Bimetallic Lanthanide Complexes Derived from Macrocycle-Appended *m*-Xylyl Derivatives: Synthesis and Spectroscopic Properties

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Dedicated to Professor *Jean-Claude Bünzli* on the occasion of his 65th birthday.

A series of bimetallic lanthanide complexes was prepared from a bimacrocyclic system in which two DO3A units are linked by a *m*-xylyl unit appended with either a NO_2 or an NH_2 group (DO3A = 1,4,7,10-tetraazacyclododecane-1,4,7-triacetic acid). The Nd-, Eu-, Tb- and Yb-complexes were all luminescent: time-resolved studies indicated that the lipophilic xylyl group restricts close approach of H_2O to the metal centre.

Introduction. – Lanthanide complexes have been widely used in imaging and assay applications for many years, particularly as a consequence of the widespread application of luminescent complexes in ultrasensitive bioassays [1] and of Gd-complexes as magnetic-resonance-imaging (MRI) contrast agents [2]. Luminescence from lanthanide complexes is long-lived as a consequence of the forbidden nature of f–f transitions, meaning that time-gating techniques can be used to distinguish long-lived luminescence from fluorescent background signals [3]. However, the forbidden nature of f–f transitions also means that lanthanide ions have very low extinction coefficients, so that direct excitation requires the use of high-intensity light sources [4]: this disadvantage can be overcome by using sensitising chromophores with large extinction coefficients. Such excitation is normally mediated by the triplet state [5] *via* both *Förster* [6] and *Dexter* [7] mechanisms, though other routes have also been implicated [8]. The energy of the emissive state of the lanthanide determines which chromophores can be used and also has a considerable impact upon the luminescence lifetime and quantum yield, since the sensitising donor state must be significantly higher in energy than the emissive state of the lanthanide to avoid back energy transfer, and since nonradiative quenching of the emissive state occurs most readily for ions with low-energy emissive states (*i.e.*, those that emit light in the near-IR part of the spectrum). This means that, although Eu- and Tb-complexes have high luminescence quantum yields when used with appropriate chromophores, the choice of chromophore is restricted to those which absorb in the UV, or at the blue edge of the VIS spectrum [9]. By contrast, Yb and Nd can be used with a wide range of sensitisers, including those

which absorb red light, but their complexes generally have low quantum yields for luminescence [9].

There has been considerable recent interest in the properties of multimetallic lanthanide complexes. Two approaches have been used to prepare such systems. In the most common, complexes are assembled under thermodynamic control, meaning that simple systems can be used to assemble complicated architectures (for reviews on this topic, see [10]). Alternatively, kinetically stable complexes can be prepared through complexation under kinetic control. We have used this second approach to prepare heterometallic lanthanide complexes that are not accessible when working under thermodynamic control (see, *e.g.*, [11]).

Linked DO3A moieties can be used to form multimetallic complexes with a high kinetic stability (DO3A = 1,4,7,10-tetraazacyclododecane-1,4,7-triacetic acid): we have previously shown how *p*-xylyl and 2,6-dimethylphenol groups can be used to link two such units together [12][13], while *Gunnlaugsson* and *Harte* [14] and *Morrow* and co-workers [15] have both used related systems to catalyse phosphate ester hydrolysis. We now report the preparation of [Ln_2(**1**)] and [Ln_2(**2**)] (*Fig. 1*), in which a substituted *m*-xylyl (= 1,3-phenylenebis(methylene)) bridging unit is used to link two DO3A units together.

