Polarographic Studies on Mixed Ligand Complexes of Cadmium with DL-3-(3,4-Dihydroxyphenyl)alanine and Some Dicarboxylic Acids

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The reductiou of Cd(II) has been carried out polarographically in the aqueous solution of DL-3-(3,4-dihydroxyphenyl)alanine(DOPA). The stability constants were determined for the simple Cd-DOPA system first, and then mixed-ligand complexes of cadmium with DOPA and dicarboxylic acids (oxalic and malic) have been studied. The stability constants of mixed-ligand complexes have been evaluated by the method of Schaap and McMasters. With these data the statistical and electrostatic effects have also been considered.

The importance of amines and their derivatives has been widely recognised in the biochemical, analytical, and pharmaceutical fields. These compounds are therefore attracting wide attention in different areas of research. Potentiometric investigations of the complexation behaviour of some metal ions with DOPA has been carried out by Rajan and coworkers.[1-4] However, there is not a single reference about the polarographic studies of cadmium with DOPA. Hence the present work has been undertaken. This communication deals with the study of simple and mixed ligand complexes of cadmium with DOPA and some dicarboxylic acids.

Theory

Since Cd forms hexacoordinated complexes with DOPA–oxalate and malate ions, there can be, at maximum a possibility of the existence of three mixed complex species of the type Cd(XY), $Cd(XY_2)$, and $Cd(X_2Y)$, the total number of ligands being limited to three due to the bidentate nature of the ligands under investigation.

Hence for a complexation reaction,

$$M + iX + jY \rightleftharpoons MX_iY_j. \quad (1)$$

Where i, j are stoichiometry numbers, X and Y are two different ligands and charges have been ignored for simplicity.

The overall stability constant β_{ij} for the above reaction is given by

$$\beta_{ij} = \frac{MX_iY_j}{M[X]^i[Y]^j}.$$

The DeFord and Hume function $F_o(X)$ may be extended to a new function $F_{oo}(X,Y)$ given by,

$$F_{oo}(X,Y) = \sum MX_iY_j[X]^i[Y]^j = \text{antilog}\frac{0.4343\,nF}{RT}\Delta E_{1/2} + \log\frac{I_m}{I_c}. \quad (2)$$

Where activity coefficients have been ignored and n is the number of electrons involved in the reversible reduction, F the Faraday number, R the gas constant, T the absolute temperature and I_m and I_c are the diffusion current constants for the metal and mixed complex respectively.

The factorization of $F_o(X,Y)$ using Leden's approach[14] leads to,

$$F_{oo}(X,Y) = \{\beta_{oo} + \beta_{01}[Y] + \beta_{02}[Y]^2 + \beta_{03}[Y]^3\}[X]^\circ + \{\beta_{10}+\beta_{11}[Y]+\beta_{12}[Y]^2\}[X] + \{\beta_{20}+\beta_{21}[Y]\}[X]^2 + \{\beta_{30}\}[X]^3 \quad (3)$$

or

$$F_{oo}(X,Y) = A + B[X] + C[X]^2 + D[X]^3 \quad (4)$$

Where A, B, C, and D have values as defined by Eq. 3.

The graphical method may be extended to the $F_{oo}(X,Y)$ data if the activity of one of the ligands is kept constant while that of the other, (Y) is varied. The intercept on the F_{oo} axis in the plot of F_{oo} *versus* [X] gives A. Therefore,

$$F_{10}(X,Y) = \frac{F_{oo}(X,Y)-A}{[X]} = B + C[X] + D[X]^2 \quad (5)$$

By a similar plotting of $F_{10}(X,Y)$ *versus* [X] and taking the intercept on $F_{10}(X,Y)$ axis as B, we have,

$$F_{20}(X,Y) = \frac{F_{10}(X,Y)-B}{[X]} = C + D[X] \quad (6)$$

and so on.

From the knowledge of C, the mixed stability constant β_{21} may be calculated. The values of β_{11} and β_{12} may be computed by the values of B at two [Y] concentrations.

