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Structural, Thermoanalytical and Antitumour Studies of Metal Chelates of Anthracene-9-Carboxaldehyde Thiosemicarbazone

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The reactions of thiosemicarbazone of anthracene-9-carboxaldehyde with acetates of manganese(II), cobalt(II) and nickel(II) gave solid complexes which were characterized by various physico-chemical methods such as microanalysis, magnetic measurements, conductivity experiments, electronic and infrared spectral studies. They were found to be of the following formulae $[MnL_2(H_2O)_2]$, $[CoL_2]$ and $[NiL_2]$ where L = monoanion of the ligand anthracene-9-carboxaldehyde thiosemicarbazone, (A9CTSC). The ligand and the chelates were screened for their possible antitumour activity. The thermal decomposition kinetics and mechanism of these chelates were studied from TG and DTA techniques.

Key Words: Structure, Thermoanalytical, Antitumour, Metal chelates, Anthracene-9-carboxaldehyde thiosemicarbazone

INTRODUCTION

Thiosemicarbazones which comprise a well known group of NS donors have been extensively used for complex formation in the recent past[1]. Many of the complexes of thiosemicarbazones and other NS donor ligands are widely employed in medicinal science[2]. Since the discovery of the antitubercular activity of thiosemicarbazones by Domagk[3], studies on their pharmacology have required a great deal of interest[4–8]. A few of these derivatives have been systematically investigated and the possibilities of their chelation with metal ions in relation to their antitumour and microbiological activity have been suggested[9–11]. Studies on thermal decomposition and kinetics of metal chelates of thiosemicarbazones have been reported[12,13]. In continuation of our work on thermal decomposition kinetics of metal chelates[14–16], we describe here the synthesis, characterization, thermoanalytical and antitumour data of some typical transition metal complexes of a novel Schiff base, anthracene-9-carboxaldehyde thiosemicarbazone.

The inhibitory activity of these complexes and ligands against tumour cells were studied *in vitro* using Ehrlich ascites and Dalton's lymphoma ascites tumour

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cells. The kinetics and mechanism of thermal decomposition of the complexes have been studied using non-isothermal methods[17, 18].

EXPERIMENTAL

The metal acetates and thiosemicarbazide were BDH AnalaR products. Anthracene-9-carboxaldehyde was bought from Sigma Company, USA. The solvents were of reagent grade and were purified before use by the standard methods[19]. The chemicals used for the antitumour screening tests were of E. Merck's reagent grade. Minimum Essential Medium (MEM) and trypsion were purchased from Hi-Media Laboratories Pvt. Ltd., Bombay. Ehrlich ascites (EA) and Daltons lymphoma ascites (DLA) tumour cells were obtained from Tata Memorial Hospital, Mumbai and propagated in the peritoneal cavity of mice.

Preparation of the thiosemicarbazone: To the refluxing solution of anthracene-9-carboxaldehyde (2.06 g, 0.01 mol) in ethanol (50 cm^3), hot solution of thiosemicarbazide (0.91 g, 0.01 mol) in 80% EtOH (20 cm^3) was added drop wise under shaking and refluxed for 3 h on a steam bath. The mixture was cooled to room temperature while brown coloured crystals of the ligand anthracene-9-carboxaldehyde thiosemicarbbazone (A9CTSC) (Fig. 1) were separated which were suction filtered, washed with dilute EtOH and dried over P_4O_{10}. m.p. 178°C.

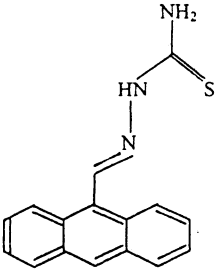

Fig. 1. A9CTSC

Preparation of complexes: Mn(II), Co(II) and Ni(II) chelates of anthracene-9-carboxaldehyde thiosemicarbazone were prepared by adding aqueous solution of the metal acetate (0.002 mol) to a refluxing solution of the ligand (0.004 mol) in DMF-EtOH mixture (1 : 20). Sodium acetate (1 g) was added and refluxed further for 1 h. The solid complexes which separated out were filtered off, washed with EtOH–H_2O mixture (1 : 1) and dried over P_4O_{10} in vacuum.