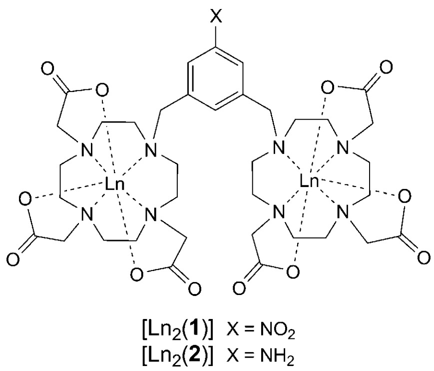
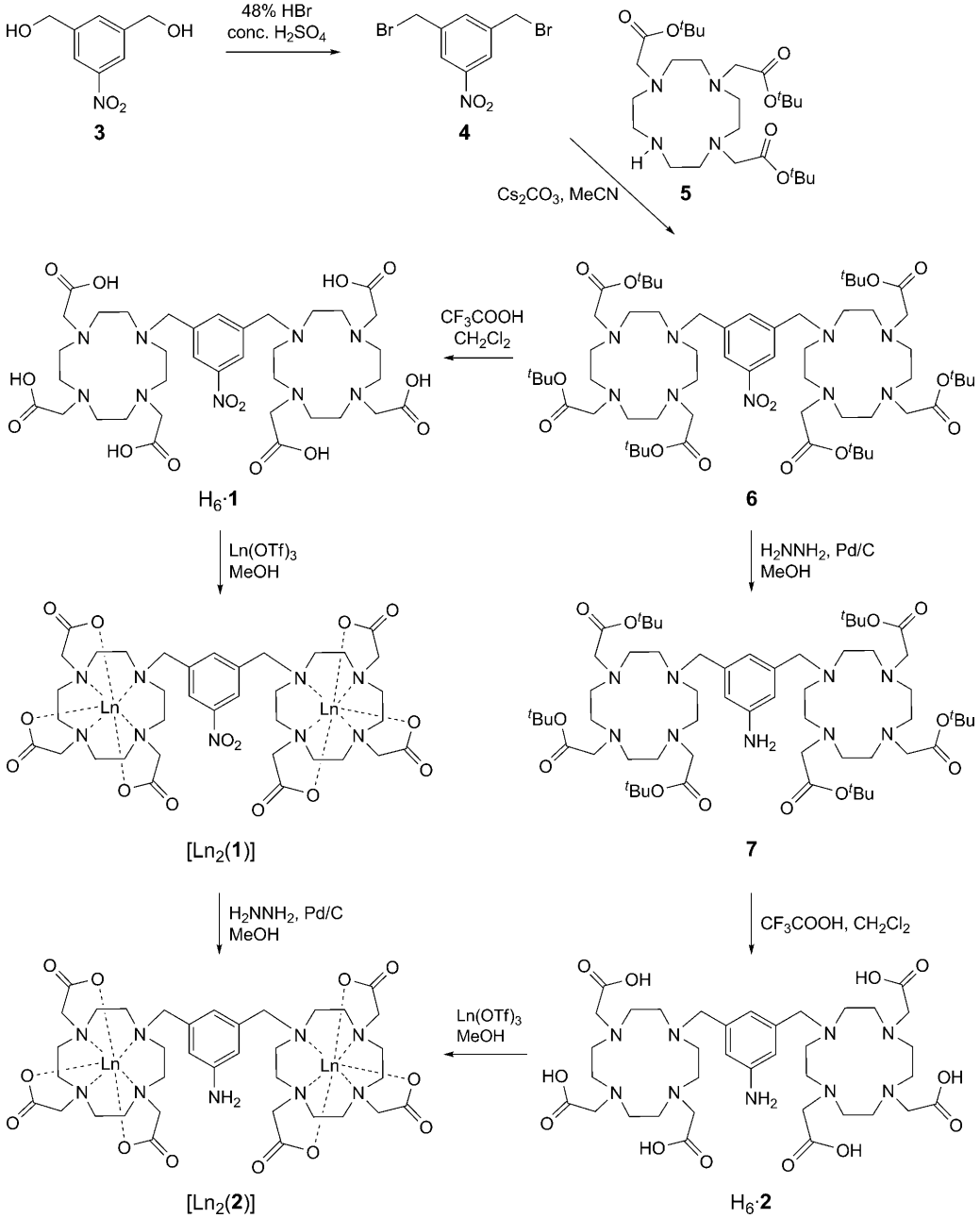


Fig. 1. *Structures of the synthesised [Ln_2(**1**)] and [Ln_2(**2**)]*

Results and Discussion. – [Ln_2(**1**)] and [Ln_2(**2**)] were prepared as shown in the *Scheme*. A modified literature procedure [16] was used to convert 5-nitrobenzene-1,3-methanol (**3**) into 1,3-bis(bromomethyl)-5-nitrobenzene (**4**): heating in the presence of HBr and H_2SO_4 for 8 h produced the product in good yield. Reaction of **4** with the well-known triester **5** [17] yielded the hexaester **6**, which was isolated as the adduct with two equiv. of NaCl. Single crystals of **6** · 2 NaBr · CH_2Cl_2 proved suitable for crystallography: the molecular representation of the structure is shown in *Fig. 2*. It can be seen that a Na^+ ion is bound in each of the binding sites, and that access to the binding site is restricted by the bulk of the *m*-xylyl linking unit.

