Mononuclear and Homobinuclear Lead(II) Complexes of Macrocyclic Schiff Bases

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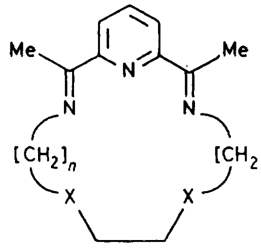
Lead(II) salts act as templates for the cyclic condensation of several organic dicarbonyl compounds with a variety of polyfunctional diprimary amines to yield complexes of macrocyclic Schiff-base ligands in moderate to good yield. Three types of macrocyclic lead(II) complex are described: (*i*) mononuclear complexes of 15- and 17-membered quinquedentate N_5 and N_3S_2 ligands; (*ii*) mononuclear complexes of 18-membered sexidentate N_3O_3, and N_2O_4 ligands; and (*iii*) binuclear complexes of a 30-membered decadentate N_6O_4 ligand. With the aid of i.r. spectra of solids and of electrical-conductance measurements on solutions, and by reference to *X*-ray structure determinations of selected complexes, the co-ordination geometries are assigned where possible. The co-ordination number of the lead(II) ion is variable between five and eight and depends on the nature of the anions present as well as on the nature of the macrocycle. Alkaline-earth metal complexes of certain of the macrocycles undergo exchange reactions with Pb^{II} in solution; possible applications of these reactions in the chelation therapy of lead poisoning are noted.

MACROCYCLIC compounds of lead(II) have been confined to a few complexes derived from crown ethers and cryptands.[1-6] These complexes have been prepared by the reaction of lead(II) salts with a preformed ligand. We report here the use of the lead(II) cation as a template agent in the synthesis of macrocyclic Schiff-base ligands. Macrocyclic complexes of Pb^{II} are of interest because the large size of the lead(II) cation, combined with the potentially stereochemically active 'lone pair' of valence electrons, might give rise to unusual geometries or to unusual macrocyclic ligands. The latter prospect is exemplified in the synthesis of both mononuclear and homobinuclear lead(II) complexes as reported herein.

RESULTS AND DISCUSSION

The macrocyclic ligands studied in this investigation are all Schiff bases prepared by the condensation of 2,6-diformylpyridine, 2,6-diacetylpyridine, or 2,5-diformylfuran with a polyfunctional diprimary amine. The reactions were carried out in methanol or aqueous ethanol in the presence of a stoicheiometric amount of $Pb[SCN]_2$ or, in a few cases, $Pb[ClO_4]_2 \cdot 3H_2O$ (see Experimental section for details). The template action of the lead(II) salt in directing the condensation preferentially towards cyclic rather than oligomeric products is evidenced by the fact that reactions conducted in the absence of metal salt led only to oils or gums of indefinite composition but containing residual carbonyl groups, whereas in the presence of the lead(II) salt the principal products of reaction were crystalline solids. On the basis of analytical, i.r. spectral, and other physical data the solids are shown to be complexes of the macrocyclic ligands L^1—L^8, as detailed below. Three classes of macrocyclic complex are described, *viz.* those of (*i*) potentially quinquedentate macrocycles, (*ii*) potentially decadentate macrocycles, and (*iii*) potentially sexidentate macrocycles.

Complexes of Potentially Quinquedentate Macrocyclic Ligands.—Complexes of the 15-membered N_5 macrocycle L^1 and of the 17-membered N_5 and N_3S_2 macrocycles L^2 and L^3 were prepared *via* the condensation of 2,6-diacetylpyridine with, respectively, 3,6-diazaoctane-1,8-diamine, 4,7-diazadecane-1,10-diamine, and 4,7-dithiadecane-1,10-diamine in methanol in the presence of $Pb[SCN]_2$ (L^1 and L^2) or $Pb[ClO_4]_2 \cdot 3H_2O$ (L^3). Derivatives containing anions other than $[NCS]^-$ or $[ClO_4]^-$ were prepared by metathesis. No crystalline complexes of definite macrocyclic constitution were isolated from reactions of 2,6-diacetylpyridine with 3,7-diazanonane-1,9-diamine, 3,6-dithiaoctane-1,8-diamine, or 3,7-dithianonane-1,9-diamine.