Standard procedures were adopted for the estimation of metals present in the complexes[20]. Sulphur was estimated gravimetrically after precipitation as $BaSO_4$. The IR spectra in the range 4000–200 cm^{-1} were recorded using KBr discs on a Perkin-Elmer 580 spectrophotometer. The solid state electronic spectra of the ligand and complexes were recorded using Hitachi-3200 UV-Vis spectrophotometer. Room temperature magnetic measurements were done on a Gouy balance using $Hg[Co(NCS)_4]$ as the calibration standard and the magnetic moments were calculated by making the necessary diamagnetic corrections[21]. Microanalyses were performed using a Heraues CHN—O rapid analyser. The molar conduc-

tances of the complexes in nitrobenzene at a concentration of *ca.* 10^{-4}M were measured at 28 ± 2°C using Toshniwal conductivity bridge with a dip type cell and a platinum electrode. The thermogravimetric measurements in air were made on Perkin-Elmer TGS-1 thermal balance with a heating rate of 10°C min^{-1} and a sample size of 1–5 mg. Computational work was carried out with a Horizon III mini computer using programming language Fortran.

The *in vitro* cytotoxicity studies were performed using Ehrlich ascites and Dalton lymphoma ascites tumour cells. Different concentrations of the drugs were incubated with 1×10^6 cells at 37°C for 3 h. After incubation percentage of dead cells was determined by the trypan blue exclusion method using Neubauer haemocytometer.

Mathematical treatment of the decomposition reaction mechanism by non-isothermal methods has been discussed by Sestak[22] and Satava[23]. The procedure is based on the assumption that the non-isothermal reaction proceeds isothermally ion an infinitesimal time interval, so that the rate can be expressed by an Arrhenius type equation.

$$\frac{d\alpha}{dt} = Ae^{-E/RT} f(\alpha) \tag{1}$$

where A is the pre-exponential factor, t the time and $f(\alpha)$ depends on the mechanism of the process. For a linear heating rate (ϕ), $dT/dt = \phi$ and substitution into equation (1) gives

$$\frac{d\alpha}{f(\alpha)} = \int_0^T \frac{A}{\phi} e^{-E/RT} dT \tag{2}$$

Integration of the left hand side of equation (2) gives

$$\int_0^\alpha \frac{d\alpha}{f(\alpha)} = g(\alpha) = \int_0^T \frac{A}{\phi} e^{-E/RT} dT \tag{3}$$

where $g(\alpha)$ is the integral form of $f(\alpha)$. A series of $f(\alpha)$ forms are proposed and the mechanism is obtained from that which gives the best representation of the experimental data. For evaluating kinetic parameters from the mechanistic equation given by Satava[23], Coats and Redfern[24] equation was used in the general form, equation (4), and the various $g(\alpha)$ values were substituted. This has been recommended to be one of the best solutions by several authors[25].

$$\ln \frac{g(\alpha)}{T^2} = \ln \frac{AR}{\phi E} - \frac{E}{RT} \tag{4}$$

Along with the mechanistic equations, two non-mechanistic methods suggested by Coats-Redfern[24] and Horowitz-Metzger[26] were also used for comparison. The reaction order can easily be estimated by comparing their values using n = 0.33, 0.5, 0.66 and 1 in equations (5) and (6).

$$1 - (1 - \alpha)^{1-n}/(1 - n)T^2 \quad vs. \quad 1/T \quad \text{for } n \neq 1 \tag{5}$$

$$\log[-\log (1 - \alpha)]/T^2 \quad vs. \quad 1/T \quad \text{for } n = 1 \tag{6}$$

RESULTS AND DISCUSSION

The physico-chemical measurements and chemical analyses data (Table-1) can be correlated so as to explain the properties, structure and geometries of the ligand and the complexes. All the complexes are coloured. The complexes are air and light stable, nonhygroscopic amorphous powders and sparingly soluble in common organic solvents, but are appreciably soluble in DMSO and DMF.