Experimental

DOPA, oxalic acid, and malic acid used were of AnalaR grade and were used as complexing agents. Potassium nitrate as supporting electrolyte was used to maintain ionic strength at 1.0 M and 0.004% gelatin in the final solution sufficed to suppress the maxima observed. The temperature was maintained constant at 303±1 K.

The experimental technique was the same as described earlier.[5]

Results

Simple Systems. Before the study of the mixed ligand complexes, the formation constants of the complexes of Cd^{2+} with DOPA, oxalic acid, and malic acid were determined by the method of DeFord and Hume.[6] The results which are in good agreement with the previous studies[7-10] are tabulated in Table 1.

The Mixed Systems. The cadmium–DOPA–oxalate and cadmium–DOPA–malate systems were studied by keeping the concentration of the weaker ligand (oxalic and malic acid) constant at two values, while varying the concentration of the second ligand.

At each fixed concentration of oxalate and malate ions with varying concentration of DOPA, the slope

of the straight line for the plot of $E_{d.e.}$ *versus* $\log \frac{i}{id-i}$ was 31±1 mV. The direct proportionality of the diffusion current to the square root of effective height of mercury column indicated that the reduction is entirely diffusion controlled.

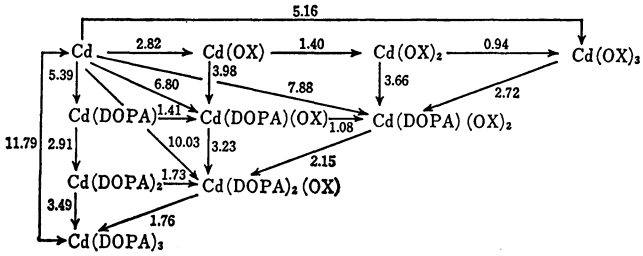
A shift in half-wave potential to more negative side with increase in DOPA concentration was observed. This shift in half-wave potential is greater in presence of the weaker ligands (oxalic and malic acid) than in their absence. This indicates mixed ligand complex formation by the DOPA and oxalate and malate ions.

The Schaap and McMasters[11] treatment was applied for calculating the $F_{1o}(X,Y)$ functions and Leden's graphical extrapolation method to calculate *A*, *B*, *C*, and *D* at two concentrations of [Ox] and [Mal]. The details of the calculations are presented in Tables 2 and 3.

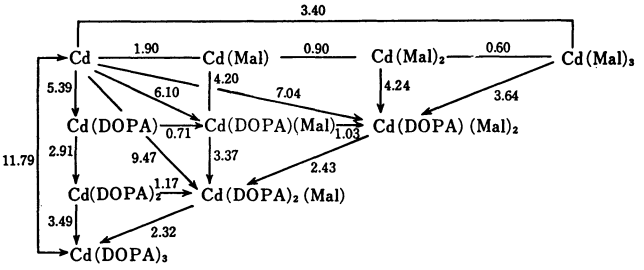
The formation constant β_{11} and β_{12} were evaluated

Table 1. Dissociation constants of DOPA, oxalate, and malate and stability constants of their simple complexes with Cd(II)
μ=1.0 M, T=30 °C.

	pK_1^H	pK_2^H	$\log \beta_1$	$\log \beta_2$	$\log \beta_3$
DOPA	9.50	—	5.39	8.30	11.79
Oxalate	1.30	4.28	2.82	4.22	5.16
Malate	3.40	5.05	1.90	2.80	3.40



Scheme 1. Cd-DOPA-oxalate system.



Scheme 2. Cd-DOPA-malate system.

Table 2(a). Data and results for cadmium-DOPA-oxalate system
Oxalate=0.02 M, $E_{1/2}$(M)=0.580 V *vs.* SCE.