	X	*n*
L^1	NH	2
L^2	NH	3
L^3	S	3

Evidence for the presence of the 15- and 17-membered macrocycles L^1—L^3 in the complexes comes from the analytical data (Table) and from i.r. and mass spectra. All the complexes exhibited a moderate-to-strong band at 1 635—1 660 cm^{-1} (Table) diagnostic, in these systems, of the azomethine group. None showed any absorption at *ca.* 1 700 cm^{-1} attributable to ν(C=O) of unchanged carbonyl groups. Moreover, complexes of L^3 displayed no ν(N-H) absorption at 3 200—3 400 cm^{-1}; the L^1 and L^2 complexes gave one or two ν(N-H) bands in this region as compared with the more intense and more complex pattern of absorption shown by the precursor tetra-amines. These observations indicate that the Schiff-base condensations have taken place, but do not, on their own, distinguish between cyclic and polymeric condensates. However, the crystalline nature of the complexes is strongly suggestive of a low-molecular-weight, *i.e.* cyclic, constitution. We were unable to obtain direct mass-spectral confirmation for this conclusion since the complexes (dithiocyanates only were examined) did not show *m/e* peaks corresponding either to the molecular ions of the parent complexes or of the free macrocycles. However, reduction of $PbL^1(NCS)_2$ and of $PbL^2(NCS)_2$ by $Na[BH_4]$ yielded the free reduced macrocycles, *i.e.* in which the azomethine groups of L^1 and L^2 have been hydrogenated, in high yield. Mass spectra of these materials gave P^+ at *m/e* 277 and 305, respectively, clearly demonstrating the presence of L^1 and L^2 in the parent complexes. Attempts at hydrogenation of L^3 in $PbL^3(ClO_4)_2$ were unsuccessful so the evidence for the formation of this macrocycle is not conclusive. We conclude, therefore, that both L^1 and L^2 are functioning as quinquedentate ligands.

Analytical, electrical-conductance, and i.r. spectral data for the complexes

	Analysis (%)								Λ[a]/S cm^2 mol^{-1}		I.r. bands (KBr discs) (cm^{-1})			
	Found				Calc.						[b]	[c]	[d]	[d]
Complex	C	H	N	S or halide	C	H	N	S or halide	MeCN	H_2O	$\nu(C{=}N)$	ν_{asym}	ν_3	ν_4
$PbL^1(NCS)_2$	34.7	4.3	17.3		34.2	3.9	16.4		181		1 635	2 060, 2 040		
$PbL^2(NCS)_2$	36.7	4.5	15.9		36.5	4.4	15.7		169		1 655	2 080, 2 050		
$PbL^2(NCS)Br$	33.3	4.3	13.1	12.2	33.4	4.2	13.0	12.4	*e*		1 660, 1 665 (sh)	2 060		
$PbL^2(NCS)I$	31.2	4.1	11.9	18.5	31.2	3.9	12.1	18.3	*e*		1 650	2 060		
$PbL^2(ClO_4)_2$	28.7	3.6	9.7	10.1	28.9	3.9	9.9	10.0	269		1 660		1 090	620
$PbL^2(BPh_4)_2$	68.0	5.8	6.3		68.1	5.9	6.1		224		1 660			
$PbL^3(ClO_4)_2$	27.4	3.4	5.5		27.5	3.4	5.7		281		1 645		1 100	618
$PbL^2(BPh_4)_2$	65.5	5.7	3.2		66.1	5.6	3.5		232		1 645			
$Pb_2L^4(NCS)_4$	34.2	3.6	11.7		34.1	3.5	11.7		*e*		1 640	2 080, 2 010		
$Pb_2L^4(NCS)_2(BPh_4)_2$	55.8	5.1	6.4		55.8	4.9	6.5		316		1 645	2 020		
$Pb_2L^4(ClO_4)_4$	26.4	3.3	6.1	10.0	26.4	3.1	6.2	10.4	512		1 650		1 100	620
$Pb_2L^4Br_4$	27.8	3.3	6.6	25.0	28.0	3.3	6.7	24.9	*e*		1 640			
$Pb_2L^4I_4$	25.1	3.4	8.9	33.8	24.5	3.2	9.5	34.5	*e*		1 640			
$PbL^5(NCS)_2$	33.4	3.5	11.2	9.2[f]	33.2	3.4	11.4	10.4	102	228	1 660, 1 655 (sh)	2 085, 2 065		
$PbL^5(ClO_4)_2{\cdot}H_2O$	25.2	3.2	5.7	9.3	25.2	3.2	5.8	9.9	292	196	1 670, 1 655 (sh)		1 100br	623, 645
$PbL^6(NCS)_2$	35.7	4.0	10.9	8.4[f]	35.3	3.9	10.9	9.9	117	186	1 639	2 080, 2 010		
$PbL^6(ClO_4)_2$	28.2	3.3	5.6	9.2	28.1	3.4	55.8	9.8	299	195	1 648		1 025, 1 100, 1 155	619, 624, 650
$PbL^7(NCS)_2$	41.5	2.1	9.5	6.4[f]	42.2	2.9	99.8	9.0	*e*	*e*	1 590	2 070, 2 050		
$PbL^7(ClO_4)_2$	34.6	2.5	5.1	8.0	34.8	2.6	55.3	8.9	286	188	1 589		1 030, 1 122	625, 630, 637
$PbL^8(NCS)_2$	32.1	2.9	9.2	7.8[f]	31.8	3.3	9.2	10.6	121	204	1 623	2 075, 2 040		