TABLE-1
COLOUR, MICROANALYTICAL, MAGNETIC AND CONDUCTANCE DATA OF THE LIGAND AND ITS METAL COMPLEXES

Compound (Colour)	Analysis %, found (calcd.)					μ_{eff} (B.M.)	Molar conductance (ohm^{-1} cm^2 mol^{-1})
	M	C	H	N	S		
LH (Brown)	—	67.58 (68.82)	5.17 (4.66)	15.52 (15.05)	11.98 (11.47)	—	—
$[MnL_2(H_2O_2)]$ (Pale yellow)	8.83 (8.49)	60.54 (59.36)	5.22 (4.33)	13.15 (12.98)	10.17 (9.89)	5.90	3.50
$[CoL_2]$ (Coffee brown)	10.84 (9.58)	64.13 (62.45)	4.71 (3.90)	12.87 (13.66)	11.36 (10.41)	2.53	1.10
$[NiL_2]$ (Coffee brown)	10.99 (9.55)	61.29 (62.47)	4.60 (3.90)	13.56 (13.66)	11.11 (10.41)	Diamag	7.32

The non-electrolytic nature of the complexes can be explained by their very low value of molar conductance in nitrobenzene (less than 10 ohm^{-1} cm^2 mol^{-1}). An octahedral geometry is suggested for the Mn(II) complex[27] which shows a magnetic moment value of 5.9 B.M. which is nearer to the spin only value of 5.92 B.M. Square-planar configuration of the nickel(II) chelate is confirmed by its diamagnetic behaviour. The observed magnetic moment of 2.53 B.M. in the case of cobalt(II) complex suggests its square-planar geometry.

The ligand exists in the thioketo form in the solid state as evidenced by the absence in the region 2650–2450 cm^{-1} due to the SH group in the IR spectra of the ligand. The bands observed at 3400, 3260 and 3170 cm^{-1} in the spectra of the ligand can be attributed to the NH vibrations. Out of these, the first one is due to the asymmetric stretching mode and the other two are assigned to the symmetric stretching modes of the terminal NH_2 and NH groups[28]. The sharp band observed in the spectra of the ligand at 1610 cm^{-1} may be attributed to the C=N stretching vibration which upon complexation shifted towards lower frequency side indicating the involvement of azomethine nitrogen in coordination. Most of the bands in the spectrum of the ligand, especially in the low frequency region, undergo frequency shifts and intensity changes during complex formation. The most marked effect is that of the 880 cm^{-1} band which may be due to C=S vibration. In the spectra of chelates, this band disappears and instead a new band in the region 700–600 cm^{-1} is exhibited. The absence of the band at 3170 cm^{-1} in the spectra of complexes indicates that the hydrogen atom of the secondary NH group

of the ligand takes part in the complex formation. These factors can be taken as an evidence for the coordination of the ligand through the thioenol form.

The broad band of medium intensity around 3450 cm^{-1} in the spectra of the Mn(II) complex indicate the presence of water molecules. In addition, a band of strong intensity at 940 cm^{-1} suggests that these water molecules are coordinated.

Further evidence for the nature of the metal ligand bonding is given by ν(M—N) and ν(M—S) bonds observed in the spectra of the complexes at 450–410 cm^{-1} and 320–290 cm^{-1} respectively[29]. Conclusively the IR data suggest that the A9CTSC behaves as a potentially bidentate ligand coordinating through azomethine nitrogen and thiolate sulphur atoms forming five-membered chelate ring.

The manganese(II) complex with a high spin d^5 state registers no characteristic bands in the visible region of the electronic spectrum. However, in the present complex the broad band at 24,752 cm^{-1} is typical charge transfer transition, as expected for an octahedral manganese(II) complex[30]. The electronic spectrum of Ni(II) complex displays a band at 25316 cm^{-1} which indicates square-planar geometry. The coffee brown colour and the absence of absorption in the region 25000-10000 cm^{-1} in the case of Co(II) complex suggests the square-planar nature.

The micro-analytical and spectral data of the complexes therefore correspond to the formulae $[MnL_2(H_2O)_2]$, $[CoL_2]$ and $[NiL_2]$ where L = monoanion of the ligand A9CTSC.

