Spectrophotometric and pH-Metric Studies of Ce(III), Dy(III), Gd(III), Yb(III) and Pr(III) Metal Complexes with Rifampicin

A.N. SONAR* and N.S. PAWAR

Pratap College, Amalner (M.S.), India
ansonar1968@rediffmail.com

Received 9 June 2010; Revised 4 September 2010; Accepted 6 November 2010

Abstract: The metal-ligand and proton-ligand stability constant of Ce(III), Dy(III), Gd(III), Yb(III) and Pr(III) metals with substituted heterocyclic drug (Rifampicin) were determined at various ionic strength by pH metric titration. NaClO₄ was used to maintain ionic strength of solution. The results obtained were extrapolated to the zero ionic strength using an equation with one individual parameter. The thermodynamic stability constant of the complexes were also calculated. The formation of complexes has been studied by Job’s method. The results obtained were of stability constants by pH metric method is confirmed by Job’s method.

Keywords: Stability constant, Ionic strength, Rifampicin, pH metric

Introduction

The substituted heterocyclic drug (Rifampicin-5,6,9,17,19,21-hexahydroxy-23-methoxy-2,4,12,16,18,20,22-heptamethyl-8-[N-(4-methyl-1-piperazinyl)formimidoyl]-2,7-(epoxypentadeca[1,11,13]trienimino)-naptho[2,1-b]furan-1,11(2H)-dione 21-acetate) has anti-tuberculosis, protein transporter, anti-hyperglycemics, anti-epileptic, neuropsychiatry therapeutics, antibacterial properties. The complex of rifampicin with cyclodextrin is used as anti-tubercular drug. Das et al. have studied the effect of ionic strength on the stability constant of complexes of Fe(III) with salicylic acid and its derivatives. Sanchez et al. have studied the influence of ionic strength on ionization constant and stability constant of 4-amino-1,6-dihydro-2-methylthio-5-nitroso-6-oxo-pyramidine and its complex with Fe(II), Co(II), Ni(II) and Cu(II). Majlesi et al. have studied the stability constant of tungsten(VI) and molybdenum(VI) with nitrilo triacetic acid and glutamic acid at different ionic strength. Meshram et al. have studied the association and dissociation constant of Pr(III) complexes with 3-(2-hydroxy-3-iodo-5-methyl phenyl)1,5 diphenyl pyrazoline at different ionic strength. The stability constant of vanadium with glycine at various ionic strength was investigated by potentiometric titration technique. Majlesi et al. have studied the stability constant of Mo(IV) with iminodiacetic acid at different ionic strength maintained by using
sodium per chlorate. Sharma et al. have studied the effect of ionic strength and solvent effect on thermodynamic parameters. They have also studied the mechanism of protonation and complex formation of binary complexes of La(III), Ce(III), Pr(III) and Nd(III) with aminopyridines.

Tekade et al. have studied the apparent metal-ligand stability constant and confirmation of complexes. The compositions of complexes were confirmed by Job’s method as modified by Vasburgh and Gold. In the present work, the values of pK, metal-ligand stability constant at different ionic strength have been determined in the 70% dioxane-water mixture. We attempted to study the effect of ionic strength on thermodynamic parameters of complexes of rifampicin with Ce(III), Dy(III), Gd(III), Yb(III) and Pr(III) metals in 70% dioxane-water mixture by pH metrically and spectrophotometrically.

Experimental

The pH measurements were carried out with equip-tronic EQ-610 pH meter (accuracy ± 0.01 units) using combine glass electrode at 208 K. All the rare earth nitrates were used of 99.9% pure. All metal nitrates used were purchased from Sigma Aldrich Chem. Co., U.S.A. Metal nitrate solutions were prepared in triply distilled water and concentration was estimated by standard method. The drug solutions were prepared in 70% 1,4 dioxane solution. The 1, 4 dioxane was purified by the method described by Vogel. The pH metric readings were taken in 70% 1, 4 dioxane-water mixture and were converted to [H+] value by applying the correction. The overall ionic strength of solution was maintained constant by adding NaClO4.