Cleavage of the *tert*-butyl esters in the presence of CF_3COOH yielded the hexa-acid H_6 · **1**, which was converted into its lanthanide complexes by treatment with the appropriate lanthanide triflate salt to yield [Ln_2(**1**)] (Ln = Nd, Eu, Gd, Tb, and Yb)

Scheme. *Synthesis of Ligands and Complexes*



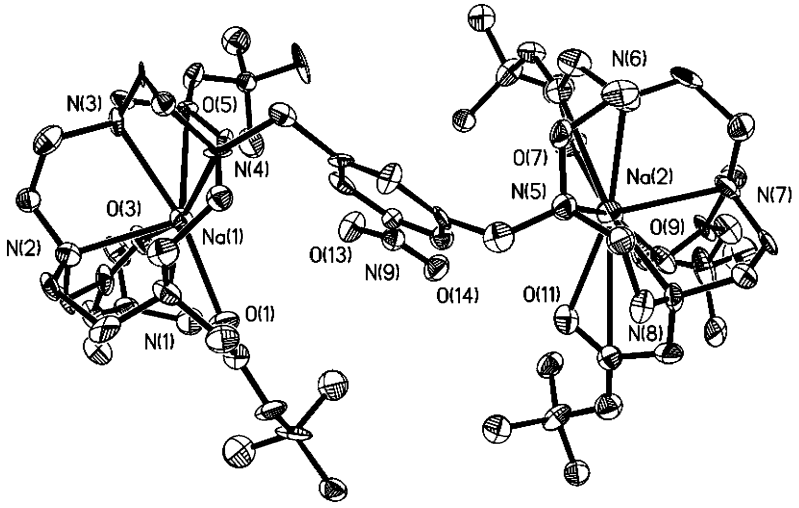


Fig. 2. *Molecular structure of* $[Na_2 \cdot \mathbf{6}]^{2+}$ (50% probability ellipsoids; lattice solvent molecules and chloride counterions omitted for clarity). Selected distances [Å] and angles [°]: Na(1)–O(1) 2.398(5), Na(1)–O(5) 2.414(5), Na(2)–O(7) 2.348(5), Na(2)–O(11) 2.415(5), Na(1)–N(1) 2.538(6), Na(1)–N(2) 2.485(6), Na(1)–N(3) 2.472(6), Na(1)–N(4) 2.692(6), Na(2)–N(5) 2.636(6), Na(2)–N(8) 2.493(6); O(1)–Na(1)–O(5) 117.13(19), O(1)–Na(1)–N(3) 166.5(2), O(5)–Na(1)–N(3) 68.35(18), N(3)–Na(1)–N(1) 112.2(2), N(2)–Na(1)–N(1) 73.0(2), O(7)–Na(2)–O(11) 114.09(19), O(7)–Na(2)–N(8) 167.9(2), N(7)–Na(2)–O(9) 64.74(18).

(triflate = trifluoromethanesulfonate). In all cases, mass spectrometry showed the presence of the molecular ions, while the IR C=O stretch was shifted to lower frequency by *ca.* 70 cm^{-1}, indicating binding of the lanthanide ions in both DO3A pockets. The ^{1}H-NMR spectrum of $[Yb_2(\mathbf{1})]$ (*Fig. 3,a*) showed further evidence for binding in a cyclen-derived pocket where each of the nearby H-atoms is nonequivalent: the four peaks in the range 110–140 ppm may be assigned to nonequivalent axial H-atoms at the cyclen ring, and to a *SAP* (square antiprismatic) isomer by analogy with the literature [18], while the less intense peaks in the range 40–70 ppm correspond to axial ring H-atoms in a minor (*TSAP* = twisted square antiprismatic) isomer. It is clear that the two isomers are in slow exchange on the NMR timescale.

Transfer hydrogenation of $[Ln_2(\mathbf{1})]$ with NH_2NH_2 in the presence of a Pd catalyst yielded the amino-group-bearing complexes $[Ln_2(\mathbf{2})]$. Once again, the molecular ions for all complexes were observed in their mass spectra. Further evidence for reduction was obtained from the absence of bands in the IR spectra at 1530 and 1350 cm^{-1}, corresponding to NO_2 group stretching vibrations in $[Ln_2(\mathbf{1})]$. The ^{1}H-NMR spectrum of the Yb-complex (*Fig. 3,b*) also showed significant changes relative to the starting material – significant line broadening was observed for the major isomer, and no peaks corresponding to the minor isomer were present.

$H_6 \cdot \mathbf{2}$ was also prepared by an alternative route (*Scheme*): transfer hydrogenation of **6** yielded the hexaester **7**, which was deprotected with CF_3COOH to yield $H_6 \cdot \mathbf{2}$. Complexes prepared from $H_6 \cdot \mathbf{2}$ proved identical in all respects to those prepared by reduction of $[Ln_2(\mathbf{1})]$.

