Potential Multifunctional Anti-cancer Metal Complexes. I. Synthesis and X-ray Structural Studies of some Dinuclear Rhodium(II) Carboxylate Complexes with Diamine-substituted Acridine Ligands in Terminal Coordination Positions

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Abstract

The preparations are reported of $[Rh(RCO_2)_2L]_2$ [where R = CH_3, C_2H_5, and CH_3OCH_2; L = 6-chloro-2-methoxy-9-[2(NR'_2)ethyl]aminoacridine (R′ = H, CH_3)]. X-ray structural studies have been carried out on two of the compounds [R = C_2H_5, R′ = H, (**1**); R = CH_3, R′ = CH_3, (**2**)]. Compound **1** is monoclinic, space group $C2/c$, with a = 20.864(11), b = 15.736(4), c = 14.402(4) Å, β = 93.14(4)°, V = 4721 Å^3, and Z = 4; **2** is monoclinic, space group $P2_1/n$, a = 8.861(2), b = 23.089(10), c = 12.014(2) Å, β = 105.84(2)°, V = 2365 Å^3, and Z = 2. Both compounds comprise the standard dinuclear rhodium(II) carboxylate unit with the substituted acridine ligands coordinated to rhodium in the axial positions, via the NH_2 group nitrogen in **1** and the $N(CH_3)_2$ nitrogen in **2**.

The dimethyl substitution on the tertiary amine group in **2**, and an associated conformational change in the diamine chain, result in an increased separation of the acridine ligand from the metal centre. There is a pronounced acridine base stacking in **1** but not in **2**.

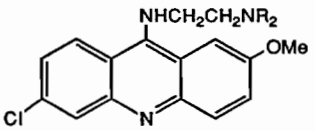
Introduction

The use of metal complexes as anti-cancer agents, either directly as cytotoxic drugs [1, 2] or as radiosensitizers in conjunction with radiotherapy [3] is now well established. In clinical practice, regimens involving combinations of drugs, e.g., cis-platin plus an organic intercalative drug, are often employed, and combinations of cytotoxic drug and radiotherapy are also used. Moreover, attention has been paid to the synthesis and anti-cancer activity of molecules containing two or more [4] intercalating units, with the aim of enhancing the efficacy and the specificity of DNA binding, and hence their cytotoxic action.

In the light of this, there seems to be considerable potential for therapeutic action by multifunctional drugs involving both intercalation and metal-containing units within the same molecule. Such compounds could, in principle, contain various combinations of moieties known to result in anti-cancer activity. Thus, a metal complex centre bonded to an intercalator unit by a linking chain of appropriate length could be one which is cytotoxic by virtue of its own ability to bind to DNA (e.g., Pt) or could facilitate radiotherapy by possessing radiosensitization behaviour. (This classification of properties is, of course, not mutually exclusive as some complexes, e.g., of Pt, are both cytotoxic and radiosensitizers [3]).

There are relatively few examples of bifunctional drug design of this type. Lown and Joshua have described [5] some antileukemic haemin-acridines which bind to duplex DNA via the acridine unit and, in the presence of reducing agents, cause oxygen-dependent strand scission. More recently, Ong has prepared [6] a related complex, 6-chloro-2-methoxy-9-triethylenetetramineacridineiron(II) dichloride, which also causes DNA strand scission *in vitro*. Lippard has described [7] a cis-platin analogue containing an intercalating unit (acridine orange) linked via 1,2-diaminoethane to the metal centre which was found to cause photoactivated DNA cleavage.

As part of a programme to prepare various types of potentially bifunctional drugs involving both intercalator and metal centres, we report here the synthesis of some rhodium(II) carboxylate complexes with diamine substituted acridines (**I**) and the structural characterisation of two of them by X-ray diffraction methods.



Ia, R = H
Ib, R = CH_3

Our choice of the dinuclear rhodium(II) carboxylate unit as the metal centre was influenced by the facts that these complexes have anti-cancer activity [8], act as radiosensitizers [9], and enhance

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the activity of organic radiosensitizer ligands bonded to them [10, 11]. Moreover, we expected to be able to bind two such acridine units to each dinuclear rhodium(II) carboxylate moiety.

