Inorganica Chimica Acta, 176 (1990) 241–246

Studies on mixed ligand complexes of ruthenium(III) edta with purines

Badar Taqui Khan* and **K. Annapoorna**
Department of Chemistry, Osmania University, Hyderabad 500 007 (India)

(Received May 2, 1990)

Abstract

Mixed ligand complexes of ruthenium(III) edta with adenine, guanine, hypoxanthine, 2,6-diaminopurine and 2-thioxanthine were synthesised and characterised by elemental analysis, conductivity, infrared spectra, electronic spectra, ^{1}H NMR, ESR and polarography. Based on the above data, it is proposed that adenine,2,6-diaminopurine and 2-thioxanthine coordinate to metal ion through N_3 and N_9, C_6NH_2 and N_7, C_6O and N_7, respectively and form diligand bridged bimetallic 2:2 complexes. Guanine and hypoxanthine form 1:1 complexes coordinating to metal ions through N_7.

Introduction

In recent years the ruthenium(III) edta complexes have been studied in great detail, in solution as well as in the solid state [1–4]. Mixed ligand complexes of ruthenium(III) edta with σ donor and π acceptor ligands have been isolated by several workers, where edta acts as a tetradentate or pentadentate ligand [4–6]. Taqui Khan *et al.* have reported several oxidation reactions where ruthenium(III) edta acts as a good catalyst such as triphenylphosphine to phosphine oxide and cyclohexene to the epoxide [7, 8]. Purines which are constituents of nucleic acids form many mixed ligand complexes with platinum group metal ions [9–16]. Mixed ligand complexes of platinum and palladium are known to possess antitumour and antibacterial activity [17, 18]. Some ruthenium(II) and (III) complexes such as *cis*[$(DMSO)_4RuCl_2$] and *cis*[$(NH_3)_4RuCl_2$]Cl are also known to exhibit antitumour and antibacterial activity [19, 20]. In view of the importance of these ruthenium complexes, we have undertaken the studies of mixed ligand complexes of ruthenium(III) edta with purines. The complexes were synthesised and were characterised by various physicochemical methods.

Experimental

Materials

Hydrated ruthenium trichloride and purines were purchased from Johnson and Matthey and Sigma Chemical Company, U.S.A. The disodium salt of ethylenediaminetetraacetic acid was obtained from BDH chemicals. Solvents used were of high purity and distilled before use.

Synthesis

K[Ru(edta-H)Cl]·$2H_2O$ (**1**) was prepared by the method of Ezerskaya and Solovykh [21] as modified by Diamantis and Dubrawski [22]. $K_2[RuCl_5(H_2O)]$ prepared by a modified method of Mercer and Buckley [23] was used as the starting material in the above preparation.

Physical measurements

Elemental analyses of the complexes were obtained from the Central Drug Research Institute, Lucknow. Conductivity data were measured on a digital conductivity meter No. DI 909. Infrared and electronic spectra of the complexes were recorded on Schimadzu IR 435 and UV-160 instruments, respectively. Far infrared spectra were recorded at RSIC, IIT, Madras; ^{1}H NMR and ^{13}C NMR spectra were recorded on Jeol 500 MHZ spectrometer at TIFR, Bombay. Electron paramagnetic resonance spectra were recorded on a Bruker ESP 300 X-band instrument at CSMCRI, Bhavnagar. Electrochemical measurements were taken at CSMCRI, Bhavnagar, on a Princeton Applied Research electrochemical instrument equipped with a precision X-Y recorder. A PAR 174 polarographic analyser was used to record d.c. and differential pulse polarograms.

---

*Author to whom correspondence should be addressed.