[a] For 10^{-3} mol dm^{-3} solutions at 25 °C. [b] Macrocycle band. [c] $[NCS]^-$ band. [d] $[ClO_4]^-$ band. [e] Insoluble. [f] Large discrepancies were consistently observed in the analyses for sulphur, even for samples characterised crystallographically. These were traced to metal interference in the analytical procedure (M. A. McKinnon, personal communication).

In all the previously investigated metal complexes of L^1 the MN_5 atom sets are coplanar to within 0.1 Å.[7] However, in these complexes the metal ions (*e.g.* Mg^{2+}, Fe^{3+}, Fe^{2+}, or Zn^{2+}) are significantly smaller than Pb^{2+} (Pauling radius 1.21 Å) so it is not unlikely that the Pb^{2+} is displaced from this plane. The larger macrocycle L^2 is more flexible and can apparently adopt several different conformations. With silver(I) [8] (Pauling radius 1.26 Å) the conformation is pentagonal planar with a C_2 distortion, whereas with manganese(II),[9] cadmium(II),[8] and mercury(II) [8] (Pauling radii 0.80, 0.97, and 1.10 Å) the ring is folded such that the pyridine nitrogen is displaced from the plane of the other four nitrogen atoms; in its complexes with Ni^{II}, L^2 occupies five sites of a distorted octahedron.[10]

The structure of $[PbL^2(SCN)][NCS]$ has been determined * and shows yet another conformation for the L^2 macrocycle. As in $[ML^2(Br)]^+$ (M = Cd or Hg) the metal is six-co-ordinate but, whereas these complexes have a pentagonal-pyramidal structure with the bromide ion in an axial position, in the lead(II) complex the ring is much more severely folded such that the sulphur atom of the $[NCS]^-$ group is positioned *trans* [S–Pb–N 166(1)°] to one of the secondary amine groups of the macrocycle. This leads to a void, in the co-ordination polyhedron, *trans* to the pyridine nitrogen which may well accommodate a stereochemically active lone pair of electrons on the metal ion; there are no contacts with the unbonded $[NCS]^-$ group or with neighbouring molecules.

In agreement with the structural results, the ν_{asym} vibration of $[NCS]^-$ in $[PbL^2(SCN)][NCS]$ is split, occurring as a strong band at 2 050 cm^{-1} and a weaker, sharp, band at 2 080 cm^{-1}. These are assigned to the ionic and the *S*-bonded $[NCS]^-$ groups, respectively. In $PbL^1(NCS)_2$ there are two ν_{asym} bands of comparable intensity at 2 060 and 2 040 cm^{-1} consistent with two inequivalent *N*-bonded $[NCS]^-$ groups or with one ionic and one *N*-bonded group. In none of the thiocyanates was the weak ν_{sym} mode identified, probably because of overlapping ligand absorption, while the bending mode at 450—500 cm^{-1} did not appear diagnostic.

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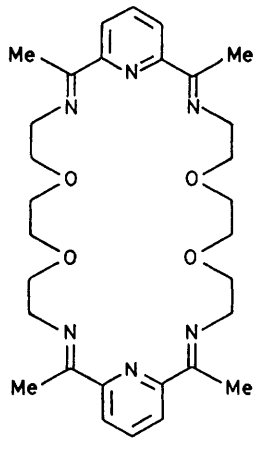
* M. G. B. Drew, unpublished work.