Experimental

Preparations

Ligands

9-(2-Aminoethyl)amino-6-chloro-2-methoxyacridine (LIa) was prepared by a modification of the literature [12] method. After removal of the excess ethylenediamine under vacuum, the solid product was recrystallized from benzene to give yellow crystals in 65% yield. *Anal.* Found: C, 63.38; H, 5.25; N, 13.84. Calc.: C, 63.68; H, 5.35; N, 13.93%.

6-Chloro-9-(2-dimethylaminoethyl)amino-2-methoxyacridine (LIb). This was obtained as in [13] but with the following modification. After ether extraction of the free base, the ether solution was dried and the solvent removed by evaporation. The resultant solid was recrystallized from benzene to give orange needles in 55% yield. *Anal.* Found: C, 65.43; H, 6.09; N, 12.73. Calc.: C, 65.55; H, 6.11; N, 12.74%.

Complexes

The anhydrous rhodium(II) carboxylate (0.25 mmol) in methanol (30 cm^3) was stirred with 2,2-dimethoxypropane (5 cm^3) for 1 h. Addition of a methanolic solution of the acridine ligand (0.5 mmol in 20 cm^3) with rapid stirring caused the formation of a brick-red precipitate. Stirring was continued for 2 h and then the complexes were filtered off, washed with cold methanol (2 × 5 cm^3) and diethyl ether (2 × 5 cm^3) and dried *in vacuo*. Yields were 80–90%. Analytical data are given in Table I.

As the above procedure gave powders rather than crystals suitable for X-ray studies, the following method was adopted. A solution of the acridine ligand (0.5 mmol) in acetonitrile (20 cm^3) was very gradually added, without stirring, to one of the anhydrous rhodium(II) carboxylate (0.25 mmol) in the same solvent (20–30 cm^3). These solutions were then allowed to evaporate slowly at room temperature. In the case of $Rh(CH_3CH_2CO_2)_2$(LIa) red tabular crystals formed after *ca.* 3 days, and for $Rh(CH_3CO_2)_2$(LIb) red plates grew over a period of *ca.* 3 weeks.

X-ray Studies

A summary of the crystal data and of the data collection and refinement parameters for the compounds $[Rh(CH_3CH_2CO_2)_2(LIa)]_2$ (**1**) and $[Rh(CH_3CO_2)_2(LIb)]_2$ (**2**) is given in Table II. Refined unit cell parameters were obtained by centering for **1** 18 and for **2** 17 reflections on a Nicolet R3m diffractometer. Intensity data were measured with graphite monochromated Cu Kα radiation using ω-scans. The data were corrected for Lorentz and polarisation factors. Numerical absorption corrections (face indexed crystals) were applied.

Both structures were solved by the heavy atom method and their non-hydrogen atoms refined anisotropically. In **1** a difference map revealed an additional peak at *ca.* 1.47 Å from C(18). This peak was interpreted as representing an alternative partial occupancy site for the C(19) methyl carbon atom. The occupancy of this site was estimated at 40% and the atom refined isotropically (the occupancy of the original site was reduced accordingly). There was also evidence for disordered solvent (*ca.* 0.2 occupancy), probably residual acetonitrile. This was also refined isotropically. In both **1** and **2** the positions of the hydrogen atoms attached to N(2) and the orientations of the methyl groups were determined from ΔF maps

The remaining hydrogen atoms (except those connected to C(19′)) were placed at idealised positions d(C–H) = 0.96 Å, assigned isotropic thermal parameters $U(H) = 1.2U_{eq}(C)$ and allowed to ride on their parent atoms.

Refinement was by block-cascade full matrix least squares and computations carried out on an Eclipse

TABLE I. Analytical Data for the Complexes

Complex[a]	Analytical results					
	Found (%)			Calculated (%)		
	C	H	N	C	H	N
$Rh(CH_3CO_2)_2$(LIa)	45.84	4.35	8.04	45.95	4.25	8.04
$Rh(CH_3CH_2CO_2)_2$(LIa)	48.05	4.71	8.17	47.97	4.76	7.63
$Rh(CH_3OCH_2CO_2)_2$(LIa)	45.45	4.37	7.29	45.33	4.50	7.21
$Rh(CH_3CO_2)_2$(LIb)	48.04	4.70	7.81	47.97	4.76	7.63
$Rh(CH_3CH_2CO)_2$(LIb)	50.01	5.15	7.42	49.80	5.22	7.26
$Rh(CH_3OCH_2CO_2)_2$(LIb)	47.01	4.86	6.98	47.19	4.95	6.88

[a]LIa = 9-(2-aminoethyl)amino-6-chloro-2-methoxyacridine; LIb = 6-chloro-9-(2-dimethylaminoethyl)amino-2-methoxyacridine.