[X] ×10³	$\Delta E_{1/2}$ V	$\log \frac{I_m}{I_c}$	F_{oo} ×10⁻³	F_{10} ×10⁻⁶	F_{20} ×10⁻⁸	F_{30} ×10⁻¹¹	F_{oo}(Cal) ×10⁻³	ΔF/%*
0.25	0.066	0.0100	0.16	0.55	6.00	8.00	0.16	±0.00
0.50	0.077	0.0250	0.39	0.74	6.80	5.60	0.40	+0.63
1.50	0.106	0.0400	3.69	2.45	13.67	6.45	3.63	−0.93
2.00	0.115	0.0500	7.52	3.75	16.75	6.38	7.43	−1.19
3.00	0.128	0.0580	20.07	6.68	20.93	5.64	20.17	+0.49
4.00	0.138	0.0690	45.74	11.43	27.58	5.90	48.15	+5.18
5.00	0.146	0.0840	87.38	17.47	34.14	6.03	90.39	+3.45
7.50	0.161	0.0970	284.10	37.80	49.97	6.13	290.03	+2.11
10.00	0.172	0.1100	679.89	67.90	67.59	6.36	671.02	−1.17
12.50	0.180	0.1200	1284.10	102.73	81.86	6.23	1239.63	−3.46

A=22.00 (Cal), B=4×10⁵, C=4×10⁸, D=(6.27±1.73)×10¹¹.

Table 2(b). Data and results for cadmium-DOPA-oxalate system
Oxalate=0.2 M, $E_{1/2}$(M)=0.580 V *vs.* SCE.

[X] ×10³	$\Delta E_{1/2}$ V	$\log \frac{I_m}{I_c}$	F_{oo} ×10⁻³	F_{10} ×10⁻⁶	F_{20} ×10⁻⁹	F_{30} ×10⁻¹¹	F_{oo}(Cal) ×10⁻³	ΔF/%*
0.25	0.106	0.0014	3.37	5.64	4.54	—	3.28	−2.67
0.50	0.111	0.0071	5.01	6.10	3.20	—	4.99	−0.39
1.50	0.126	0.0106	15.94	9.32	3.21	4.73**	16.41	+2.88
2.00	0.132	0.0186	25.72	11.88	3.69	5.95	25.88	+0.62
3.00	0.142	0.0230	55.89	17.98	4.49	6.63	54.60	−2.46
4.00	0.149	0.0275	96.55	23.65	4.79	5.93	99.32	+2.86
5.00	0.156	0.0327	167.04	33.02	5.70	6.40	163.83	−1.90
7.00	0.166	0.0365	362.51	51.51	6.72	6.03	366.90	+1.21
10.00	0.178	0.0403	916.98	91.50	8.70	6.20	911.96	−0.54
12.50	0.185	0.0600	1640.40	131.08	10.13	6.10	1650.00	+0.57

A=1.96×10³, B=4.5×10⁶, C=2.5×10⁹, D=(6.15±0.48)×10¹¹.

TABLE 3(a). DATA AND RESULTS FOR CADMIUM-DOPA-MALATE SYSTEM
Malate=0.04 M, $E_{1/2}$(M)=0.588 V *vs.* SCE.

[X] $\times 10^4$	$\Delta E_{1/2}$ V	$\log \frac{I_m}{I_c}$	F_{oo} $\times 10^{-2}$	F_{10} $\times 10^{-5}$	F_{20} $\times 10^{-8}$	F_{30} $\times 10^{-11}$	F_{oo}(Cal) $\times 10^{-2}$	ΔF/%*
0.50	0.038	0.060	0.21	3.12	0.40	—	0.22	+4.76
1.50	0.052	0.073	0.64	3.91	5.40	14.7**	0.61	−4.68
2.50	0.059	0.100	1.16	4.42	5.28	8.32**	1.13	−2.58
3.50	0.064	0.118	1.77	4.90	5.14	5.54	1.79	+1.12
4.50	0.069	0.139	2.72	5.92	6.27	6.82	2.66	−2.20
5.00	0.071	0.149	3.24	6.37	6.54	6.68	3.18	−1.85
10.00	0.088	0.156	12.13	12.08	8.98	5.78	12.50	+3.05
15.00	0.100	0.176	31.84	21.19	12.06	5.91	32.66	+2.57

A=5.4 (Cal), $B=3.10\times10^5$, $C=3.20\times10^8$, $D=(6.15\pm0.67)\times10^{11}$.