Treatment of $[PbL^2(SCN)](NCS)$ with NaX (X = Br or I) in solution gave the complexes $PbL^2X(NCS)$ in which, as judged from i.r. spectra (Table), it seems that the *S*-bonded $[NCS]^-$ group has been replaced. Again it is difficult to determine whether one or both of the two anions present are co-ordinated to the metal. By analogy with $[PbL^2(SCN)][NCS]$, it is probable that the bromo- and iodo-complexes have similar six-co-ordinate structures, namely $[PbL^2X][NCS]$. Support for the view that I^-, at least, is bonded to the metal is provided by the orange colour of this complex as compared with the yellow of the bromide and dithiocyanate. These colours arise from ill defined shoulders in the 23 000—27 000 cm^{-1} region on the side of a more intense absorption of the co-ordinated macrocycle at *ca.* 33 000 cm^{-1}. All the above complexes exhibit 1 : 1 electrolyte behaviour in MeCN solution (Table).

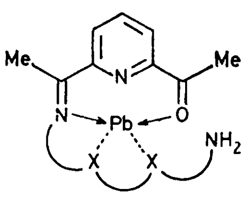
For the complexes $PbL^2(ClO_4)_2$ and $PbL^3(ClO_4)_2$ the ν_3 and ν_4 bands of the $[ClO_4]^-$ group occurring at *ca.* 1 090 and *ca.* 620 cm^{-1} are unsplit and are not noticeably broader than found in the spectra of analogous complexes known to contain only ionic $[ClO_4]^-$.[7] The absence of significant broadening or resolved splitting suggests, at most, only a weak interaction between the metal ion and $[ClO_4]^-$ ion. The i.r. spectral bands of the $[BPh_4]^-$ derivatives are as expected for salts of this ion and we conclude that in all these cases the metal is five-co-ordinate as found previously for $[AgL^2][ClO_4]$.[8]



L^4

Homobinuclear Metal Complexes.—In contrast to the reaction of the N_4 and N_2S_2 diamines with dicarbonyls to produce quinquedentate macrocyclic complexes, the reaction of 2,6-diacetylpyridine with 3,6-dioxaoctane-1,8-diamine in methanol in the presence of $Pb[SCN]_2$ gave yellow crystals of the binuclear complex $[Pb_2L^4(SCN)_4]$ in high yield, containing the 30-membered N_6O_4 macrocycle L^4 formed by the condensation of two molecules of diketone with two molecules of diamine. This was confirmed by a single-crystal *X*-ray structure determination of this complex [11] and by mass-spectral analysis of the free hydrogenated macrocycle which showed P^+ at *m/e* 558. The complex, which has a two-fold axis of symmetry at the centre of the ring, comprises two PbN_3O_2 planes intersecting at an angle of 65.1°. Each lead(II) ion is seven-co-ordinate, being bonded to three nitrogen atoms [2.54(3), 2.56(3), and 2.47(2) Å] and two oxygen atoms [2.96(3) and 2.88(3) Å] of the ring and, above and below this plane, to two thiocyanate sulphur atoms [2.81(2) and 3.00(2) Å]. [One of the thiocyanate groups showed signs of disorder in that it was not bonded to the metal through sulphur in all the unit cells. A parameter *x* was introduced where *x* $[NCS]^-$ groups are bonded *via* sulphur and (1 — *x*) *via* nitrogen, and this was refined to 0.77(2)]. In qualitative agreement with these findings, the i.r. spectrum showed two ν_{asym} vibrations, a sharp band at 2 080 cm^{-1} and a broad band at 2 010 cm^{-1}. The metal–metal separation in the complex is 5.27 Å. The O–Pb–O angle is large [113.7(8) Å] so that the co-ordination geometry may be considered as hexagonal bipyramidal with one equatorial site unoccupied. Conceivably, this site could accommodate a lone pair of electrons of the metal ion but it is equally possible that the large angle is merely a consequence of the most favourable conformation of the macrocycle which allows each metal atom to lie in the N_3O_2 planes.