TABLE II. Summary of Crystal Data and Intensity Collection

Compound	1	2
Formula	$C_{44}H_{52}N_6O_{10}Cl_2Rh_2$	$C_{44}H_{52}N_6O_{10}Cl_2Rh_2$
M_r	2203.3	2203.3
Crystal System	monoclinic	monoclinic
Space group	$C2/c$	$P2_1/n$
a (Å)	20.864(11)	8.861(2)
b (Å)	15.736(4)	23.089(10)
c (Å)	14.402(4)	12.014(2)
β (°)	93.14(4)	105.84(2)
Cell volume (Å^3)	4721	2365
Z	4	2
Crystal dimensions (mm)	0.05 × 0.22 × 0.26	0.10 × 0.25 × 0.64
ρ (calc.) (g cm^{-3})	1.546	1.547
μ(calc.) (cm^{-1})	74	73
Radiation	Cu Kα	Cu Kα
Unique reflections measured	2423	2423
Reflections considered observed $\lvert F_o\rvert > 3\sigma(\lvert F_o\rvert)$	2198	2302
Weight (G)[a]	0.00041	0.00032
No. of parameters varied	313	309
R	0.032	0.028
R_w	0.034	0.032

[a] $w^{-1} = \sigma^2(F) + GF^2$.

S140 computer using the SHELXTL program system [14]. Atomic scattering factors were from reference [15]. Fractional coordinates for the non-hydrogen atoms in **1** and **2** are given in Tables III and IV respectively. Tables V and VI give the respective bond lengths and angles.

Results and Discussion

The results of the synthetic work show that it is possible to bind ligands containing the intercalating acridine ring system to the dinuclear $Rh_2(RCO_2)_4$ unit by use of a diamine bonded to the 9-position of the acridine. Red compounds of stoichiometry $Rh(RCO_2)_2 \cdot L$ were obtained for R = CH_3, C_2H_5, and CH_3OCH_2 in good yields from methanol solutions (Table I).

The molecular structures of two representative members of the series, **1** and **2**, are shown in Figs. 1 and 2 respectively. Both structures are centrosymmetric and show that the usual 'lantern' dinuclear structure [8] is retained in both cases, and also that the ligands LIa and LIb bind to the rhodium atoms via the diamine NH_2 (LIa) and NMe_2 (LIb) groups respectively, rather than by the acridine ring nitrogen. The observed mode of coordination was that expected, but we considered it important to establish it unambiguously as a basis for the synthesis of related molecules whose substituents in the 9-position of the acridine ring are varied to alter the potential binding of the acridine units to DNA.

In both compounds the binding of the diamine-substituted acridine ligands produces no unusual

TABLE III. Atom Coordinates (× 10^4) and Temperature Factors (Å^2 × 10^3) for **1**

