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# Potentiometric Studies on Electrolyte Effects on Complex Equilibria of Some Substituted 5-(2-Hydroxy Phenyl) Pyrazoles

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## ABSTRACT

*The proton-ligand stability constants of five important substituted 5-(2-hydroxy phenyl) pyrazoles and metal-ligand stability constants of their complexes with Co (II) and Ni (II) metal ions have been determined in 70% v/v dioxane-water media at different ionic strength (0.02, 0.04, 0.06, 0.08, 0.1 mol dm$^{-3}$ of electrolyte, $KNO_3$) and at constant temperature of 303.15K by potentiometric method. The pK and logK values decreased with increase in ionic strength of medium, which indicated the opposite charges on reacting species. The values of stability constants for Ni (II) were greater than for Co (II) metal ion. The thermodynamic stability constants at zero ionic strength have also been determined. The effect of presence of an extra electrolyte on dissociation and complex equilibria of pyrazoles has been studied.*

**Keywords**: potentiometric titration, stability constants, ionic strength.

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## INTRODUCTION

Dissociation of organic acids and their interactions with metal ions (complex formation) may be extremely sensitive to ionic strength of the medium. If charges on the reacting species are opposite then there is a decrease in the reaction rate with increasing ionic strength whereas if the charges are identical, an increase in the reaction rate will occur and if one of the reactant is charge less the reaction rate does affect by ionic strength of the medium. Ionic strength measures the intensity of an electric field of solution due to the presence of ions in a solution. Ionic strength of medium affects the rates at which ions react with each other and hence the extent to which the reaction occurs. It is related to the concentration of electrolytes and indicates how effectively the charge on a particular ion is shielded or stabilized by other ions in an electrolyte.

Pyrazoles and its derivatives have biological applications [1-3]; they are good complex forming agents as they contain donor atoms like nitrogen and oxygen. Study of stability constants of these compounds with metal ions at different ionic strength of medium provides tool for the determination of charges on the reacting species and evaluation of stability constants at zero ionic strength. The complex formation equilibria of pyrazole derivatives and different metal ions have been reported [4-7]. Many workers have studied the effect of electrolyte concentration (ionic strength of medium) on proton-ligand and metal-ligand stability constants of different organic ligands [8-14].

Pyrazoles gained importance due to analgesic, antipyretic and anti-inflammatory activities [15], in view of the importance of pyrazoles, present investigation deals with the study of physicochemical properties and effect of ionic strength of electrolyte on complex equilibria of pyrazoles and metal ions in 70% v/v dioxane-water mixture by pH-metric titration technique and hence to study the primary kinetic salt effect.

## MATERIALS AND METHODS

All the chemicals used in present study were of analytical grade. Metal ion solutions (0.002 mol $dm^{-3}$) were prepared from metal chlorides in doubly distilled water and standardized by using EDTA solution [16]. The stock solutions of 0.01 mol $dm^{-3}$ $HNO_3$, 0.1103 mol $dm^{-3}$ NaOH and 1 mol $dm^{-3}$ $KNO_3$ were prepared by dissolving accurate amounts Analytical reagent grade compounds in $CO_2$-free doubly distilled water and same solutions were used for all the titrations. The NaOH solution was standardized with oxalic acid solution. The ligand solutions (0.002 mol $dm^{-3}$) were prepared by dissolving accurate amount of compound in dioxane-water. Dioxane was purified by the recommended procedure [17].

The measurement of pH was carried out with ELICO-L1-10 pH meter with accuracy ±0.05 units using combined electrode assembly. The pH meter was calibrated against standard buffers solutions (pH 4.00 and 9.18). The pH meter was switched on before half an hour for warm up of instrument. The pH-metric titrations of following solutions were performed against NaOH solution:

***a) Acid titration***: 5 ml of 0.01 mol $dm^{-3}$ HCl + 2.25 ml 1 mol $dm^{-3}$ $KNO_3$ + 35 ml dioxane + 7.75 ml water
***b) Ligand titration***: 5 ml of 0.01 mol $dm^{-3}$ HCl + 2.25 ml 1 mol $dm^{-3}$ $KNO_3$ + 30 ml dioxane + 7.75 ml water + 5 ml of 0.002 mol $dm^{-3}$ ligand
***c) Metal titration***: 5 ml of 0.01 mol $dm^{-3}$ HCl + 2.25 ml 1 mol $dm^{-3}$ $KNO_3$ + 30 ml dioxane + 5.25 ml water + 5 ml of 0.002 mol $dm^{-3}$ ligand + 2.5 ml of 0.002 mol $dm^{-3}$ metal salt