It is noteworthy that the lead(II) ions lie significantly closer to the nitrogen than to the oxygen donors and this, we believe, is the clue to the understanding of the formation of the ' double ' 30-membered macrocycle in preference to the ' single ' 15-membered macrocycle, as occurs with L^1.[11] An essential first step to the formation of a macrocycle, whether ' single ' or ' double ', is the condensation of one primary amine group of the polyfunctional amine with one keto-group of 2,6-diacetylpyridine to give an open-chain mono-Schiff-base intermediate. When metal ion is present this intermediate will be co-ordinated. We suggest that the subsequent course of reaction, leading either to a ' single ' or to a ' double ' ring, will be determined by the conformation of the co-ordinated intermediate which, in turn, will be determined by the affinity of the donor groups X for the metal ion. If a strong interaction between Pb^{II} and X occurs then the terminal NH_2 and C=O groups of the intermediate can be brought into the *cis* relation necessary for intramolecular ring closure, as represented in (I), to yield a single ring. Such is presumed to be the case for X = NH (L^1, L^2) or S (L^3). On the other hand the more weakly co-ordinating ether groups (X = O) are not expected to compete effectively with solvent (methanol) for co-ordination sites, with the result that the terminal NH_2 and C=O functions are not constrained into close proximity. In these circumstances a preferential



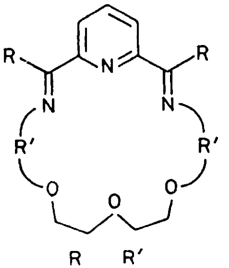
(I)

intermolecular self-condensation of two molecules of the intermediate may occur to yield the ' double ' ring L^4.

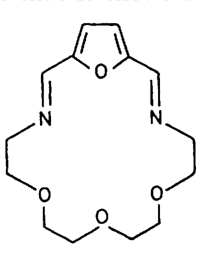
A number of derivatives of $[Pb_2L^4(SCN)_4]$ containing other anions were prepared by metathesis (Table). In $Pb_2L^4(NCS)_2(BPh_4)_2$ the $[NCS]^-$ ν_{asym} occurs as a single strong bond at 2 020 cm^{-1}, *i.e.* well below the position expected for ionic $[NCS]^-$ (2 040—2 060 cm^{-1}) and we conclude that the $[NCS]^-$ ions are *N*-bonded giving an overall six-co-ordinate geometry to each metal ion. Consistent with this conclusion is the observation that the bimetallic complex is a 2 : 1 electrolyte in MeCN. For $Pb_2L^4(ClO_4)_4$ the ν_3 and ν_4 bands are unsplit but somewhat broader than expected for ionic $[ClO_4]^-$, suggesting a weak metal–oxygen interaction with at least one of the $[ClO_4]^-$ ions. The electrical conductance of this complex in MeCN is close to that expected for a 4 : 1 electrolyte. The complexes $Pb_2L^4Br_4$ and $Pb_2L^4I_4$, like the thiocyanate, probably contain seven-co-ordinate metal ions as judged by the occurrence of metal–halide charge-transfer bands at 24 000—28 000 cm^{-1}.

Mononuclear Complexes of Potentially Sexidentate Macrocycles.—Extension of the chain length of the α,ω-aminoethers, as in, for example, 3,6,9-trioxaundecane-1,11-diamine, leads to the synthesis of potentially sexidentate ligands. Crystalline products having properties (see later) consistent with metal complexes of such macrocyclic ligands were obtained by treatment of 2,6-diformylpyridine or 2,6-diacetylpyridine with 3,6,9-trioxaundecane-1,11-diamine (macrocycle L^5 and L^6) and of 2,6-diformylpyridine with 1,5-bis(2-aminophenoxy)-3-oxapentane (macrocycle L^7) in the presence of lead(II) salts. Similar reactions starting with 2,5-diformylfuran and 3,6,9-trioxaundecane-1,11-diamine in n-butanol–triethyl orthoformate in the presence of $Pb[SCN]_2$ gave crystals of $PbL^8(NCS)_2$. Attempts to prepare other furan-containing macrocycles were unsuccessful.

Infrared spectra of these complexes show no bands attributable to carbonyl or amine groups and indicate the presence of an imine function. The mass spectra, with the exception of $PbL^6(NCS)_2$, give as the highest mass peak that of the free macrocyclic ligand. The complex $PbL^6(NCS)_2$ is unique in that it shows a peak at *m/e* 598 corresponding to P^+, as well as a considerable breakdown pattern which included a peak at *m/e* 275 for the free ligand.