TABLE 3(b). DATA AND RESULTS FOR CADMIUM-DOPA-MALATE SYSTEM
Malate=0.2 M, $E_{1/2}$(M)=0.588 V *vs.* SCE.

[X] $\times 10^4$	$\Delta E_{1/2}$ V	$\log \frac{I_m}{I_c}$	F_{oo} $\times 10^{-2}$	F_{10} $\times 10^{-5}$	F_{20} $\times 10^{-8}$	F_{30} $\times 10^{-11}$	F_{oo}(Cal) $\times 10^{-2}$	ΔF/%*
0.50	0.059	0.032	0.99	7.36	5.20	—	1.00	+1.0
1.50	0.067	0.045	1.88	8.39	8.60	4.67**	1.89	+0.53
2.50	0.073	0.049	3.00	9.51	9.64	6.96	3.00	±0.00
3.50	0.078	0.057	4.49	11.05	11.29	9.69**	4.38	−2.44
4.50	0.082	0.063	6.18	12.35	11.67	8.38	6.06	−1.94
10.00	0.098	0.094	22.62	22.00	14.90	7.00	22.72	+0.44
15.00	0.108	0.101	49.45	32.55	16.97	6.05	53.00	+8.08

A=62.20 (Cal), $B=7.10\times10^5$, $C=7.90\times10^8$, $D=(7.10\pm1.28)\times10^{11}$.

TABLE 4. STABILITY CONSTANTS OF MIXED-LIGAND COMPLEXES OF Cd(II) WITH DOPA AND OXALATE, MALATE (μ=1.0, T=30 °C)

System	$\log \beta_{11}$	$\log \beta_{12}$	$\log \beta_{21}$
Cd-DOPA-oxalate	6.80	7.88	10.03
Cd-DOPA-malate	6.10	7.04	9.47

from the two values of B, the two values of C gave two values of β_{21} in good agreement with each other and have been presented in Table 4.

The experimental values of D should also coincide with β_{30} as at the final concentration of DOPA, all the dicarboxylate ions have been replaced and only $Cd(DOPA)_3$ complex exists in solution. This indeed is found to be so.

$$\log \beta_{30} = 11.790$$

$$\log D = \begin{cases} 11.797,\ 11.789 \text{ (for oxalate)} \\ 11.789,\ 11.851 \text{ (for malate)} \end{cases}$$

The results are summarised in the form of Schemes 1 and 2 where the numerical values indicate the logarithms of the equilibrium constant.

Discussion

The mixed ligand complex formation may also be explained by considering Schemes 1 and 2. The tendency to add X (X=DOPA) to CdX and CdY (Y= oxalate and malate) can be compared. The logarithm of stability constants of the above complexes are (2.91 and 3.98) and (2.91 and 4.20) for cadmium–DOPA–oxalate and cadmium–DOPA–malate respectively. The largest part of the difference in $\log K$ must be attributed to entropy and electrostatic effects which would favour the formation of a charged complex. The logarithm of stability constants of addition of oxalate to Cd(Ox) and Cd(DOPA) and malate to Cd(mal) and Cd(DOPA) are 1.40 and 1.41 and 0.90 and 0.71 respectively, indicating that the mixed ligand complexation is favoured.

The $\log K$ values for addition of X to $Cd(X)_2$, Cd(XY), and $Cd(Y)_2$ are (3.49, 3.23, and 3.66) and (3.49, 3.37, and 4.24) for Cd–DOPA–oxalate and Cd–DOPA–malate respectively and show that the addition of amino acids is preferred to a weaker ligand.