0020-1693/90/$3.50

Preparation of complexes

Potassium di-μ-adenine bis[ethylenediaminetetraacetatoruthenate(III)] tetrahydrate (**2**); Potassium (ethylenediaminetetraacetato) guanine ruthenate(III) monohydrate (**3**); Potassium (ethylenediaminetetraacetato) hypoxanthine ruthenate(III) monohydrate (**4**); Potassium di-μ-2,6-diaminopurine bis[ethylenediaminetetraacetato ruthenate(III)] tetrahydrate (**5**); Potassium di-μ-2-thioxanthine bis[ethylenediaminetetraacetato ruthenate(III)] tetrahydrate (**6**)

Potassium chloroethylenediaminetetraacetatoruthenate(III) (0.4 mM) dissolved in water was added to a hot solution of the ligand (0.4 mM) (adenine, guanine, 2,6-diaminopurine, hypoxanthine,2 thioxanthine) in water, when the yellow colour of the solution changed to red with the first three ligands, deep yellow and dark blue with the fourth and fifth ligands, respectively. The pH of the solution was between 3 to 4. The solution was refluxed for 10–12 h in an atmosphere of pure nitrogen and completion of reaction was checked by TLC. The solution was concentrated to one fourth of its volume and was precipitated with ethanol/acetone. The complex was washed with acetone water mixture, finally with acetone and was then vacuum dried. Complexes are soluble in water.

Results and discussion

The analytical and conductivity data of the complexes are presented in Table 1. The complexes are 1:1 electrolytes.

Infrared spectra of the complexes

The infrared spectra of the complexes indicate the presence of lattice water, coordination of edta to the metal ion and the presence of purine in these complexes. The complexes contain lattice water as shown by the broad νOH absorption band in the region 3400–3300 cm^{-1}. The νNH and νCH stretching vibrations due to the coordinated secondary ligand were observed in the region 3100–2950 cm^{-1}. In K[Ru(edtaH)Cl]$\cdot$2H$_2$O (**1**) a sharp peak at 1720 cm^{-1} and a broad peak at 1650 cm^{-1} indicate the presence of uncoordinated and coordinated carboxylic acid groups of edta, respectively [20]. In the mixed ligand complexes the peak at 1720 cm^{-1} disappears, indicating the absence of a free COOH group. A broad peak observed at 1680–1580 cm^{-1} is due to the coordinated carboxylate group of edta in these complexes and also due to the NH$_2$ deformation mode of adenine, guanine or 2,6-diaminopurine of complexes **2**, **3** and **5**, respectively. The νC=O stretching frequencies at 1700 and 1680 cm^{-1} for guanine and hypoxanthine complexes, respectively, show that the carbonyl group is not involved in coordination to the metal ion. In the 2-thioxanthine complex, the νC=O stretching frequency shifts to lower frequency by 20 cm^{-1} as compared to the ligand indicating that the C=O group is involved in coordination to the metal ion. The νC=C and νC=N stretching frequencies of the secondary ligand in these complexes shift to lower frequencies by 40 to 70 cm^{-1} indicating that ring nitrogens are involved in coordination to the metal ion. The νM–N and νM–O stretching frequencies in the complexes are observed around 500 and 400 cm^{-1}, respectively, showing that edta coordinates to the metal ion through oxygen and nitrogen.

TABLE 1. Analytical and conductivity data of complexes

Complex no.	Complex	Analysis[a] (%)			Molar conductivity at 30 °C in H$_2$O (mhos cm^{-2})
		Carbon	Hydrogen	Nitrogen	
1	K[Ru(edta-H)Cl]$\cdot$2H$_2$O	24.20 (24.00)	3.30 (3.39)	5.51 (5.59)	326
2	K$_2$[Ru(edta)(ade)]$_2\cdot$4H$_2$O	30.01 (30.04)	3.4 (3.5)	16.02 (16.30)	316
3	K[Ru(edta)(gua)]$\cdot$H$_2$O	28.1 (28.4)	2.96 (3.00)	15.30 (15.49)	214
4	K[Ru(edta)(hyp)]$\cdot$H$_2$O	32.1 (31.00)	3.3 (3.26)	14.9 (14.4)	253
5	K$_2$[Ru(edta)(2,6-diampul)]$_2\cdot$4H$_2$O	26.5 (27.1)	3.28 (3.3)	16.04 (16.9)	311
6	K$_2$[Ru(edta)(2-thioxan)]$_2\cdot$4H$_2$O	29.0 (28.5)	3.20 (3.17)	13.4 (13.29)	320

[a] Calculated value in parentheses.

The electronic spectral absorption bands and their assignments for the complexes are shown in Table 2. The weak bands in the 500–600 nm region observed in some of the complexes are d–d transitions with some MLCT character.