	R	R'
L^5	H	$[CH_2]_2$
L^6	Me	$[CH_2]_2$
L^7	H	o-C_6H_4



L^8

As with the previously discussed complexes, the i.r. spectral patterns observed for the anions pose difficulties in the assignment of definite molecular structures to the complexes. That this is so is reinforced by reference to the crystal structure of $[PbL^5(NCS)(SCN)]$.[12] In this complex the lead(II) ion is situated within the macrocyclic cavity with all the six heteroatoms of the ligand bonded to the metal. The thiocyanate groups are *trans* to each other, one being *S*- and the other *N*-bonded. As with $[Pb_2L^4(SCN)_4]$, linkage isomerism may therefore be proposed to account for the observed splitting of the ν_{asym} mode. The values of 2 085 and 2 065 cm^{-1} are just within the ranges predicted for *S*- and *N*-bonded $[NCS]^-$ groups, respectively.[13,*]

As found for $[Pb_2L^4(SCN)_4]$, the lead(II) ion is also asymmetrically positioned within the cavity of L^5 in $[PbL^5(NCS)(SCN)]$, showing a distinct preference for bonding to the three nitrogen donors (mean Pb–N 2.60, mean Pb–O 3.07 Å). It has been noted that Tl^I, also a $6s^2$ cation, interacts preferentially with the nitrogen atoms in a mixed nitrogen–oxygen donor system.[14] In both cases the nitrogen donors are part of a rigid delocalised ligand array so the preferential interaction may be a reflection of the ' softer ' nature of this donor set. The preferred interaction of Pb^{II} in $[PbL^5(NCS)_2]$ with the delocalised nitrogen donors lends support to the proposition that it is a similar preference that leads to the formation of $[Pb_2L^4(SCN)_4]$. In contrast, in both the lead(II) thiocyanato-complexes of cryptands,[5,6] in which the nitrogen donors are saturated, a preferential interaction with the nitrogen atoms is not observed. In all the complexes the Pb–S are longer than the Pb–N distances. The disposition of the macrocycle and the bonding anions in $[PbL^5(NCS)(SCN)]$ are such that a vacant area is created in the bonding sphere around the Pb^{II}. It is possible that the non-bonding pair of 6*s* electrons is stereochemically active and sited in this area. However, a sulphur atom from the *N*-bonded $[NCS]^-$ group of a neighbouring molecule encroaches into this vacant area at a distance of 3.42 Å from the metal and it may be that it is a weak Pb · · · S interaction that is responsible for the unusual conformation of L^5 around the metal rather than the stereochemical activity of the lone pair.

For all the remaining thiocyanate complexes the i.r. spectra show splittings of ν_{asym} but the range of values is wide. For reasons already given, the assignment of the bonding mode of this anion in these complexes is uncertain. However, the complexes exhibit electrolyte

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[*] The problem of assignment of anion disposition is further emphasised by reference to the analogous alkaline-earth metal complexes (D. E. Fenton, D. H. Cook, I. W. Nowell, and P. E. Walker, *J.C.S. Chem. Comm.*, 1977, 623; 1978, 279). For these, similar values for the ν_{asym} mode are observed to those reported here but the anions are differently disposed being either *trans-N*-bonded as in $[CaL^5(NCS)_2]$ or *cis-N*-bonded as in $[SrL^5(NCS)_2]\cdot H_2O$. The rules for assigning the mode of bonding according to the i.r. pattern observed break down, and this may be a consequence of the more ionic bonding found in these complexes as compared with the more covalent bonding prevalent in the transition-metal complexes from whose spectra the rules for assignment were deduced.

behaviour in MeCN solution intermediate between that expected for non-electrolytes and 1 : 1 electrolytes, an observation which suggests that both $[NCS]^-$ groups are co-ordinated in the solid.