Atom	x	y	z	U[a]
Rh	2767(1)	7951(1)	5573(1)	39(1)*
Cl	5554(1)	9433(1)	11418(1)	74(1)*
C(1)	2193(2)	8051(3)	8680(3)	47(2)*
C(2)	1604(3)	8272(3)	8961(4)	51(2)*
C(3)	1532(3)	8797(4)	9743(4)	61(2)*
C(4)	2060(3)	9102(3)	10223(3)	57(2)*
C(5)	4312(2)	9293(3)	10846(3)	49(2)*
C(6)	4912(2)	9047(3)	10714(3)	50(2)*
C(7)	5047(3)	8451(3)	10027(3)	51(2)*
C(8)	4557(3)	8151(3)	9457(3)	50(2)*
C(9)	3393(2)	8133(3)	8946(3)	37(2)*
C(10)	1061(3)	7472(4)	7747(4)	77(3)*
C(11)	3910(2)	8419(3)	9535(3)	39(2)*
C(12)	3779(3)	8982(3)	10279(3)	42(2)*
C(13)	2692(2)	8883(3)	9984(3)	44(2)*
C(14)	2762(2)	8344(3)	9194(3)	41(2)*
C(15)	3929(3)	7814(3)	7458(3)	49(2)*
C(16)	3871(2)	8701(3)	7057(3)	52(2)*
C(17)	1420(3)	8278(3)	5309(3)	55(2)*
C(18)	802(3)	8747(4)	5436(4)	83(3)*
C(19)	502(5)	9032(7)	4506(9)	91(5)*
C(19')	720(9)	9282(11)	6256(12)	95(5)
C(20)	2006(3)	9689(4)	2804(4)	73(2)*
C(21)	2669(3)	9371(3)	3025(3)	55(2)*
C(22)	2663(3)	8655(3)	3728(3)	48(2)*
N(1)	3191(2)	9217(2)	10500(3)	47(2)*
N(2)	3479(2)	7625(2)	8181(3)	43(1)*
N(3)	3225(2)	8871(2)	6637(3)	46(1)*
O(1)	1033(2)	8034(2)	8523(3)	68(2)*

(continued)

TABLE III. *(continued)*

Atom	x	y	z	U [a]
O(2)	1912(2)	8518(2)	5794(2)	51(1)*
O(3)	2595(2)	7039(2)	6549(2)	46(1)*
O(4)	3595(2)	7326(2)	5289(2)	50(1)*
O(5)	2891(2)	8807(2)	4539(2)	51(1)*

[a]Asterisk indicates equivalent isotropic U defined as one third of the trace of the orthogonalised U_{ij} tensor.

effects on the geometry of the $Rh_2(RCO_2)_4$ units. The Rh–Rh bonds (2.405(1) in **1**; 2.409(1) Å in **2**), Rh–O bonds (2.034–2.055(3) in **1**; 2.038–2.047(3) Å in **2**), Rh–N bonds (2.280(4) in **1**; 2.344(3) Å in **2**) are similar to those found [8, 11] in other dinuclear rhodium(II) carboxylates with amine ligands in the axial coordination positions. In each case, the axial N–Rh–Rh′–N′ chain is very nearly linear with NRhRh′ angles of 176.3(1)° for **1** and 175.2(1)° for **2**.

Turning to the significant features of the coordinated acridines, a striking difference between **1** and **2** is in the conformations of the diamine chains. Whereas in **1** there is a *gauche* relationship between N(2) and N(3) [N(2)–C(15)–C(16)–N(3) torsion angle 59°], in **2** the geometry is *anti* (torsion angle 161°). As a consequence, in **2** the through-space distance between the rhodium atom and the acridine ring carbon C(9) is 5.99 Å whilst in **1** it is significantly shorter (4.97 Å). The expected conformation for such a system is the *gauche* arrangement displayed by **1** and clearly the incorporation of the bulky methyl groups on N(3) in **2**, and their associated imposed steric constraints, must be responsible for the change observed.

TABLE IV. Atom Coordinates ($\times 10^4$) and Temperature Factors ($Å^2 \times 10^3$) for **2**