The NMR spectra of the complexes (Table 3) was of great help in assigning the binding sites of the ligands to the metal ion. Such spectra are difficult to record [4] with low resolution NMR spectrometers because of paramagnetism of ruthenium(III). In order to overcome this problem the spectra were recorded with 500 MHz FT NMR in the present work. The resolution observed was obtained after lengthy computation of the spectra. One of the representative spectra of complex **2** is given in Fig. 1. The ^1H NMR spectral data of complex **1** are given in Table 3. The crystal structure of the complex has been reported [24], where edta is pentadentate and the sixth position is occupied by chloride. The ^1H NMR spectrum of complex **2** shows a downfield shift in the C_2H and C_8H protons by 0.23 and 0.29 ppm, respectively, as compared to the ligand, inferring that adenine coordinates to the metal ion through N_3 and N_9. The ^1H NMR spectra of complexes **3**

TABLE 2. Electronic spectral data of Ru(III) edta mixed ligand complexes and secondary ligands

Complex no.	Ligand/Complex	Absorption maxima λ_{max} (nm)	ϵ max (M^{-1} cm^{-1})	Transition
1	$K[Ru(edta\text{-}H)Cl]\cdot 2H_2O$	283	2.71×10^3	LMCT
		350	5.8×10^2	d–d
	Adenine	262	1.30×10^4	π–π^*
2	$K_2[Ru(edta)(ade)]_2\cdot 4H_2O$	261	2.2×10^4	LMCT adenine
		354	1.86×10^3	LMCT edta
		522	1.9×10^2	d–d Ru(III)
		803	6.0×10	d–d
	Guaninehydrochloride	246	–	π–π^*
		276		
3	$K[Ru(edta)(gua)]\cdot H_2O$	234	1.30×10^4	LMCT guanine
		276	8.01×10^3	
		355	7.4×10^2	LMCT edta
		551	1.0×10^2	d–d
		780	5×10	d–d
		802	5×10	d–d Ru(III)
		976	6×10	d–d
	Hypoxanthine	250	1.05×10^4	π–π^*
4	$K[Ru(edta)(hyp)]\cdot H_2O$	248	1.43×10^4	LMCT hypoxanthine
		354	8.2×10^2	LMCT edta
		974	4×10	d–d Ru(III)
	2,6-Diaminopurine	214	1.57×10^4	electronic transitions of ligand
		242	7.49×10^3	
		281	8.15×10^3	
5	$K_2[Ru(edta)(2,6\text{-}diampu)]_2\cdot 4H_2O$	214	4.47×10^4	
		238	2.68×10^4	LMCT 2,6-diaminopurine
		281	2.34×10^4	
		354	1.39×10^3	LMCT edta
		882	9.02×10	d–d Ru(III)
		965	1.12×10^2	d–d
	2-Thioxanthine	230	1.36×10^4	electronic transitions of ligand
		284	1.97×10^4	
6	$K_2[Ru(edta)(2\text{-}thioxan)]_2\cdot 4H_2O$	272	2.27×10^4	LMCT 2-thioxanthine
		368	2.29×10^3	LMCT edta
		582	2.43×10^3	d–d
		798	2.33×10^2	d–d Ru(III)

TABLE 3. ^1H NMR spectra data (ppm) of Ru(III) edta mixed complexes and secondary ligands

Complex no.	Complex/Ligand	Purine base		edta protons		
		C_2H	C_8H	$N–CH_2–CH_2–N$	CH_2COO^- (free)	CH_2COO (coordinated)
1	$K[Ru(edta\text{-}H)Cl]\cdot 2H_2O$			3.26; 3.48	3.68	4.0
	Adenine	8.2	8.32			
2	$K_2[Ru(edta)(ade)]_2\cdot 4H_2O$	8.43	8.61	2.82; 3.4	3.7	3.8
	Guaninehydrochloride		7.68			
3	$K[Ru(edta)(gua)]\cdot H_2O$		7.97	3.62; 3.8	4.03	4.16
	Hypoxanthine[a]	7.96	8.10			
4	$K[Ru(edta)(hyp)]\cdot H_2O$[a]	7.90	9.16	3.45; 3.63	3.95	4.20
	2,6-Diaminopurine		7.8			
5	$K_2[Ru(edta)(2,6\text{-}diampu)]_2\cdot 4H_2O$		8.14	3.35; 3.7	3.92	4.12
	2-Thioxanthine[a]		8.00			
6	$K_2[Ru(edta)(2\text{-}thioxan)]_2\cdot 4H_2O$[a]		8.36	3.00; 3.25	3.9	4.2

[a]Solvent: $D_2O/DMSO\text{-}d_6$.