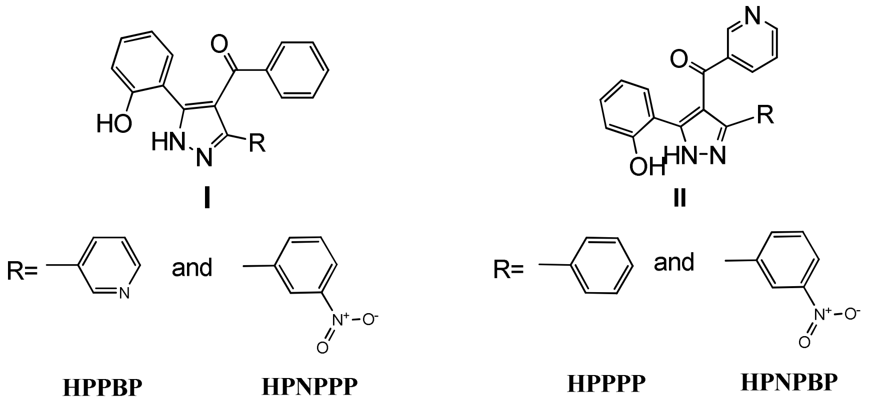


**Fig. 1. General structures of pyrazoles (ligands) used in this investigation**

Every time the appropriate quantity of 1 mol $dm^{-3}$ $KNO_3$ stock solution was added to the system to maintain the ionic strength at 0.02, 0.04, 0.06, 0.08 and 0.1. The total volume of each mixture was adjusted to 50 ml by 70:30 (v/v) dioxane-water media. All the potentiometric titrations were performed over the pH range 2.0-11.0. Bjerrum-Calvin titration technique as applied by Van Uitert et al for aqueous-non-aqueous media was used. The pH meter readings were corrected according to Van Uitert procedures [18]. The structures of substituted pyrazoles used in investigation are shown in Figure (1).

The structure of one of the ligand, [5-(2-hydroxyphenyl)-3-(pyridin-3-yl)-4-(benzoyl)]-pyrazol and its deprotonated species are shown in Figure (2).

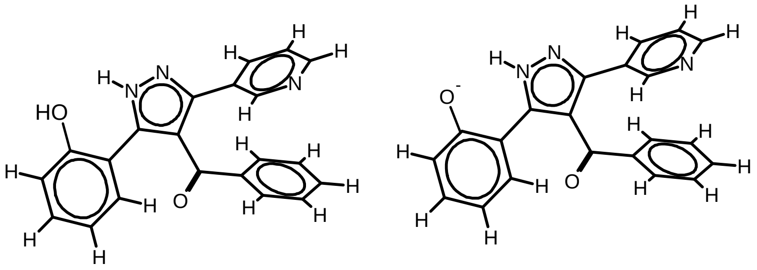


**Figure (2): Energy stabilized structures of 5-(2-hydroxyphenyl)-3-(pyridin-3-yl)-4-(benzoyl)]-pyrazol and its deprotonated species**

## Theoretical

The number of protons associated with pyrazoles at different pH values were calculated from titration curves of the acid in absence and presence of a ligand according to Calvin-Bjerrum's pH titration technique as used by Irving and Rossotti. According to Calvin-Bjerrum's method, the average number of protons associated with the anionic ligand is given by following equation:

$$\bar{n}_A = \gamma - \frac{(E^0 + N)(V_2 - V_1)}{(V^0 + V_1) \cdot T^0{}_L} \ldots(1)$$

Where, $\gamma$ is total proton number associated with the original ligand, $V_1$ and $V_2$ are the volumes of alkali required to reach the same pH on the titration curves of hydrochloric acid and organic ligand respectively, $V^0$ is initial volume of the acid + ligand solution, N is the normality of NaOH solution, $E^0$ initial free acid concentration and $T^0{}_L$ is total initial concentration of the ligand.

The average of proton-ligand formation number at various pH values for the ligand was determined by using above equation and the formation curves for proton-ligand systems were constructed. Using half integral method, the value of p*K*a was read directly as a pH at which proton ligand formation number equal to 0.5.