Atom	x	y	z	U [a]
Rh	−199(1)	515(1)	−101(1)	31(1)*
C(1)	−6775(4)	2927(2)	−961(3)	33(1)*
C(2)	−7916(4)	3329(2)	−1018(3)	37(1)*
C(3)	−9249(5)	3347(2)	−1976(3)	48(2)*
C(4)	−9378(4)	2978(2)	−2871(3)	43(1)*
C(5)	−7608(4)	1441(2)	−4787(3)	40(1)*
C(6)	−6656(4)	994(2)	−4814(3)	35(1)*
C(7)	−5393(4)	860(2)	−3864(3)	44(2)*
C(8)	−5095(4)	1193(2)	−2906(3)	41(1)*
C(9)	−5776(4)	2060(2)	−1824(3)	30(1)*
C(10)	−6650(5)	3729(2)	814(4)	71(2)*
C(11)	−6038(4)	1684(2)	−2801(3)	28(1)*
C(12)	−7363(4)	1795(2)	−3775(3)	32(1)*
C(13)	−8203(4)	2556(2)	−2870(3)	32(1)*
C(14)	−6895(4)	2516(1)	−1879(3)	27(1)*
C(15)	−3284(4)	1623(2)	−425(3)	44(1)*
C(16)	−1899(4)	1788(2)	−852(4)	48(2)*
C(17)	802(5)	1715(2)	−787(4)	61(2)*
C(18)	127(5)	1750(2)	1004(4)	59(2)*
C(19)	−1112(5)	57(2)	3108(4)	57(2)*
C(20)	−671(4)	36(2)	1998(4)	40(2)*
C(21)	2998(4)	170(2)	960(3)	38(1)*
C(22)	4727(4)	266(2)	1425(4)	49(2)*
N(1)	−8425(3)	2216(1)	−3811(2)	37(1)*
N(2)	−4583(4)	2027(1)	−845(3)	42(1)*
N(3)	−376(3)	1528(1)	−190(3)	39(1)*
O(1)	−7908(3)	3739(1)	−195(2)	56(1)*
O(2)	2141(3)	612(1)	680(2)	41(1)*
O(3)	301(3)	451(1)	−1662(2)	47(1)*
O(4)	−2504(3)	345(1)	−888(2)	45(1)*
O(5)	−718(3)	508(1)	1451(2)	44(1)*
Cl	−7008(1)	561(1)	−6052(1)	60(1)*

[a]Asterisk indicates equivalent isotropic U defined as one third of the trace of the orthogonalised U_{ij} tensor.

TABLE V. Bond Lengths and Angles for **1**

Bond lengths (Å)

Rh–N(3)	2.280(4)	Rh–O(2)	2.035(3)
Rh–O(3)	2.055(3)	Rh–O(4)	2.048(3)
Rh–O(5)	2.034(3)	Rh–Rh′	2.405(1)
Cl–C(6)	1.746(5)	C(1)–C(2)	1.361(7)
C(1)–C(14)	1.439(7)	C(2)–C(3)	1.412(7)
C(2)–O(1)	1.369(6)	C(3)–C(4)	1.357(7)
C(4)–C(13)	1.422(7)	C(5)–C(6)	1.334(7)
C(5)–C(12)	1.429(7)	C(6)–C(7)	1.403(7)
C(7)–C(8)	1.360(7)	C(8)–C(11)	1.424(7)
C(9)–C(11)	1.409(6)	C(9)–C(14)	1.423(7)
C(9)–N(2)	1.380(6)	C(10)–O(1)	1.430(7)
C(11)–C(12)	1.428(6)	C(12)–N(1)	1.336(7)
C(13)–C(14)	1.434(6)	C(13)–N(1)	1.352(6)
C(15)–C(16)	1.513(7)	C(15)–N(2)	1.471(6)
C(16)–N(3)	1.473(6)	C(17)–C(18)	1.505(8)
C(17)–O(2)	1.268(6)	C(17)–O(4′)	1.282(6)

(continued)

TABLE V. *(continued)*

C(18)–C(19)	1.515(13)	C(18)–C(19′)	1.468(19)
C(20)–C(21)	1.489(8)	C(21)–C(22)	1.515(7)
C(22)–O(5)	1.259(6)	C(22)–O(3′)	1.274(6)
O(3)–C(22′)	1.274(6)	O(4)–C(17′)	1.282(6)

Bond angles (deg)