In the i.r. spectrum of $PbL^7(ClO_4)_2$ the ν_3 mode is split (1 030 and 1 122 cm^{-1}) implying that both $[ClO_4]^-$ anions are acting as unidentate ligands; an eight-co-ordinate structure, probably *trans*, is therefore suggested for this complex. Similarly, the broadening or splitting of the ν_3 and ν_4 bands observed in the spectra of the remaining two complexes suggests some interaction of at least one of the $[ClO_4]^-$ anions with the metal but, as before, in the absence of *X*-ray structure determinations our information is insufficient to allow the assignment of definite molecular geometries. All the perchlorate complexes are 2 : 1 electrolytes in MeCN solution.

Metal-exchange Reactions.—Current treatment of lead poisoning centres around the propensity of lead (Pauling radius 1.21 Å) to replace calcium (Pauling radius 0.94 Å) at a biological site.[15] Acute poisoning is treated with intravenous injections of calcium disodium ethylenediaminetetra-acetate, $CaNa_2$(edta), with further lowering of the lead burden by administration of D-penicillamine. Exploitation of the selective properties of synthetic macrocyclic ligands has been proposed as a method for the removal of lead.[2,16]

If the complex $[CaL^6(NCS)_2]$ [17] is heated under reflux in aqueous ethanol over lead(II) thiocyanate for *ca.* 36 h then yellow crystals of $[PbL^6(NCS)_2]$ are recovered. Lead(II) can similarly replace strontium and barium from their complexes with L^6 but a much shorter reaction time is required. An analogous series of exchange reaction occurs between the lead(II) thiocyanate and calcium, strontium, and barium complexes of L^5 but warming for *ca.* 10 min is sufficient to complete the process. Displacement of Pb^{II} from its complexes by calcium has not been effected.

The molecular structure of $[CaL^5(NCS)_2]$,[17] $[SrL^5(NCS)_2]\cdot H_2O$,[17] and $[PbL^5(NCS)(SCN)]$ clearly indicate that the mean Pb–N(macrocycle) distance (2.60 Å) is smaller than the mean Pb–O(macrocycle) distance (3.07 Å) and that it is shorter than the metal–donor distances in the alkaline-earth metal analogues where the mean M–N(macrocycle) and M–O(macrocycle) distances do not vary significantly for either M = Sr (2.78 Å) or Ca (2.64 Å). It is suggested that the relatively strong affinity of lead for the nitrogen donors of the macrocyclic ligand is the driving force for the exchange reactions.

It is possible to envisage that macrocyclic complexes based on the type reported here could be exploited in the chelation therapy of lead. The requisite ligand could be introduced as its calcium complex which would then undergo exchange with lead(II) deposits to give a removable lead(II) complex and leave calcium behind. The ligands L^5 and L^6 are specific for calcium and Pb^{II} over magnesium ions * and so, in theory, could provide a therapeutic agent. In practice, however, problems of ligand toxicity and behaviour under physiological conditions may necessitate modification of the basic ligand moiety.

EXPERIMENTAL

2,6-Diacetylpyridine and 3,6-diazaoctane-1,8-diamine were used as supplied (Aldrich). 2,6-Diformylpyridine was prepared by the method of Papadoupoulous *et al.*[18] and 2,5-diformylfuran was prepared by a modification [19] of the method of Oleinik and Novitskii.[20] 4,7-Diazadecane-1,10-diamine,[21] 3,7,9-trioxaundecane-1,11-diamine,[22] 1,5-bis(2-aminophenoxy)-3-oxapentane,[23] and 4,7-dithiadecane-1,10-diamine [24] were synthesised by the literature methods.

Preparation of the Complexes.—$PbL^1(NCS)_2$. Finely divided $Pb(NCS)_2$ (0.01 mol), 2,6-diacetylpyridine (0.01 mol), and 3,6-diazaoctane-1,8-diamine (0.01 mol) were heated under reflux in methanol (600 cm^3) for 15 h. The resulting pale yellow solution was filtered while hot and the filtrate concentrated to *ca.* 100 cm^3 by rotary evaporation. A pale yellow solid separated and recrystallised from methanol; yields 60—65% in different preparations. The complex $PbL^2(NCS)_2$ was prepared in the same way except that 4,7-diazadecane-1,10-diamine was used. The initially formed product was recrystallised from isopropyl alcohol to give large yellow crystals in 60% yield.

$PbL^2(NCS)Br$. Sodium bromide (0.3 g) dissolved in a little methanol was added to a solution of $PbL^2(NCS)_2$ (1.87 g), also in methanol. On standing for 1 h the product separated as pale yellow crystals. These were separated and washed with methanol; yield 74%. The complex $PbL^2(NCS)I$ was prepared analogously; yield 70%.