The $\log K$ values for the addition of Y to $Cd(Y)_2$, Cd(XY), and $Cd(X)_2$ are (0.94, 1.08, and 1.73) and (0.60, 1.03, and 1.17) for oxalate and malate systems respectively, indicating that the addition of dicarboxylate ion is preferred to [Cd(dicarboxylate)(DOPA)] as compared to Cd(dicarboxylate)$_2$ and $Cd(DOPA)_2$.

The case of mixed ligand complex formation by the addition of dicarboxylate ions to $Cd(DOPA)_2$ and [Cd(DOPA)(dicarboxylate)] may easily be confirmed on the basis of statistical considerations[12] using Eqs. 7—9 as proposed by Watter's and Dewitt.[13]

$$\beta_{11} = 2 \times 3 \times \beta_{20}^{1/3} \times \beta_{03}^{1/3} \quad (7)$$

$$\beta_{12} = 3 \times \beta_{30}^{1/3} \times \beta_{03}^{2/3} \quad (8)$$

$$\beta_{21} = 3 \times \beta_{30}^{2/3} \times \beta_{03}^{1/3} \quad (9)$$

The values of stability constants so obtained from

Table 5. Values of stability constants of mixed-ligand complexes of Cd(II) with DOPA and oxalate and malate as calculated by Watters and Dewitteqs

System	$\log \beta_{11}$	$\log \beta_{12}$	$\log \beta_{21}$
Cd-DOPA-oxalate	6.42	7.84	10.05
Cd-DOPA-malate	5.84	6.67	9.46

above equations are given in Table 5 and when compared with the observed values, it indicates that MXY, MXY_2, and MX_2Y complexes have been formed purely on the statistical factors.

The tendency of formation of simple and mixed complexes can be easily expressed by calculating the disproportionation constant K^D for the equilibria

$$2Cd(XY) \rightleftharpoons Cd(X)_2 + Cd(Y)_2$$

The value of $\log K^D$ is -0.6 statistically but the observed values are found to be -1.08 and -1.10 for the Cd(DOPA)(Ox) and Cd(DOPA)(Mal) systems respectively. More negative values of $\log K^D$ for each equilibria account for the stability of the mixed ligand complexes.

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References

1) K. S. Rajan, S. Mainer, and J. M. Danis, *Bio. Inorg. Chem.*, **9**, 187 (1978).
2) Gergely. Arthur Kiss, *Tamas. Magy. Kem. Foly.*, **81**, 264 (1975).
3) J. E. Gorton and R. F. Jameson, *J. Chem. Soc., Dalton. Trans*, **1972**, 310.
4) K. S. Rajan, S. Mainer, and J. M. Danis, *J. Inorg. Nucl. Chem.*, **40**, 2089 (1978).
5) S. C. Khurana and C. M. Gupta, *Aust. J. Chem.*, **26**, 971 (1973).
6) D. D. DeFord and D. N. Hume, *J. Am. Chem. Soc.*, **73**, 5321 (1951).
7) D. J. Perkins, *Biochem. J.*, **53**, 649 (1953).
8) S. K. Shah Ph. D. Thesis, University of Rajasthan, Jaipur (India) (1980).
9) N. P. Sachan, C. P. S. Chandel, and C. M. Gupta, *Chemica Scripta*, **20**, 111 (1982).
10) S. C. Khurana, J. K. Gupta, and C. M. Gupta, *Electrochim. Acta*, **18**, 59 (1973).
11) W. B. Schaap and D. L. McMasters, *J. Am. Chem. Soc.*, **83**, 4699 (1961).
12) D. D. Perrin and V. S. Sharma, *J. Chem. Soc.*, **17**, 2060 (1969).
13) J. I. Watters and R. Dewitt, *J. Am. Chem. Soc.*, **82**, 1333 (1960).
14) I. Leden, *Z. Phys. Chem.*, **188**, 160 (1941).