N(3)–Rh–O(2)	87.4(1)	N(3)–Rh–O(3)	93.8(1)
O(2)–Rh–O(3)	90.7(1)	N(3)–Rh–O(4)	96.5(1)
O(2)–Rh–O(4)	176.1(1)	O(3)–Rh–O(4)	89.0(1)
N(3)–Rh–O(5)	90.4(1)	O(2)–Rh–O(5)	88.4(1)
O(3)–Rh–O(5)	175.7(1)	O(4)–Rh–O(5)	91.7(1)
N(3)–Rh–Rh′	176.3(1)	O(2)–Rh–Rh′	89.4(1)
O(3)–Rh–Rh′	88.0(1)	O(4)–Rh–Rh′	86.8(1)
O(5)–Rh–Rh′	87.8(1)	C(2)–C(1)–C(14)	119.9(4)
C(1)–C(2)–C(3)	121.6(5)	C(1)–C(2)–O(1)	124.8(5)
C(3)–C(2)–O(1)	113.5(5)	C(2)–C(3)–C(4)	119.6(5)
C(3)–C(4)–C(13)	122.1(5)	C(6)–C(5)–C(12)	121.7(4)
Cl–C(6)–C(5)	120.8(4)	Cl–C(6)–C(7)	117.7(4)
C(5)–C(6)–C(7)	121.4(5)	C(6)–C(7)–C(8)	118.9(5)
C(7)–C(8)–C(11)	122.3(4)	C(11)–C(9)–C(14)	117.6(4)
C(11)–C(9)–N(2)	122.5(4)	C(14)–C(9)–N(2)	119.8(4)
C(8)–C(11)–C(9)	123.7(4)	C(8)–C(11)–C(12)	117.7(4)
C(9)–C(11)–C(12)	118.6(4)	C(5)–C(12)–C(11)	117.8(4)
C(5)–C(12)–N(1)	117.7(4)	C(11)–C(12)–N(1)	124.5(4)
C(4)–C(13)–C(14)	118.0(4)	C(4)–C(13)–N(1)	118.0(4)
C(14)–C(13)–N(1)	123.9(4)	C(1)–C(14)–C(9)	123.0(4)
C(1)–C(14)–C(13)	118.8(4)	C(9)–C(14)–C(13)	118.2(4)
C(16)–C(15)–N(2)	114.5(4)	C(15)–C(16)–N(3)	112.2(4)
C(18)–C(17)–O(2)	117.4(5)	C(18)–C(17)–O(4′)	117.1(5)
O(2)–C(17)–O(4′)	125.5(5)	C(17)–C(18)–C(19)	110.7(6)
C(17)–C(18)–C(19′)	121.2(8)	C(19)–C(18)–C(19′)	118.7(9)
C(20)–C(21)–C(22)	110.6(5)	C(21)–C(22)–O(5)	117.6(4)
C(21)–C(22)–O(3′)	116.6(4)	O(5)–C(22)–O(3′)	125.8(4)
C(12)–N(1)–C(13)	116.8(4)	C(9)–N(2)–C(15)	124.3(4)
Rh–N(3)–C(16)	120.1(3)	C(2)–O(1)–C(10)	117.3(4)
Rh–O(2)–C(17)	118.3(3)	Rh–O(3)–C(22′)	118.1(3)
Rh–O(4)–C(17′)	120.0(3)	Rh–O(5)–C(22)	119.9(3)

TABLE VI. Bond Lengths and Angles for **2**

Bond lengths (Å)

Rh–N(3)	2.344(3)	Rh–O(2)	2.041(2)
Rh–O(3)	2.047(3)	Rh–O(4)	2.042(2)
Rh–O(5)	2.038(3)	Rh–Rh′	2.409(1)
C(1)–C(2)	1.360(5)	C(1)–C(14)	1.436(5)
C(2)–C(3)	1.407(5)	C(2)–O(1)	1.367(5)
C(3)–C(4)	1.352(6)	C(4)–C(13)	1.425(5)
C(5)–C(6)	1.338(5)	C(5)–C(12)	1.432(5)
C(6)–C(7)	1.398(5)	C(6)–Cl	1.748(4)
C(7)–C(8)	1.349(5)	C(8)–C(11)	1.434(5)
C(9)–C(11)	1.427(5)	C(9)–C(14)	1.436(5)
C(9)–N(2)	1.352(4)	C(10)–O(1)	1.405(5)
C(11)–C(12)	1.436(4)	C(12)–N(1)	1.345(5)
C(13)–C(14)	1.420(4)	C(13)–N(1)	1.347(4)
C(15)–C(16)	1.503(6)	C(15)–N(2)	1.460(5)
C(16)–N(3)	1.492(5)	C(17)–N(3)	1.483(6)
C(18)–N(3)	1.473(5)	C(19)–C(20)	1.489(7)

(continued)

TABLE VI. *(continued)*

C(20)–O(5)	1.266(4)	C(20)–O(3')	1.270(5)
C(21)–C(22)	1.497(5)	C(21)–O(2)	1.262(5)
C(21)–O(4')	1.263(5)	O(3)–C(20')	1.270(5)
O(4)–C(21')	1.263(5)		

Bond angles (deg)