The accurate values of pK were determined by pointwise calculations using following equation. The values of proton ligand formation number selected for this were 0.2-0.8.

$$\log \frac{\bar{n}}{(1-\bar{n})} = pK - pH \ldots(2)$$

Average values of proton ligand formation number were taken as correct value of pK. The values of pK calculated by pointwise calculations method were in good agreement with those obtained by the half integral method.

For calculation of the stability constants of binary complexes using the potentiometric titration data of the solutions from (*a*) to (*c*) and according to Irving and Rossotti's method, the metal-ligand formation number at various pH values were determined. According to Calvin-Bjerrum's method, the metal-ligand formation number is given by equation:

$$\bar{n} = \frac{(E^0 + N)(V_3 - V_2)}{(V^0 + V_2) \cdot \bar{n}_A T^0{}_M} \text{...(3)}$$

Where, $V_1$, $V_2$, and $V_3$ are the volumes of alkali required to reach the same pH on the titration curves of hydrochloric acid, ligand and complex, respectively, $V^0$ is initial volume of the acid plus ligand solution, N is the normality of NaOH solution, $E^0$ is initial free acid concentration and $T^0M$ is the total concentration of metal ions present in solution.

The free ligand exponent (pL), was calculated by following equation, 4 [19].

$$pL = \log_{10} \frac{\sum_{n=0}^{n=i} \beta_n{}^H \left(\frac{1}{[H^+]}\right)^n}{\{T^0{}_L - \bar{n} T^0{}_M\}} \times \frac{(V^0 + V_3)}{V^0} \text{...(4)}$$

Formation curve of the metal-ligand system was drawn according to Irving and Rossotti method and half integral values of stability constants $\log K_1$ and $\log K_2$ were read directly from the formation curves at metal ligand formation number = 0.5 and 1.5 respectively.

Metal-ligand stability constants for 1:1 and 1:2 complex formations were calculated by pointwise calculations using equations (5) and (6).

$$\log \frac{\bar{n}}{(1-\bar{n})} = \log K_1 - pL \text{...(5)}$$

$$\log \frac{(\bar{n}-1)}{(2-\bar{n})} = \log K_2 - pL \text{...(6)}$$

The linear equation was solved for different values of metal ligand formation number and pL. The averages of the values were taken as correct value of log $K_1$ and log$K_2$. The values of metal ligand formation number were selected in the range 0.2 to 0.8 and 1.2-1.8 for 1:1 and 1:2 complex formations respectively. All calculations were done using excel program on a personal computer.

**Table (1): pK values of substituted pyrazoles at 0.15 mol dm$^{-3}$ ionic strength in 70% dioxane-water**

| Sr. No. | Name of ligand | Proton ligand stability constants | |
|---|---|---|---|
| | | Pointwise method | Half integral method |
| 1 | HPPBP | 5.03 | 5.12 |
| 2 | HPNPPP | 4.86 | 4.98 |
| 3 | HPNPBP | 5.07 | 5.21 |
| 4 | HPPPP | 5.79 | 5.92 |
| 5 | HPNPFP | 4.98 | 5.21 |

## RESULTS AND DISCUSSION

The ligand titration curves were displaced to right side of acid titration curve along volume (ml of NaOH solution) axis which is an indication dissociation of proton from pyrazoles at a given pH. Also, the metal titration curves were displaced to the right side of ligand titration curves along volume axis indicated the formation of complex upon proton release. Complex formation was also conformed by change in color of solution. Metal ion solutions used in present study were very dilute; hence there was no possibility of formation of polynuclear complexes [20]. The maximum value of metal ligand formation number was ≈ 2 indicating the formation of 1:1 and 1:2 (n (metal): n (ligand)) complexes only. The large decrease in pH for the metal titration curves relative to ligand titration curves points to the formation of strong metal complexes [21]. The color of the solution after complex formation was observed to be different from the color of the ligand at the same pH.