TABLE 4. Electrochemical data for Ru(III) edta mixed ligand complexes

Complex no.	Complex	$E_{1/2}$ values		
		Ru^{3+}/Ru^{2+}	Ru^{2+}/Ru^+	$(H^+/1/2H_2)$
1	$K[Ru(edta\text{-}H)Cl]\cdot 2H_2O$	−0.220	−0.842	−1.012
2	$K_2[Ru(edta)(ade)]_2\cdot 4H_2O$	−0.112 −0.183		−1.017
4	$K[Ru(edta)(hyp)]\cdot H_2O$	−0.175		−0.978
5	$K_2[Ru(edta)(2,6\text{-}diampu)]_2\cdot 4H_2O$	−0.128 −0.293	−0.742	−1.269
6	$K_2[Ru(edta)(2\text{-}thioxan)_2\cdot 4H_2O$	−0.095 −0.173		−0.803

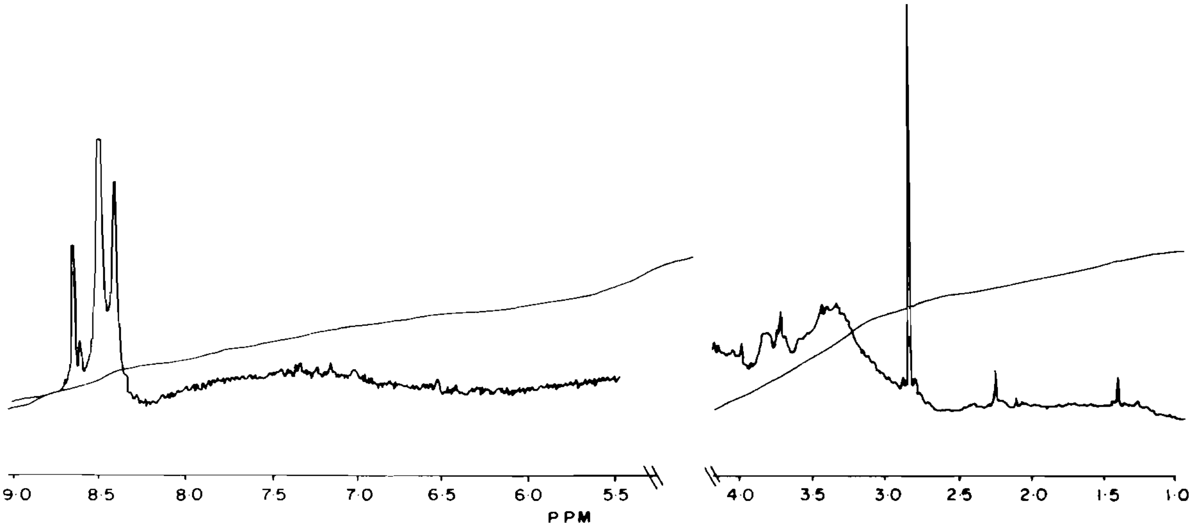

Fig. 1. ^1H NMR spectrum of $K_2[Ru(edta)(ade)]_2\cdot 4H_2O$.

(a)

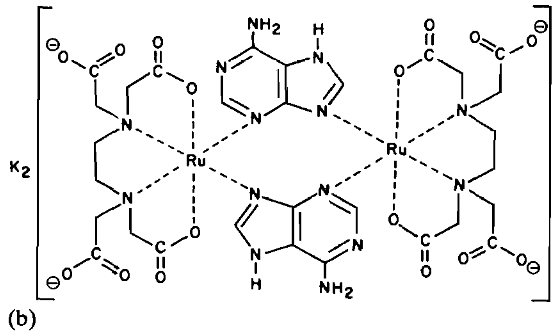

Fig. 2. (a) Model structure; (b) structure of $K_2[Ru(edta)(ade)]_2 \cdot 4H_2O$.