N(3)–Rh–O(2)	87.6(1)	N(3)–Rh–O(3)	93.4(1)
O(2)–Rh–O(3)	89.0(1)	N(3)–Rh–O(4)	97.2(1)
O(2)–Rh–O(4)	175.2(1)	O(3)–Rh–O(4)	90.0(1)
N(3)–Rh–O(5)	91.2(1)	O(2)–Rh–O(5)	92.0(1)
O(3)–Rh–O(5)	175.3(1)	O(4)–Rh–O(5)	88.6(1)
N(3)–Rh–Rh'	175.2(1)	O(2)–Rh–Rh'	87.7(1)
O(3)–Rh–Rh'	87.6(1)	O(4)–Rh–Rh'	87.5(1)
O(5)–Rh–Rh'	87.9(1)	C(2)–C(1)–C(14)	120.9(3)
C(1)–C(2)–C(3)	120.5(3)	C(1)–C(2)–O(1)	125.4(3)
C(3)–C(2)–O(1)	114.1(3)	C(2)–C(3)–C(4)	120.1(4)
C(3)–C(4)–C(13)	121.8(3)	C(6)–C(5)–C(12)	120.7(3)
C(5)–C(6)–C(7)	121.4(3)	C(5)–C(6)–Cl	119.6(3)
C(7)–C(6)–Cl	119.0(3)	C(6)–C(7)–C(8)	119.8(4)
C(7)–C(8)–C(11)	122.9(3)	C(11)–C(9)–C(14)	117.0(3)
C(11)–C(9)–N(2)	126.4(3)	C(14)–C(9)–N(2)	116.6(3)
C(8)–C(11)–C(9)	125.8(3)	C(8)–C(11)–C(12)	115.8(3)
C(9)–C(11)–C(12)	118.3(3)	C(5)–C(12)–C(11)	119.4(3)
C(5)–C(12)–N(1)	116.2(3)	C(11)–C(12)–N(1)	124.4(3)
C(4)–C(13)–C(14)	118.3(3)	C(4)–C(13)–N(1)	117.3(3)
C(14)–C(13)–N(1)	124.4(3)	C(1)–C(14)–C(9)	122.9(3)
C(1)–C(14)–C(13)	118.2(3)	C(9)–C(14)–C(13)	118.8(3)
C(16)–C(15)–N(2)	111.1(3)	C(15)–C(16)–N(3)	114.8(3)
C(19)–C(20)–O(5)	117.3(4)	C(19)–C(20)–O(3')	117.8(4)
O(5)–C(20)–O(3')	124.9(4)	C(22)–C(21)–O(2)	117.4(4)
C(22)–C(21)–O(4')	117.8(3)	O(2)–C(21)–O(4')	124.9(3)
C(12)–N(1)–C(13)	117.0(3)	C(9)–N(2)–C(15)	133.8(3)
Rh–N(3)–C(16)	117.7(2)	Rh–N(3)–C(17)	105.3(2)
C(16)–N(3)–C(17)	106.1(3)	Rh–N(3)–C(18)	107.7(2)
C(16)–N(3)–C(18)	111.6(3)	C(17)–N(3)–C(18)	107.7(3)
C(2)–O(1)–C(10)	117.3(3)	Rh–O(2)–C(21)	119.7(2)
Rh–O(3)–C(20')	119.7(3)	Rh–O(4)–C(21')	119.8(2)
Rh–O(5)–C(20)	119.9(3)		

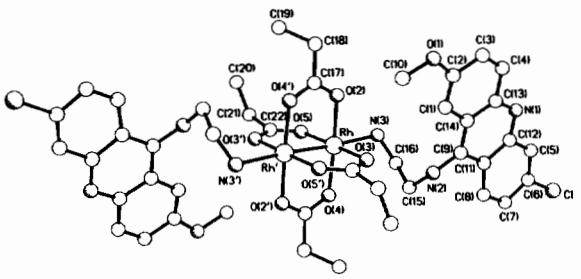

Fig. 1. Molecular structure of $\{Rh(C_2H_5CO_2)_2[9\text{-}(2\text{-amino-ethyl})amino\text{-}6\text{-}chloro\text{-}2\text{-}methoxyacridine]\}_2$, giving the crystallographic numbering scheme.