Thermal studies

The TG curves of the chelates $[CoL_2]$ and $[NiL_2]$ exhibit two clear cut and nonoverlapping stages of decomposition while the manganese(II) chelate undergoes decomposition in three stages. Mass loss considerations and X-ray diffraction data confirm the products to be the corresponding oxides. The TG and DTA curves are represented in Figs. 2–4.

The three stage decomposition pattern of $[MnL_2(H_2O)_2]$ is supported by DTA data. The first stage represents the loss of $2H_2O$ molecules. According to Nikolaev *et al.*[31], water eliminated above 150°C can be considered as coordinated water. The second and third stages of decomposition in the TG curves show the removal of the two ligand moieties. The overall loss of mass from the curve is 88% while the theoretical mass loss for the conversion of $[MnL_2(H_2O)_2]$ to Mn_3O_4 is 87.8%. In the case of Co(II) and Ni(II) chelates, the two stage decomposition observed in the TG curves agrees with the loss of the two ligand molecules in two different steps.

The thermal data for the metal chelates are given in Table-2. Independent pyrolytic experimental data are also given in this table. The kinetic parameters calculated from TG data for the nine mechanistic equations are given in Table-3. The corresponding values E, A, ΔS and r from non-mechanistic equations (Coats-Redfern[24] and Horowitz-Metzger[26]) and the appropriate mechanistic equations are given in Table-4. The activation energies obtained for the different decomposition stages of the three chelates are also comparable to those of coordination compounds of 3d transition metals having similar structures[32].

TABLE-2
THERMAL DECOMPOSITION DATA OF Mn(II), Co(II) AND Ni(II) COMPLEXES OF ANTHRACENE-9-CARBOXALDEHYDE THIOSEMICARBAZONE (LH)

Complex	Stage	Temp. ranges in TG (°C)	Peak temp. in TG (°C)	Peak temp. in DTA (°C)	Loss of mass (%)			Probable assignment
					From TG	Theoretical	From pyrolysis (total mass loss)	
$[MnL_2(H_2O)_2]$	I	30–200	—	—	07.00	5.57	—	Loss of $2H_2O$
	II	200–340	280	270	43.00	42.97	—	Loss of L
	III	340–550	530	520	38.00	39.26	—	Loss of L
					88.00	87.80	87.70	
$[CoL_2]$	I	100–330	270	260	45.00	45.21	—	Loss of L
	II	330–560	540	530	42.00	41.31	—	Loss of L
					87.00	86.52	86.54	
$[NiL_2]$	I	100–330	310	315	46.00	45.23	—	Loss of L
	II	330–420	410	410	42.00	46.62	—	Loss of L
					88.00	87.85	87.85	