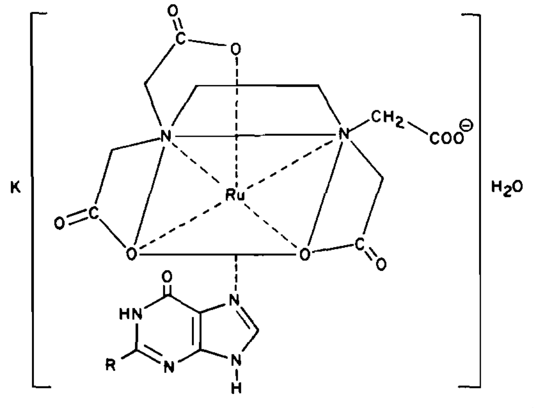

Fig. 3. Structure of $K[Ru(edta)(gua)] \cdot H_2O$ ($R=NH_2$) (**3**) structure of $K[Ru(edta)(hyp)] \cdot H_2O$ ($R=H$) (**4**).

and **4** show a downfield shift in the C_8H proton by 0.29 and 1.08 ppm, respectively, indicating that guanine and hypoxanthine coordinate to the metal ion through N_7. The ^1H NMR spectrum of complex **5** shows a downfield shift in the C_8H proton by 0.34 ppm, which indicates that 2,6-diaminopurine coordinates to the metal ion through N_7. The $^{13}C\{^1H\}$ NMR spectrum of complex **5** also supports the coordination of 2,6-diaminopurine to the metal ion through N_7 and C_6NH_2. In the ligand 2,6-diaminopurine the resonances are: $C_2=156.37$; $C_4=150.84$; $C_5=138.89$; $C_6=154.18$; $C_8=148.93$; and in the complex the resonances are: $C_2=156.5$; $C_4=152.0$; $C_5=144.0$; $C_6=157.0$; $C_8=151.5$. There is a downfield shift in the C_8 carbon by 2.57 ppm; in the C_5 carbon by 5.11 ppm and in the C_6 carbon by 2.82 ppm as compared to resonances in the ligand showing that 2,6-diaminopurine coordinates to the metal ion through N_7 and C_6NH_2. The ethylenic carbons of edta show peaks at 60.6 and 65 ppm and the methylenic carbons of edta show peaks at 70, 72, 76 and 78 ppm. The free carboxylate group of edta is observed at 170 ppm and the signals due to the coordinated carboxylate groups are observed at 184 and 185 ppm. The ^1H NMR spectrum of complex **6** shows a downfield shift in the C_8H proton by 0.36 ppm, inferring that 2-thioxanthine coordinates to the metal ion through N_7. The edta protons in these complexes resonate between 3.0 and 4.2 ppm.

The electron paramagnetic resonance spectra of these complexes in general show rhombic or isotropic distortions. Complex **1** shows compressed rhombic distortion with g values 2.37, 2.324 and 1.944. Complexes **2** and **6** show rhombic distortion with g values 2.29, 2.115 and 1.965 with $g_{av}=2.128$; and 2.39, 2.26 and 2.02 with $g_{av}=2.228$, respectively. Complexes **3**, **4** and **5** show isotropic distortions with one g value. The g values for the three complexes are 2.36, 2.180 and 2.274, respectively.

The electrochemical data of the complexes are given in Table 4. The differential pulse polarograms of complexes **2**, **5** and **6** show a split peak for the Ru^{3+}/Ru^{2+} couple. On comparison of $E^{1/2}$ values of the Ru^{3+}/Ru^{2+} couple, a split peak differing in potentials by -0.071 V in complex **2**, -0.165 V in complex **5** and -0.078 V in complex **6** was observed as compared to complex **1**. This small difference in potentials is attributed to stepwise reduction of two metal centres in a binuclear complex, rather than one centre inferring that 2:2 diligand bridged bimetallic complexes are formed in these complexes. In the case of complex **4**, a single peak for the Ru^{3+}/Ru^{2+} couple was observed which supports the formation of a 1:1 complex. In these complexes the potentials are more positive as compared to complex **1**, indicating the drift of electron density from the metal ion to the ligand, and the secondary ligand thus acts as a weak π acid. This is supported by weak MLCT bands around 500–600 nm in the electronic spectra of these complexes.