There are notable differences between the orientations of the acridine ligands and the planes of the N(2) imine groups. In **1** the C(15)N(2)C(9)C(11) torsion angle is 51°, whereas in **2** the analogous angle is 3°. In **1** the plane of the acridine ligand lies approxi-

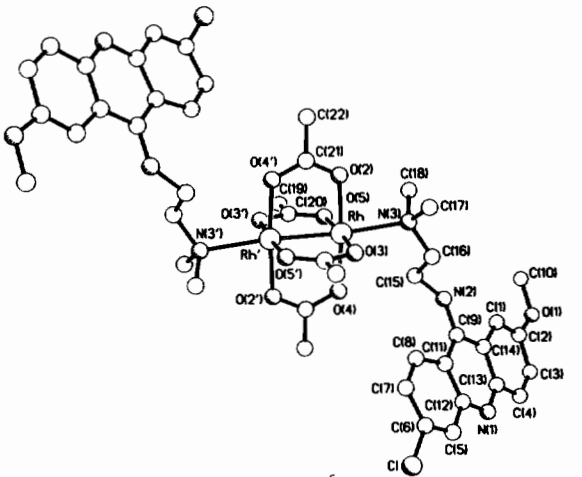

Fig. 2. Molecular structure of $\{Rh(CH_3CO_2)_2[6\text{-chloro-}9\text{-}(2\text{-dimethylaminoethyl})amino\text{-}2\text{-}methoxyacridine]\}_2$, giving the crystallographic numbering scheme.

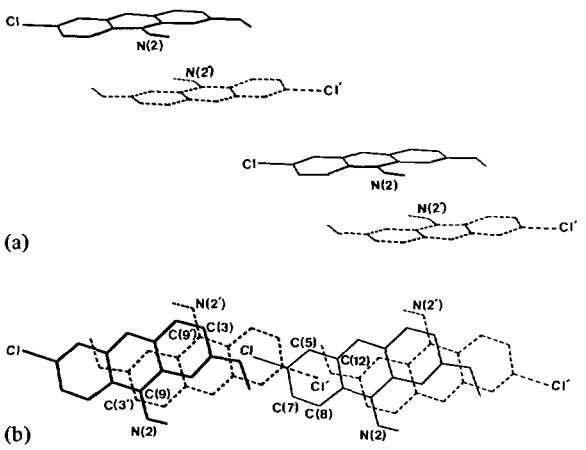

Fig. 3. Elevation (a) and plan (b) views of part of the continuous stepped stacking arrangement of the acridine ligands in 1.

mately parallel with the O(2)RhO(4) axis and normal to the RhO(2)O(3)O(4)O(5) plane, but, in **2** the acridine plane approximately bisects the O(3)RhO(4) angle and is inclined by *ca.* 55° to the RhO(2)O(3)-O(4)O(5) plane.

In **1** there is a weak intramolecular hydrogen bond between the imine nitrogen, N(2), and one of the carboxylate oxygen atoms, O(3), [O(3)···N(2) = 3.05, O(3)···H(2) = 2.18 Å, O···H–N angle = 147°]. The *anti*-geometry in **2** prevents an equivalent interaction.

Investigation of the packing of the molecules of **1** in the crystal shows a pronounced stacking of the acridine ligands. Figure 3(a, b) illustrates the stepwise nature of the overlap of these ligands. The infinite stacking interaction comprises two types: (i) ring overlap involving a 3.5 Å interlayer separation, with a minimum interlayer atomic separation of 3.57 Å between C(3) and C(9); (ii) overlap of the chlorine atoms of one ligand with the centre of the aromatic ring [C(5) to C(12)] of the next and vice versa, (in each case the distance between the Cl-atom and the centroid of the overlapping ring is 3.67 Å, with the Cl-ring centroid vector inclined by 84° to the ring plane)

In **2** there are no evident stacking interactions between the acridine ligands. The only intermolecular interaction is an N–H···N hydrogen bond (2.95 Å) between the imine nitrogen N(2) and N(1) in the acridine ligand (H(2)···N(1) 2.09 Å, N–H···N angle = 146°).

Work is now in progress to explore the effects of changing the nature of the metal centre involved and the nature and length of chains employed to bind the intercalating units.

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