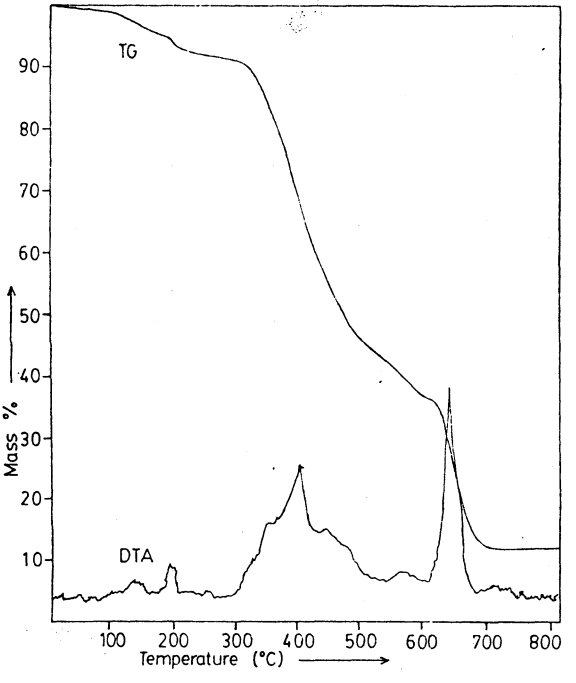

Fig. 2. TG and DTA traces of $[MnL_2(H_2O)_2]$

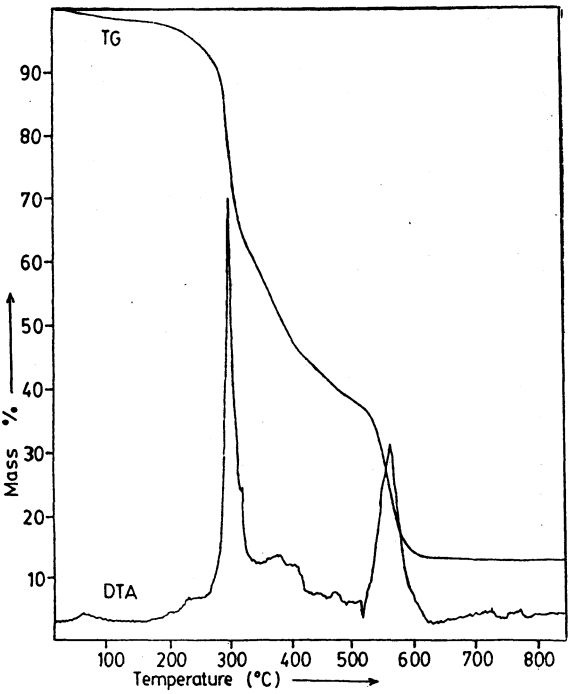

Fig. 3. TG and DTA traces of $[CoL_2]$

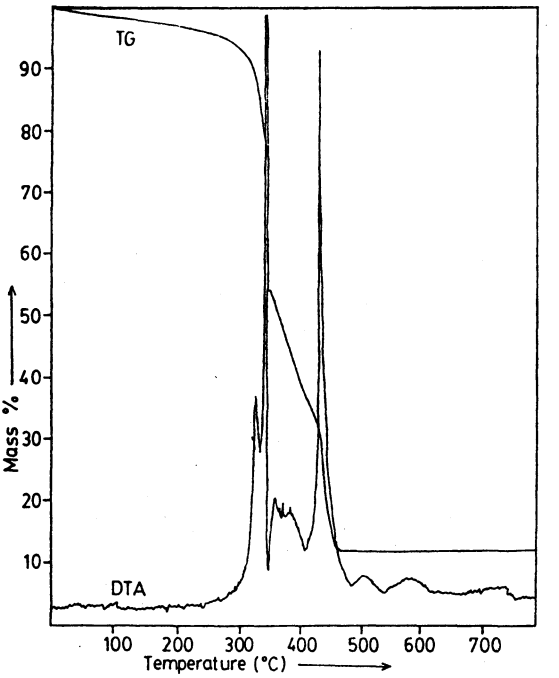

Fig. 4. TG and DTA traces of $[NiL_2]$

Table-3

KINETIC PARAMETERS FOR THE DECOMPOSITION OF Mn(II), Co(II) AND Ni(II) COMPLEXES OF ANTHRACENE-9-CARBOXALDEHYDE THIOSEMICARBAZONE FROM TG USING MECHANISTIC EQUATIONS