**Table (2): pK and log K values of pyrazoles and their complexes with Ni (II) and Co (II) at different ionic strength in 70% dioxane-water**

| μ | √μ | pK | $\log K_1$ | $\log K_2$ | $\log K_1$ | $\log K_2$ |
|---|---|---|---|---|---|---|
| | | | Ni (II) | | Co (II) | |
| 5-(2-hydroxyphenyl)-3-(pyridin-3-yl)-4-(benzoyl)]-pyrazol (HPPBP) | | | | | | |
| 0.02 | 0.1414 | 5.96 | 6.23 | 5.98 | 5.95 | 5.61 |
| 0.04 | 0.2000 | 5.73 | 6.12 | 5.83 | 5.76 | 5.29 |
| 0.06 | 0.2449 | 5.52 | 5.81 | 5.61 | 5.53 | 5.09 |
| 0.08 | 0.2828 | 5.39 | 5.58 | 5.33 | 5.39 | 4.93 |
| 0.10 | 0.3162 | 5.23 | 5.24 | 4.93 | 4.96 | 4.81 |
| 5-(2-hydroxyphenyl)-3-(3-nitrophenyl)-4-(3-pyridinoyl)]-pyrazol (HPNPPP) | | | | | | |
| 0.02 | 0.1414 | 5.89 | 5.98 | 5.47 | 5.23 | 5.06 |
| 0.04 | 0.2000 | 5.67 | 5.86 | 5.23 | 5.12 | 4.92 |
| 0.06 | 0.2449 | 5.42 | 5.69 | 5.03 | 4.98 | 4.71 |
| 0.08 | 0.2828 | 5.21 | 5.41 | 4.91 | 4.79 | 4.59 |
| 0.10 | 0.3162 | 5.04 | 5.28 | 4.78 | 4.53 | 4.37 |
| 5-(2hydroxyphenyl)-3-(3-nitrophenyl)-(4-benzoyl)]-pyrazol (HPNPBP) | | | | | | |
| 0.02 | 0.1414 | 6.05 | 5.76 | 5.24 | 6.16 | 4.83 |
| 0.04 | 0.2000 | 5.93 | 5.71 | 5.16 | 6.03 | 4.69 |
| 0.06 | 0.2449 | 5.74 | 5.61 | 5.03 | 5.89 | 4.41 |
| 0.08 | 0.2828 | 5.52 | 5.48 | 4.91 | 5.63 | 4.23 |
| 0.10 | 0.3162 | 5.29 | 5.39 | 4.82 | 5.39 | 4.03 |
| 5-(2-hydroxyphenyl)-3 (phenyl)-4-(3-pyridinoyl)]-pyrazol (HPPPP) | | | | | | |
| 0.02 | 0.1414 | 6.81 | 6.12 | 5.53 | 6.07 | 5.76 |
| 0.04 | 0.2000 | 6.56 | 5.98 | 5.28 | 5.92 | 5.54 |
| 0.06 | 0.2449 | 6.41 | 5.86 | 5.02 | 5.76 | 5.35 |
| 0.08 | 0.2828 | 6.28 | 5.67 | 4.91 | 5.59 | 5.12 |
| 0.10 | 0.3162 | 6.01 | 5.34 | 4.72 | 5.38 | 4.90 |
| 5-(2-hydroxyphenyl)-3-(3-nitrophenyl)-4-(2-furoyl) pyrazol (HPNPFP) | | | | | | |
| 0.02 | 0.1414 | 5.74 | 5.93 | 4.53 | 5.16 | 4.83 |
| 0.04 | 0.2000 | 5.64 | 5.61 | 4.38 | 5.06 | 4.68 |
| 0.06 | 0.2449 | 5.58 | 5.29 | 4.16 | 4.89 | 4.47 |
| 0.08 | 0.2828 | 5.43 | 5.07 | 3.95 | 4.65 | 4.29 |
| 0.10 | 0.3162 | 5.32 | 4.86 | 3.71 | 4.29 | 4.15 |

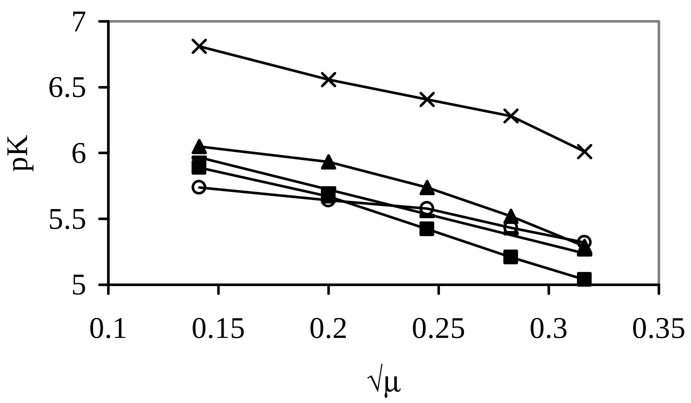
The pK and logK values were calculated by using Calvin-Bjerrum's pH titration technique as used by Irving and Rossotti [22 and 23]. The metal ligand stability constants of Ni (II) are greater than Co (II) which may be due to two reasons (1) the additional stabilization present in Co(II) due to John-Teller distortion and (2) the favourable entropy effect.

