2^-] = 0.04 \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}$ (NaCl), $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ \text{C}$

G. Michaelis-Menten Plot

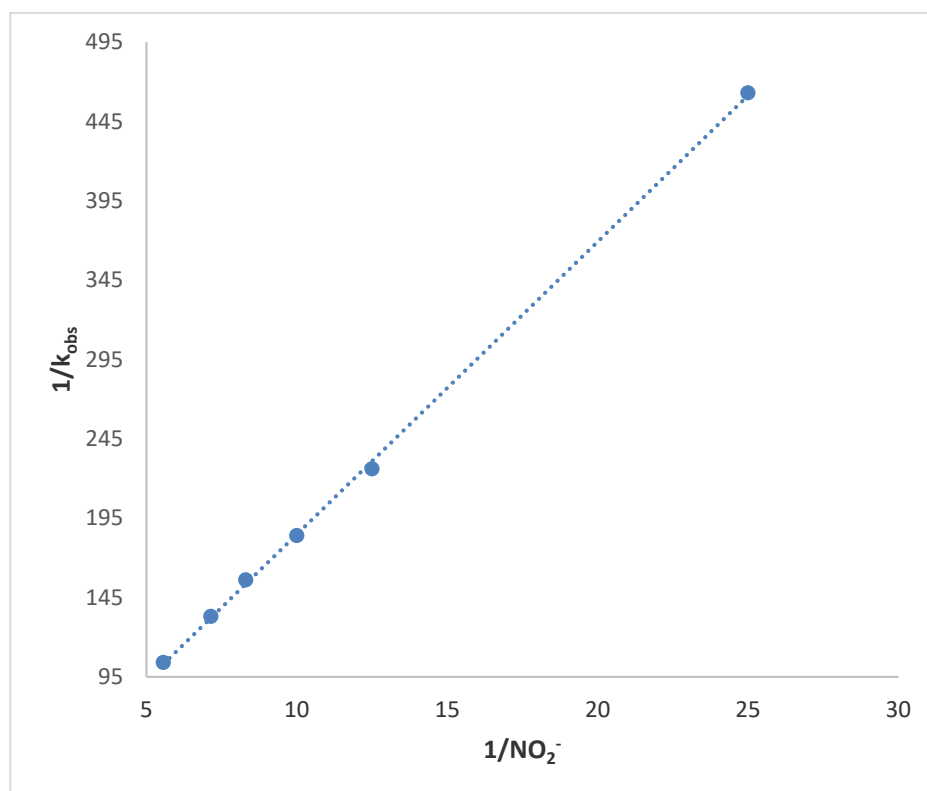


Figure 4: Plot of $1/k_{\text{obs}}$ versus $1/[\text{NO}_2^-]$ at $[\text{Co}^{2+}] = 0.4 \times 10^{-2} \text{ mol dm}^{-3}$, $I = 0.6 \text{ mol dm}^{-3}$ (NaCl), $[\text{H}^+] = 0.15 \text{ mol dm}^{-3}$, $\lambda_{\text{max}} = 250 \text{ nm}$ and $T = 30 \pm 0.1^\circ \text{C}$

IV. CONCLUSION

The redox reaction between bis-(aspartato) (phenylamine) Cobalt (II) dehydrate with nitrite ion in aqueous acidic medium:

- Has a stoichiometry of 1:6. That is, one mole of nitrite ion reacted with six moles of Co(II) COMPLEX
- The product analysis showed that NO and Co(III) were the product formed at the end of the reaction
- The reaction followed first order kinetics with respect to the concentration of each of the reactant, giving an overall order of two
- The reaction is acid dependent and reaction rates were enhanced as medium dielectric constant decreased
- Reaction rates also increased with increase in added ion and ionic strength.
- Free radicals did not participate in the reaction and there is no evidence to implicate intermediate complex formation as seen in the free radical test and test for intermediate complex formation.

V. MECHANISM



From equations (5) and (6), the rate equation can be written as:

$$\text{Rate} = k_2 [\text{HCo}^{2+}] + k_3 [\text{Co}^{3+}] [\text{NO}_2^-] \quad (7)$$

From equation (4),

$$[\text{HCo}^{2+}] = k_1 [\text{Co}^{2+}] [\text{H}^+] \quad (8)$$

Substituting equation (8) into (7), we obtain:

$$\text{Rate} = k_1 k_2 [\text{HCo}^{2+}] + k_3 [\text{NO}_2^-] [\text{Co}^{3+}] \quad (9)$$

$$\text{Rate} = (k_3 + k_1 k_2 [\text{H}^+]) [\text{Co}^{3+}] [\text{NO}_2^-] \quad (10)$$

Equation (10) is analogous to equation (2), where:

$$a = k_3 = 2.7 \times 10^{-3} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$

$$b = k_1 k_2 = 8.7 \times 10^{-2} \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$$

REFERENCES

- [1] Hamza M. Abdudel- halim, Adnan S. Abu- sirrah and Shatha E. Qaqish, Kinetics of oxidation of L -cystien by transition metal complexes. *Asiya J Chem.*947-956(2006)
- [2] I.U Nkole, S.O Idris, thermodynamics and kinetic investigation of reaction of Acriflavin with L- cysteine in aqueous medium. *Chemistry Africa*,731-740(2021)
- [3] Ismaila, I. Idris, S. O. and Onu, A. D. (2016). Kinetics and mechanism of redox reaction of neutral red with nitrite ion in aqueous acidic medium. *International Letters of Chemistry, Physics and Astronomy*, 67, 50-57.
- [4] S. A Hamza, J.F. Iyun, S.O. Idris, kinetics and mechanism of toluidine blue and nitrite ion in aqueous acidic medium (2012). *Archive of Applied Science Research*.2012,4(1):10-18(<http://scholars.research.library.com/archive.html>)

- [5] Umoru, P. E. and Effiong, U. I. (2022). Kinetics and mechanism of the reduction of tartrazine by nitrite ion in aqueous acidic medium. *Academic Journal of Chemistry*, 7(1), 10-16.
- [6] Vlasova, E. A., Hessenauer-Ilicheva, N., Salnikov, D. S., Kudrik, E. V., Makarov, S. V., & van Eldik, R. (2009). Kinetics and mechanism of the Co (II)-assisted oxidation of L-ascorbic acid by dioxygen and nitrite in aqueous solution. *Dalton Transactions*, (43), 9637-964
- [7] Duboc, C. et al. (2018). Redox Interconversion between Cobalt (III) Thiolate and Cobalt (II) Disulfide Compounds. *Inorganic Chemistry*, 57(13), 7701-7711.
- [8] Vlasova, E. A. et al. (2009). The Kinetics and Mechanism of the Co (II)-Assisted Oxidation of L-Ascorbic Acid by Dioxygen and Nitrite in Aqueous Solution. *Dalton Transactions*, 43, 9637-9646.
- [9] Sutin, N. (1983). Electron Transfer Reactions in Transition Metal Complexes. *Progress in Inorganic Chemistry*, 30, 441-496
- [10] Duboc, C. et al. (2018). Redox Interconversion between Cobalt (III) Thiolate and Cobalt (II) Disulfide Compounds. *Inorganic Chemistry*, 57(13), 7701-7711.