Complex	Parameter*	Mechanistic equations								
		1	2	3	4	5	6	7	8	9
$[MnL_2(H_2O)_2]$										
Stage II	E	77.93	86.42	96.76	89.83	49.51	20.39	10.69	41.47	44.01
	A	4.56×10^4	2.16×10^5	7.23×10^5	1.18×10^5	1.59×10^2	1.15×10^{-1}	7.24×10^{-3}	8.88	1.19×10^1
	ΔS	−160.92	−147.98	−137.94	−153.03	−207.97	−268.17	−291.14	−231.98	−229.54
	r	0.9784	0.9854	0.9916	0.9878	0.9945	0.9913	0.9849	0.9861	0.9845
Stage III	E	150.45	171.60	196.95	180.01	105.31	46.15	26.43	85.74	91.97
	A	1.19×10^7	2.13×10^8	3.33×10^9	1.95×10^8	2.37×10^4	1.16	4.36×10^{-2}	4.05×10^2	7.96×10^2
	ΔS	−117.76	−93.74	−70.88	−94.50	−169.46	−250.10	−279.33	−203.32	−197.70
	r	0.9852	0.9827	0.9798	0.9817	0.9743	0.9672	0.9566	0.9784	0.9770
$[CoL_2]$										
Stage I	E	99.11	108.13	119.21	111.79	61.23	26.33	14.70	52.60	55.33
	A	5.38×10^6	2.85×10^7	1.12×10^8	1.64×10^7	2.50×10^3	5.38×10^{-1}	2.38×10^{-2}	1.23×10^2	1.72×10^2
	ΔS	−121.09	−107.23	−95.83	−111.84	−184.93	−255.16	−281.08	−209.95	−207.21
	r	0.9737	0.9705	0.9661	0.9691	0.9565	0.9436	0.9238	0.9636	0.9614
Stage II	E	117.50	146.25	187.93	159.76	111.02	48.97	28.28	77.18	87.41
	A	7.89×10^4	5.28×10^6	1.24×10^9	1.13×10^7	7.90×10^4	2.73	6.76×10^{-2}	1.19×10^2	4.69×10^2
	ΔS	−159.57	−124.61	−79.23	−118.28	159.56	−244.99	−275.77	−213.57	−202.20
	r	0.9584	0.9500	0.9373	0.9456	0.9179	0.8986	0.8718	0.9343	0.9289
$[NiL_2]$										
Stage I	E	90.73	94.98	99.53	96.50	47.48	19.15	9.70	44.04	45.17
	A	8.15×10^4	1.16×10^5	7.88×10^4	3.75×10^4	3.39×10^1	3.76×10^{-2}	3.15×10^{-3}	4.25	3.78
	ΔS	−156.53	−153.56	−156.81	−162.99	−221.28	−277.88	−298.50	−238.55	−239.51
	r	0.9686	0.9665	0.9643	0.9658	0.9553	0.9347	0.8959	0.9857	0.9575
Stage II	E	169.89	185.58	203.55	191.50	106.01	47.63	28.17	91.97	96.40
	A	5.15×10^{10}	4.97×10^{11}	4.18×10^{12}	3.66×10^{11}	7.68×10^5	1.03×10^1	1.89×10^{-1}	2.11×10^4	3.52×10^4
	ΔS	−46.76	−27.89	−10.19	−30.43	−139.19	−232.48	−265.74	−169.11	−164.84
	r	0.9303	0.9408	0.9499	0.9443	0.9510	0.9401	0.9254	0.9399	0.9445

*E in KJ mol^{-1}; A in S^{-1}; ΔS in JK^{-1} mol^{-1}; r = Correlation coefficient

Initial decomposition temperature and inflection temperature have been used to determine the thermal stability of the metal chelates[33]. On the basis of our findings the relative thermal stabilities of the metal chelates can be given as $[MnL_2(H_2O)_2] < [CoL_2] < [NiL_2]$.

Decomposition kinetics

From Tables 3 and 4, it can be seen that more than one equation gives good linear curves with high correlation coefficient. It thus becomes difficult to assign

TABLE-4
KINETIC PARAMETERS FOR THE DECOMPOSITION OF Mn(II), Co(II) AND Ni (II) COMPLEXES OF ANTHRACENE-9-CARBOXALDEHYDE THIOSEMICARBAZONE FROM TG USING NON-MECHANISTIC EQUATIONS