All the solutions were titrated with standard carbonate free NaOH (0.2 N) solution at different ionic strengths using NaClO4 (0.02, 0.04, 0.06, 0.08 M). The solutions involved in the experimental procedure for pH metric titrations are:

1) Free HClO4(A);
2) Free HClO4 + Ligand (A+L), Free HClO4 + Ligand +Metal ion (A+L+M)

The volume of NaOH added in each titration was plotted against pH and the corresponding volume at successive pH for each set was determined and calculated. The metal–ligand stability constant of lanthanide metal complexes with rifampicin were investigated spectrophotometrically. The absorbance measurements were carried out with Shimadzu UV-1800 ENG 240V, Japan spectrophotometer. The solutions of metal nitrates and rifampicin were prepared in 70% dioxane-water mixture. NaClO4 was used for maintaining the constant ionic strength. The different composition of metal ion (1x10^-4 M) and ligand ion (1x10^-4 M) were prepared in ten series. For determination of λmax, 50% metal ion solution was used, at which maximum absorbance observed The absorption of all composition was measured at constant wave length (λmax) and at constant pH.

Results and Discussion

In the present investigation the dependence of proton-ligand stability constant (pK) and metal-ligand stability constant (log K) on ionic strength of medium was examined by keeping fixed concentration of metal nitrates and ligand solution during pH metric titration. The system has been studied at 0.02, 0.04, 0.06 and 0.08 M ionic strength by varying the concentration of sodium per chlorate. The total ionic strength of medium was calculated.

The values of proton–ligand and metal-ligand constant of lanthanide metal complexes at different ionic strength 0.02, 0.04, 0.06 and 0.08 M were determined. These values were determined by using Irving-Rossotties method. From Table 1, it shows that the values of proton–ligand stability constant (pK) decreases with increasing ionic strength of medium. The metal-ligand stability constant (log K) also decrease with increasing ionic strength. For determination of stability constant at zero ionic strength the Bronsted equation was used.
log K = \log K^0 + A \Sigma \Delta Z^2 \sqrt{\mu} \\
pK = pK^0 - A \Delta Z^2 \sqrt{\mu} 

Table 1. Proton-ligand (pK) and metal-ligand stability constant (log K) values for Ce(III), Dy(III), Gd(III), Yb(III) and Pr(III) metal ions with rifampicin at various ionic strength (µ).

| µ    | \sqrt{\mu} | \sqrt{\mu}/1+\sqrt{\mu} | \left[\sqrt{\mu}/1+\sqrt{\mu}\right]−0.3 \sqrt{\mu} | Pk   | logK₁ | logK₂ |
|------|-------------|--------------------------|------------------------------------------------|------|------|------|
|      |            |                          |                                                 |      |      |      |
| Rifampicin + Ce(III) |            |                          |                                                 |      |      |      |
| 0.02 | 0.1414      | 0.1239                   | 0.0815                                          | 8.035234 | 7.00 | 4.95 |
| 0.04 | 0.2000      | 0.1667                   | 0.1067                                          | 7.982331 | 6.45 | 4.55 |
| 0.06 | 0.2450      | 0.1968                   | 0.1233                                          | 7.853715 | 6.25 | 4.25 |
| 0.08 | 0.2828      | 0.2205                   | 0.1356                                          | 7.615693 | 5.80 | 4.00 |
| Rifampicin + Dy(III) |            |                          |                                                 |      |      |      |
| 0.02 | 0.1414      | 0.1239                   | 0.0815                                          | 8.035234 | 7.15 | 5.20 |
| 0.04 | 0.2000      | 0.1667                   | 0.1067                                          | 7.982331 | 6.90 | 4.95 |
| 0.06 | 0.2450      | 0.1968                   | 0.1233                                          | 7.853715 | 6.75 | 4.80 |
| 0.08 | 0.2828      | 0.2205                   | 0.1356                                          | 7.615693 | 6.25 | 4.50 |
| Rifampicin + Gd(III) |            |                          |                                                 |      |      |      |
| 0.02 | 0.1414      | 0.1239                   | 0.0815                                          | 8.035234 | 7.55 | 5.15 |
| 0.04 | 0.2000      | 0.1667                   | 0.1067                                          | 7.982331 | 6.95 | 4.75 |
| 0.06 | 0.2450      | 0.1968                   | 0.1233                                          | 7.853715 | 6.75 | 4.55 |
| 0.08 | 0.2828      | 0.2205                   | 0.1356                                          | 7.615693 | 5.90 | 4.20 |
| Rifampicin + Yb(III) |            |                          |                                                 |      |      |      |
| 0.02 | 0.1414      | 0.1239                   | 0.0815                                          | 8.035234 | 7.75 | 5.45 |
| 0.04 | 0.2000      | 0.1667                   | 0.1067                                          | 7.982331 | 7.55 | 4.95 |
| 0.06 | 0.2450      | 0.1968                   | 0.1233                                          | 7.853715 | 7.25 | 4.80 |
| 0.08 | 0.2828      | 0.2205                   | 0.1356                                          | 7.615693 | 6.50 | 4.15 |
| Rifampicin + Pr(III) |            |                          |                                                 |      |      |      |
| 0.02 | 0.1414      | 0.1239                   | 0.0815                                          | 8.035234 | 7.70 | 5.10 |
| 0.04 | 0.2000      | 0.1667                   | 0.1067                                          | 7.982331 | 7.45 | 4.90 |
| 0.06 | 0.2450      | 0.1968                   | 0.1233                                          | 7.853715 | 7.25 | 4.70 |
| 0.08 | 0.2828      | 0.2205                   | 0.1356                                          | 7.615693 | 6.40 | 4.10 |