The proton ligand stability constants determined by both pointwise and half integral method for pyrazoles at constant ionic strength (0.15 mol $dm^{-3}$ of $KNO_3$) are reported in Table (1). The proton ligand and metal ligand stability constants at different ionic strengths of medium are reported in Table (2).

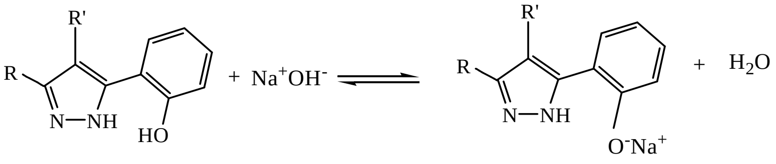
It can be seen from Table (2) that the pK values decreases with increase in ionic strength of the medium for all the pyrazoles. This clearly indicates that, there is increase in hydrogen ion concentration upon increase in ionic strength of medium. It can be clearly observed from Table (1) and (2) that there is a great difference in pK values of pyrazoles at maximum ionic strength (0.15 mol $dm^{-3}$) and minimum ionic strength (0.02 mol $dm^{-3}$). From 0.15 mol $dm^{-3}$ to 0.02 mol $dm^{-3}$ of ionic strength the stability constants have increased a lot. Thermodynamic proton ligand stability constants, $pK^0$ were determined at zero ionic strength from the plots of pK versus $\sqrt{\mu}$, by extrapolating the curves to zero ionic strength, Figure (3).

**Figure (3): Plots of pK versus $\sqrt{\mu}$**

*(× = HPPPP, ▲ = HPNPBP,  = HPPBP, ▪ = HPNPPP and ○ = HPNPFP)*



The dissociation of weak acid, pyrazole at particular pH can be represented as follows:



The $H^+$ ions produced by dissociation of pyrazoles follows the following equation [24]:

$$\log H^{+} = \log Ka + \log \frac{[HOPy]}{[OPy^{-}]} + \frac{2A\mu^{1/2}}{1+\mu^{1/2}} \quad ...(7)$$

Where, μ is ionic strength of medium, [HOPy] is concentration of substituted pyrazole, $[OPy^-]$ =concentration of deprotonated substituted pyrazole, A=constant characteristic of solvent at a given temperature. Above equation can be best fitted to dissociation equilibria of these compounds. Hence the concentration of hydrogen ion increases if ionic strength is increased and the rate of dissociation of proton will also increase. This effect of added salt ($KNO_3$) on weak acid dissociation equilibria is secondary salt effect. For metal-ligand stability constants, the dependence of logK on ionic strength according to primary salt effect is given by following equation [24]