Complex	Parameter*	Coats-Redfern	Horowitz-Metzger	Mechanistic	Equation followed	Order of reaction (n)
$[MnL_2(H_2O)_2]$						
Stage II	E	49.51	64.44	49.51		1
	A	1.59×10^2	2.25×10^3	1.59×10^2	Equation V:	
	ΔS	−207.97	−185.99	−207.97	Mampel equation	
	r	0.9945	0.9905	0.9945		
Stage III	E	79.78	98.15	85.74	Equation VIII:	1/3
	A	2.86×10^2	5.53×10^3	4.05×10^2	Phase boundary	
	ΔS	−206.21	−181.58	−203.33	reaction	
	r	0.9798	0.9872	0.9784	cylindrical symmetry	
$[CoL_2]$						
Stage I	E	50.02	65.48	52.60	Equation VIII:	1/3
	A	1.23×10^2	4.84×10^3	1.23×10^2	Phase boundary	
	ΔS	−209.99	−179.44	−209.95	reaction	
	r	0.9657	0.9814	0.9636	cylindrical symmetry	
Stage II	E	67.95	86.86	77.19	Equation VIII:	1/3
	A	4.73×10^1	9.97×10^2	1.19×10^2	Phase boundary	
	ΔS	−221.28	−195.93	−213.57	reaction	
	r	0.9394	0.9622	0.9343	cylindrical symmetry	
$[NiL_2]$						
Stage I	E	42.94	58.52	44.05	Equation VIII:	1/3
	A	6.38	2.21×10^2	4.25	Phase boundary	
	ΔS	−235.17	−205.70	−238.56	reaction	
	r	0.9598	0.9782	0.9587	cylindrical symmetry	
Stage II	E	106.02	129.57	106.02		1
	A	7.68×10^5	2.61×10^7	7.68×10^5	Equation V:	
	ΔS	−139.19	−109.91	−139.19	Mampel equation	
	r	0.9510	0.9551	0.9510		

*α in kJ mol^{-1}; A in S^{-1}; ΔS in JK^{-1} mol^{-1}; r = Correlation coefficient

the reaction mechanisms unequivocally from the linearity of the curve alone. In such case, some authors chose the function $g(\alpha)$, which gives the kinetic parameters in agreement with those obtained by the numerical method. In the present case it is observed that the second stage decomposition of the Mn(II) and Ni(II) complexes, the E, A and ΔS values obtained from the Coats-Redfern[24] equation with n = 1 are in good agreement with E, A and ΔS values obtained from the Mampel equation which is based on random nucleation, one nucleus on each particle. For the first stage of decomposition of the nickel(II) chelate and both first and second stage of decomposition of Co(II) complex, good agreement is resulted between the kinetic parameters obtained from Coats-Redfern[24] method with n = 1/3 and the R_2 mechanism based on a phase boundary reaction, cylindrical symmetry.

Antitumour studies

All the compounds, both the ligand and complexes were screened for their antitumour activity. Cytotoxicity studies using Ehrlich ascites and DLA tumour cells *in vitro* (Table-5) reveal that the ligand A9CTSC has negligible cytotoxic action while all the complexes exhibit marked cytotoxic power. The more active compound $[MnL_2(H_2O)_2]$ produced complete cell death even at the drug concentration of 25 $\mu g\ cm^{-3}$. Even though remarkable progress in understanding the antitumour activities of related compounds has been made by biological methods, the chemistry behind them still remains rather obscure. It has been suggested that similar compounds interfere with the incorporation of thymine in DNA and also interact with cellular thiols diminishing their concentration[34, 35]. Metal coordination increases the lipophilicity, which may be a contributing factor to the enhanced activity of the metal chelates.

TABLE-5
CYTOTOXIC ACTION OF THE LIGAND (LH) AND ITS METALCOMPLEXES ON DALTON'S LYMPHOMA ASCITES (DLA) AND EHRLICH ASCITES (EA) TUMOUR CELLS

Drug	Tumour cell line	Percentage of dead cells				
		50	25	10	5	1
LH	DLA	19	17	05	—	—
	EA	23	22	10	—	—
$[MnL_2(H_2O)_2]$	DLA	100	100	94	73	59
	EA	100	96	79	53	47
$[CoL_2]$	DLA	30	23	21	20	15
	EA	66	47	34	31	23
$[NiL_2]$	DLA	92	59	48	35	26
	EA	88	54	46	40	31