$PbL^2(ClO_4)_2$. The salt $Na[ClO_4]\cdot H_2O$ (1.0 g) in the minimum quantity of methanol was added to a solution of $PbL^2(NCS)I$ (0.5 g) in methanol. Cream crystals of the diperchlorate separated after a few minutes. They were recrystallised from methanol; yield 54%. The complex $PbL^2(BPh_4)_2$ was prepared analogously using $Na[BPh_4]$; yield 55%.

$PbL^3(ClO_4)_2$. 2,6-Diacetylpyridine (0.01 mol), 4,7-dithiadecane-1,10-diamine (0.01 mol), and $Pb[ClO_4]_2\cdot 3H_2O$ (0.01 mol) were heated under reflux in methanol (1 l) for 15 h at which stage the hot solution was filtered while hot and the filtrate concentrated to *ca.* 400 cm^3. A pale yellow solid separated, which on recrystallisation from methanol afforded the product in 28% yield. The $[BPh_4]^-$ salt was prepared in almost quantitative yield by addition of $Na[BPh_4]$ to a hot methanol solution of this complex.

$Pb_2L^4(NCS)_4$. To a solution of 2,6-diacetylpyridine (0.01 mol) and 3,6-dioxaoctane-1,8-diamine (0.01 mol) in methanol (600 cm^3) was added solid $Pb[SCN]_2$ with stirring. The mixture was warmed to 40—45 °C and stirred at this temperature for 45 min during which time the $Pb[SCN]_2$ gradually dissolved and the solution became yellow. The mixture was filtered free from any unchanged $Pb[SCN]_2$ and the filtrate deposited yellow crystals on standing. They were recrystallised from methanol; yields 75—85% in different preparations.

$Pb_2L^4Br_4$ and $Pb_2L^4I_4$. These were prepared from the above complex by treatment of methanolic solutions with NaBr and NaI, respectively; yields 50—70%. The complex $Pb_2L^4(NCS)_2(BPh_4)_2$ was prepared similarly using

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* Magnesium complexes of L^5 and L^6 have not been isolated using template conditions. This is seen as a manifestation of an ion-size effect, magnesium being too small to act efficiently towards a sexidentate macrocycle.

$Na[BPh_4]$. The pale yellow product was obtained in almost quantitative yield.

$Pb_2L^4(ClO_4)_4$. Silver(I) perchlorate (0.41 g) in methanol was added to a well stirred solution of $Pb_2L^4(NCS)_4$ in methanol. After removal of the precipitated Ag[SCN] the filtrate yielded white crystals of the diperchlorate on standing; yield 40%.

The complexes of the sexidentate ligands (L^5,L^6,L^7) were prepared by the following general procedure. The dicarbonyl compound (0.001 mol) and the diamine (0.001 mol) were dissolved in aqueous ethanol, stirred, and warmed over $Pb[SCN]_2$ or $Pb[ClO_4]\cdot 3H_2O$ (0.001 mol) for 30 min. Unchanged lead salt was filtered off and on cooling the crystalline products separated in 40—60% yield. Recrystallisation was effected from ethanol.

$PbL^8(NCS)_2$. This complex was prepared by stirring and warming 2,5-diformylfuran, 3,7,9-trioxaundecane-1,11-diamine, and $Pb[SCN]_2$ (1 : 1 : 1 mol ratio) in n-butanol–triethyl orthoformate under dinitrogen. Unchanged lead salt was filtered off and the complex separated on standing (*ca.* 50% yield).

Metal-exchange Reactions.—The complex $CaL^6(NCS)_2$ [19] (0.1 g) was dissolved in aqueous ethanol and heated under reflux over an excess of $Pb[SCN]_2$ for 36 h. Unchanged lead salt was filtered from the yellow solution and on cooling yellow crystals of $PbL^6(NCS)_2$ were recovered and characterised by comparison with an authentic sample. Similar procedures were adopted for the reactions of $SrL^6(NCS)_2$ [19] and $BaL^6(NCS)_2$.[19] Reaction times of *ca.* 5 min were required for analogous reactions using alkaline-earth metal complexes of L^5. The yields averaged 80%.

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