Where, K^0 is the formation constant at zero ionic strength. pK^0 is proton-ligand stability constant at zero ionic strength. ‘A’ is the Debye-Hückel constant. ΔZ² is the difference in square of the changes of product and reactant ion. The pK^0 and logK^0 values were calculated by plotting the graph of pK, log K₁, log K₂ versus \sqrt{\mu} (Figures 1-3).
From Table 2, it is seen that the good agreement among thermodynamic constant obtained from different plots. The plots of pK, log K₁, log K₂ versus √µ gives straight line over the entire range of ionic strength for both systems. It shows that the Bronsted relationship is valid for dissociation equilibrium. Fazlur Rahman et al. have determined similar results of stability constant of different metal complexes with substituted acetophenone oxime at 0.1, 0.05 and 0.01 M ionic strength in 70% dioxane-water mixture.

Table 2. Thermodynamic stability constant (pK₀ and log K₀) values for Ce(III), Dy(III), Gd(III), Yb(III) and Pr(III) metal ions with rifampicin

|               | pK₀ vs. √µ | log K₁ vs. √µ | log K₁ vs. [√µ/1+√µ] - 0.3√µ | log K₂ vs. √µ | log K₂ vs. √µ/1+√µ - 0.3√µ |
|---------------|------------|---------------|---------------------------|--------------|---------------------------|
| Rifampicin + Ce(III) | 8.4893 | --            | --                        | --           | --                        |
| Rifampicin + Dy(III)  |     | 8.1314        | 8.4623                   | 8.7185       | --                        |
| Rifampicin + Gd(III)  |     | 8.0467        | 8.2752                   | 8.4488       | --                        |
| Rifampicin + Yb(III)  |     | 9.1301        | 9.5563                   | 9.8824       | --                        |
| Rifampicin + Pr(III)  |     | 8.9488        | 9.5184                   | 9.7952       | --                        |
| Rifampicin + Pr(III)  |     | 9.0234        | 9.3378                   | 9.5739       | --                        |

The values of ∆Z² were calculated from the slope of plots pK vs. √µ, log K₁ vs. √µ, log K₂ vs. √µ. The value of ‘A’ was taken equal to 0.5161. The value of ∆Z² shown in Table 3. The observed value of ∆Z² is different from the expected value. These values do not give conclusive evidence regarding the magnitude of the charge of reacting species. This discrepancy may be due to the limited applicability of Bronsted equation. The conditional stability constant of rifampicin-lanthanide metals complexes were determined for all systems by using the following equation.
Table 3. Values of $\Delta Z^2$ determined from the plots of pK vs. $\sqrt{\mu}$

| Reaction equilibria | System                  | $\Delta Z^2$ | Slope   | $\Delta Z^2$ |
|--------------------|-------------------------|--------------|---------|--------------|
| $\text{HL} \rightarrow \text{H}^+ + \text{L}^-$ | Ce(III)+ Rifampicin     | 2.00         | -2.8401 | -5.5030      |
| $\text{L}^- + \text{M}^{3+} \rightarrow \text{ML}^{2+}$ | -6.00 | -8.0820 | -15.659 |
| $\text{ML}^{2+} + \text{L} \rightarrow \text{ML}_2^{+1}$ | -4.00 | -6.7186 | -13.0180 |
| $\text{L}^- + \text{M}^{3+} \rightarrow \text{ML}^{2+}$ | Dy(III)+ Rifampicin     | -6.00 | -5.9100 | -11.4513     |
| $\text{ML}^{2+} + \text{L} \rightarrow \text{ML}_2^{+1}$ | -4.00 | -4.317  | -9.1682 |
| $\text{L}^- + \text{M}^{3+} \rightarrow \text{ML}^{2+}$ | Gd(III)+ Rifampicin     | -6.00 | -10.7810 | -20.8894     |
| $\text{ML}^{2+} + \text{L} \rightarrow \text{ML}_2^{+1}$ | -4.00 | -6.4694 | 12.5352 |
| $\text{L}^- + \text{M}^{3+} \rightarrow \text{ML}^{2+}$ | Yb (III)+ Rifampicin    | -6.00 | -7.9892 | -15.4799     |
| $\text{ML}^{2+} + \text{L} \rightarrow \text{ML}_2^{+1}$ | -4.00 | -8.5748 | -16.6146 |
| $\text{L}^- + \text{M}^{3+} \rightarrow \text{ML}^{2+}$ | Pr (III)+ Rifampicin    | -6.00 | -3.8912 | -16.2589     |
| $\text{ML}^{2+} + \text{L} \rightarrow \text{ML}_2^{+1}$ | -4.00 | -6.5769 | -12.7435 |