$$\log K = \log K^{0} + \frac{2A\mu^{1/2}}{(1+\mu^{1/2})} z_A z_B \ldots(8)$$

If $\mu^{1/2}$ <<<1 then,

$$\log K = \log K^{0} + 2.A.z_A z_B \mu^{1/2} \ldots(9)$$

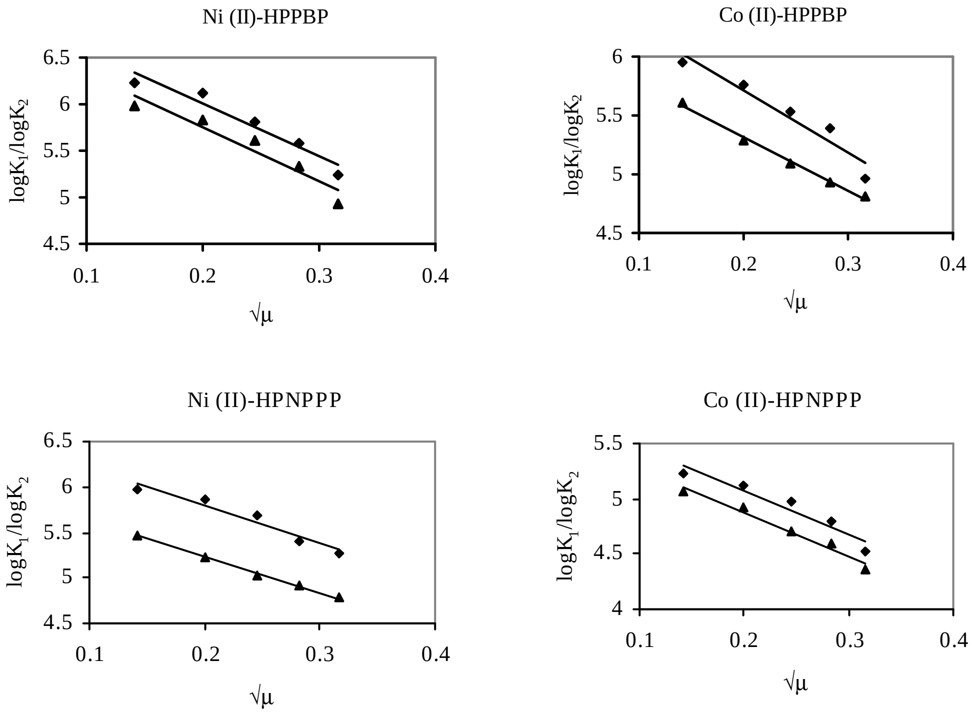
$$\log K = \log K^{0} + 1.02\, z_A z_B \mu^{1/2} \ldots(10)$$

Also; for proton-ligand stability constant:

$$pK = pK^{0} + 1.02\, z_A z_B \mu^{1/2} \ldots(11)$$

Where, logK is metal-ligand stability constant of actual ionic media, $\log K^0$ is metal-ligand stability constant of reference ionic media that is at zero ionic strength and $z_A$ and $z_B$ are the charges on reacting species, that is metal ions and pyrazole. Here the metal ions and ligand have opposite charges, metal ion has two positive charges and on loss of one proton at particular pH the pyrazole ligand will have one negative charge, therefore for such ions of unlike charges as expected we observed the negative slope of the plot of logK versus $\sqrt{\mu}$, Figure (4–7).

**Figure (4-7): Plots of $\log K_1/\log K_2$ vs. $\sqrt{\mu}$ for pyrazoles and complexes**
*(▪$\log K_1$ and ▲=$\log K_2$)*



The logK values decreases with increasing ionic strength of the medium. The thermodynamic proton ligand and metal ligand stability constants are reported in Table (3). The difference in the $\log K_1$ and $\log K_2$ is small which is due to the simultaneous formation of complexes [25].

Literature survey reveals that log K versus √μ plots are generally linear up to 0.1 M ionic strength [26].

**Table (3): Thermodynamic stability constants of pyrazoles and their complexes**

| Ligands | $pK^0$ | $logK_1^0$ | | $logK_2^0$ | |
|---|---|---|---|---|---|
| | | Ni (II) | Co (II) | Ni (II) | Co (II) |
| HPPBP | 6.5519 | 7.1389 | 6.7723 | 6.9149 | 6.2303 |
| HPNPPP | 6.6213 | 6.6364 | 5.8487 | 6.0199 | 5.6519 |
| HPNPBP | 6.7369 | 6.1080 | 6.8523 | 5.6201 | 5.5501 |
| HPPPP | 7.4331 | 6.7848 | 6.6631 | 6.1833 | 6.4904 |
| HPNPFP | 6.1048 | 6.8185 | 5.9438 | 5.2570 | 5.4324 |

Saied Abedini Khorrami et al [27] have studied stability constant of vanadium (V) with Glycine at different ionic strengths, Moreno-Carretero M. N. et al [28] studied the influence of ionic strength on stability constants of Ag (I), Zn (II), Cd (II) and Hg (II) complexes with some 4-amino-5-nitroso-pyrimidine derivatives. The plots of pK and log K versus √μ gave straight lines over the entire range of ionic strengths for all the ligands and their metal complexes. This means that Bronsted relationship is valid for the dissociation of ligand and complex equilibria of chelates. These plots for some representative systems are shown in (Figure 3 and 4-7).

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