Based on analytical and spectroscopic data, the model structure for complex **2** shown in Fig. 2(a) and the corresponding structure shown in Fig. 2(b) are proposed for complex **2**, which is a dimer where edta is tetradentate and two adenines act as bidentate bridging ligands binding through N_3 and N_9 to two ruthenium metal ions, respectively. Complexes **3** and **4** with structures shown in Fig. 3(a) and (b), respectively, are monomers, where edta is pentadentate and guanine and hypoxanthine coordinate to the metal ion through N_7. Complex **5** is a dimer wherein two Ru–edta moieties are bridged by two 2,6-diaminopurines coordinating through C_6NH_2 and N_7 to two metal ions, respectively. In the case of complex **6** two Ru–edta moieties are bridged by two 2-thioxanthines coordinating through C_6O to one metal ion and through N_7 to the other metal ion forming a 2:2 diligand bridged bimetallic complex.

Acknowledgement

Miss K. Annapoorna (Senior Research Fellow) is grateful to CSIR, New Delhi, for financial assistance.

References

1 T. Matsubara and C. Creutz, *Inorg. Chem., 18* (1979) 1956.

2 M. M. Taqui Khan, A. Hussain, G. Ramachandraiah and M. A. Moiz, *Inorg. Chem., 25* (1986) 3023.

3 (a) N. A. Ezerskaya and T. P. Solovykh, *Zh. Neorg. Khim., 11* (1966) 1855; (b) *11* (1966) 2197; (c) *12* (1967) 2922; (d) *11* (1966) 1462; (e) *13* (1968) 186; (f) *11* (1966) 2569.

4 A. A. Diamantis and J. V. Dubrawski, *Inorg. Chem., 22* (1983) 1934.

5 B. Taqui Khan and K. Annapoorna, *Inorg. Chim. Acta, 171* (1990) 157.

6 M. M. Taqui Khan and S. Zaheeda, *Inorg. Chem.*, to be published.

7 M. M. Taqui Khan, M. R. H. Siddiqui, A. Hussain and . A. Moiz, *Inorg. Chem., 25* (1986) 2765.

8 M. M. Taqui Khan, *Proc. Indian Natl. Sci. Acad., Part A,* (1986) 830.

9 W. M. Beck, J. C. Calabrese and N. D. Kottmair, *Inorg. Chem., 18* (1979) 176.

10 B. T. Khan and A. Mehamood, *J. Inorg. Nucl. Chem., 60* (1978) 1938.

11 B. T. Khan, S. Vijaya Kumari and G. Narsa Goud, *Indian J. Chem., 21A* (1982) 264.

12 S. Kohata, K. Sagara, H. Takada and A. Ohyoshi, *Polyhedron, 4* (1985) 1059 (in English).

13 N. Farrell and N. G. Deoliveira, *Inorg. Chim. Acta., 66* (1982) L61.

14 B. T. Khan, A. Gaffuri, P. Nageswara Rao and S. M. Zakeeruddin, *Polyhedron, 6* (1987) 387.

15 B. T. Khan, S. Vijaya Kumari, K. Murali Mohan and G. Narsa Goud, *Polyhedron, 4* (1985) 1617.

16 B. T. Khan, K. Najmuddin, S. Shamsuddin and S. M. Zakeeruddin *Inorg. Chim. Acta, 170* (1990) 129.

17 M. J. Cleare and J. D. Hoeshele, *Platinum Met. Rev., 15* (1973) 42.

18 B. Rosenberg in T. G. Spiro (ed.), *Nucleic Acid Metal Ion Interactions,* Vol. 1, Marcel Dekker, New York, 1979, p. 127.

19 S. Giraldi, G. Sava, G. Bertouli, G. Mestronic and G. Zassinovich, *Cancer Res., 37* (1977) 2662.

20 M. J. Clarke, *Inorg. Chem. Biol. Med.,* ACS Symp. Ser., 140, 1980, pp. 157–180.

21 N. A. Ezerskaya and T. P. Solovykh, *Russ. J. Inorg. Chem., 11* (1966) 991.

22 A. A. Diamantis and J. V. Dubrawski, *Inorg. Chem., 20* (1981) 1142.

23 E. E. Mercer and R. R. Buckley, *Inorg. Chem., 4* (1965) 1692.

24 M. M. Taqui Khan, *Inorg. Chem.,* to be published.