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REFERENCES

1. M.J.M. Campbell, *Coord. Chem. Rev.*, **15**, 279 (1975)
2. D.L. Klayman, J.P. Scovili, J.F. Bartosevich and C.J. Mason, *J. Med. Chem.*, **22**, 1367 (1979).
3. G. Domagk, R. Behnish, F. Mietzsch and H. Schmidt, *Naturwissenchaften*, **33**, 315 (1946).
4. L. Heilmeuer, *Dent. Med. Wochscr.*, **74**, 161 (1949).
5. J.P. Jouin and N.G. Ph. Buuttoi, *Ann. Inst. Pasteur.*,**72**, 580 (1946).
6. E. Hoggarth, A.E. Martin, N.E. Storey and E.H.P. Young, *Brit. J. Pharmacol.*, **4**, 248 (1949).
7. R. Donovick, F. Pansy, G. Stryker and J. Bernstein, *J. Bacteriol.*, **59**, 667 (1950).
8. H.G. Petering, H.H. Buskirk and G.E. Underwood, *Cancer Res.*, **64**, 367 (1964).
9. Sankar Jayasree and Kuttamath K. Aravindakshan, *Transition Met. Chem.*, **18**, 85 (1993).
10. L.A. Saryan, K. Mailer, C. Krishnamurti, W. Antholine and D.H. Petering, *Biochem. Pharmacol.*, **30**, 595 (1981)
11. S. Jayasree and K.K. Aravindakshan, *Polyhedron*, **12**, 1187 (1993).
12. M. Lehtinen and K. Maire, *Acta Pharm. Fenn.*, **90**, 187 (1981).
13. L. Pardeshi and R.A. Bhobe, *Acta Cienc. Indica*, **9**, 18 (1983).
14. S. Laly and G. Parameswaran, *Thermochim. Acta*, **43**, 169 (1991).
15. K. Joby Thomas and Geetha Parameswaran, *J. Indian Chem. Soc.*, **72**, 155 (1995).
16. K.J. Thomas and G. Parameswaran, *J. Therm. Anal.*, **45**, 1491 (1995).
17. F. Skavara and V. Satava, *J. Therm. Anal.*, **2**, 325 (1970).
18. K.N. Ninan and C.G.R. Nair, *Thermochim. Acta*, **23**, 161 (1978).
19. A.I. Vogel, A Text Book of Practical Organic Chemistry, 3rd edn., Longmans, London, pp. 163–179 (1956).
20. A.I. Vogel, A Text Book of Quantitative Inorganic Analysis, ELBS and Longman, 1978
21. B.N. Figgis and J. Lewis in J. Lewis and R.G. Wilkins (Eds), Modern Coordination Chemistry, Interscience, New York, p. 403 (1960).
22. J. Sestak and G. Berggren, *Thermochim. Acta*, **3**, 1 (1971).
23. V. Satava, *Thermochim. Acta*, **2**, 2 (1971).
24. A.W. Coats and J.P. Redfern, *Nature* (London), **201**, 68 (1964).
25. M.D. Judd and M.T. Pope, *J. Therm. Anal.*, **4** (1972) 31; J. Zsako, *J. Therm. Anal.*, **8**, 349 (1975).
26. J.H. Horowitz and G. Metzger, *Anal. Chem.*, **35**, 1464 (1963).
27. B.N. Figgis and J. Lewis, in: F.A. Cotton (Ed.), Progress in Inorganic Chemistry, Vol. 6, Interscience, New York (1964).
28. B.A. Gingras, R.W. Hornal and C.H. Bayley, *Can. J. Chem.*, **38**, 712 (1960).
29. N.C. Mishra, B.B. Mahapatra and S. Guru, *J. Inorg. Nucl. Chem.*, **41**, 408 (1979).
30. A.B.P. Lever, Inorganic Electronic Spectroscopy, Elsevier, London (1968).
31. A.V. Nikolaev, V.A. Logvinenko and L.I. Myachina, Thermal Analysis, Academic Press, New York (1969).
32. S. Vatsala and G. Parameswaran, *J. Therm. Anal.*, **31**, 883 (1986); R.S. Naidu, E.N. Rao, R. Ruby and K.G. Mallikarjun, *Thermochim. Acta*, **13**, 299 (1988); **40**, 97 (1989).
33. S. Seshagiri and S.B. Rao, *Z. Anal. Chem.*, **262**, 275 (1972) R.S. Naidu and R.R. Naidu, *Indian J. Chem.*, **15**, 652 (1977).
34. G.J. Vangiessen, J.A. Crim, D.H. Petering and H.G. Petering, *J. Natl. Cancer Inst.*, **51**, 139 (1973).
35. D.H. Petering, *Bioinorg. Chem.*, **1**, 255 (1972).

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