$K = \frac{x}{(a_1-x)} \cdot \frac{1}{(b_1-x)} = \frac{x}{(a_2-x)} \cdot \frac{1}{(b_2-x)}$

Where, $K$ = conditional stability constant, $x$ = concentration of complex, $a_1$ and $b_1$ were concentration of metal ion and ligand before dilution. $a_2$ and $b_2$ were concentration of metal ion and ligand after dilution. The values of ‘$x$’ were calculated from the graph plotted between optical density and % composition of metal ions in solution (Figure 4-7). From Table 4, it is seen that there is good agreement among thermodynamic constant obtained from pH metry and spectrophotometrically.

**Figure 4.** Plots of O.D. vs. % composition of metal ions -Yb(III)

**Figure 5.** Plots of O.D. vs. % composition of metal ions -Pr(III)

**Figure 6.** Plots of O.D. vs. % composition of metal ions -Gd(III)

**Figure 7.** Plots of O.D. vs. % composition of metal ions -Dy(III)
Table 4. Metal-ligand stability constants (log K) values obtained by pH-metry and spectrophotometry techniques (Ionic strength = 0.08 M)

| System       | pH-metry | Spectrophotometry |
|--------------|----------|-------------------|
| Dy(III)+ Rifampicin | 4.50     | 4.75              |
| Gd(III)+ Rifampicin | 4.20     | 4.34              |
| Yb(III)+ Rifampicin | 4.15     | 4.40              |
| Pr(III)+ Rifampicin | 4.10     | 4.58              |

Conclusion

The calculated values of stability constant at various ionic strength are high. From the results obtained in this experiment, the complexes of rifampicin with Ce(III), Dy(III), Gd(III), Yb(III) and Pr(III) metal ions were quite stable at over all range of ionic strength. The values of thermodynamic parameters are nearly same from all plots, were good agreement of results. The values of conditional metal-ligand stability constant shows good agreement with the values determined by pH-metrically.

References

1. Niemi M, Buckman J T and Fromm M F, Adis International., 2003, 42(9), 819-850.
2. Kuchekar, Eastern Pharmacist., 1998, 41(492), 133-134.
3. Das Sunanda and Cattopadyaya M C, J Indian Chem Soc., 2006, 83(9), 922.
4. Sanchez-sanchez M P, Salas-Peargrin J M, Romero-Molina M A and Colacio-Rodriguez E, Thermochimica Acta., 1985, 89, 165.
5. Majlesi K and Zare Karim, Phy Chem Liquids, 2006, 44(3), 257
6. Mehram Y K, Mandakmare A U and Narwade M L, Orient J Chem., 1999, 15(1), 173-175.
7. Khorrami S A, Bayat H, Sharifi S and Shafai M, J Chem Eng Data., 1996, 41(6), 1322.
8. Majlesi K, Gharib F and Arafati M, Russ J Inorg Chem., 2006, 51(2), 1982-1986.
9. Sharma S, Shah M C, Dalwadi D, Thakkar F and Vora J J, Res J Chem Environ., 2008, 12(4), 29-34.
10. Tekade P V, Patil K N, Narwade M L and Bodkhe P S, Asian J Chem., 2006, 18(4), 2657.
11. Gould K R and Vasburgh W C, J Am Chem Soc., 1942, 64, 1630.
12. Jaeffery G H, Bassetl J, Mendham J and Denney R C, Vogel’s, Text Book of Quantitative Chemical Analysis, 1997, 5th Ed., ELBS Longman, 53.
13. Rahman F, Rastogi S N and Jettey U K, J Indian Chem Soc., 1990, 67, 342.
14. Robinson R A and Strokes R H, Electrolyte Solutions II Ed., Butterworths, London, 1959, 468.