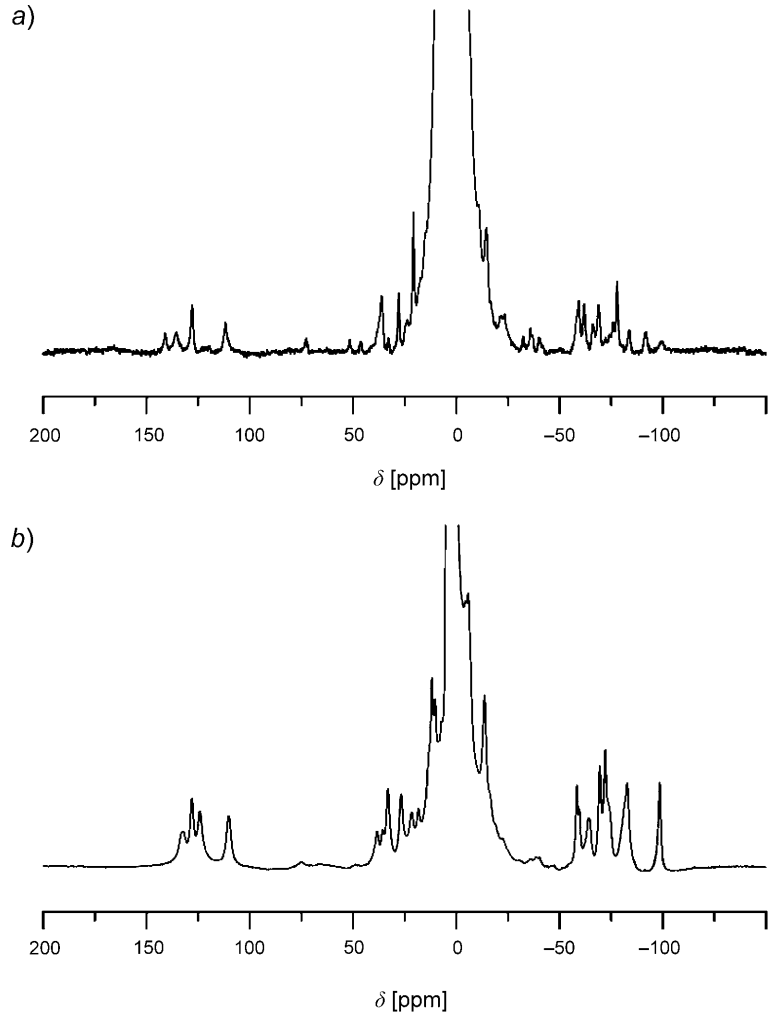


Fig. 3. *^{1}H-NMR Spectrum of* a) *[Yb_2(**1**)], and* b) *[Yb_2(**2**)]*

Physical Properties of the Complexes. The luminescence properties of the complexes are summarised in the *Table*. All the complexes proved to be luminescent: with the exception of [Eu_2(**2**)], all gave rise to intense lanthanide-centred emission following excitation through the arene chromophore.

The anomalous behaviour of [Eu_2(**2**)] is likely to be a consequence of nonradiative quenching of the excited state through ligand-to-metal charge transfer (LMCT) [19]. This is confirmed by the excitation and emission spectra (*Fig. 4*) of [Eu_2(**2**)]. The excitation spectrum bears little resemblance to the absorption spectrum; in the excitation spectrum, f–f transitions are prominent despite their low extinction coefficients, and nonradiative quenching pathways must dominate the fate of the excited state of the lanthanide ions.

Table. *Photophysical Properties of the Complexes*[a])

	λ_{ex} [nm]	λ_{em} [nm]	τ_{H_2O} [μs]	τ_{D_2O} [μs]	q
[Eu_2(**1**)]	280	617	550	1760	1.2
[Eu_2(**2**)][b])	280, 397	617	500	980	0.8
[Tb_2(**1**)]	280	545	1400	2240	1.0
[Tb_2(**2**)]	280	545	1820	2980	0.8
[Nd_2(**1**)]	337	1055	0.09	0.38	
[Nd_2(**2**)]	337	1055	0.10	0.33	
[Yb_2(**1**)]	337	980	1.60	5.31	0.3
[Yb_2(**2**)]	337	980	0.90	5.83	0.8

[a]) Lifetimes are ±10% and calculated q values ±20%. q Values are not reported for Nd complexes since their lifetimes are highly dependent on structure. [b]) The low intensity of emission from this complex results in a large uncertainty in the fitted decays, and hence in the value of q.

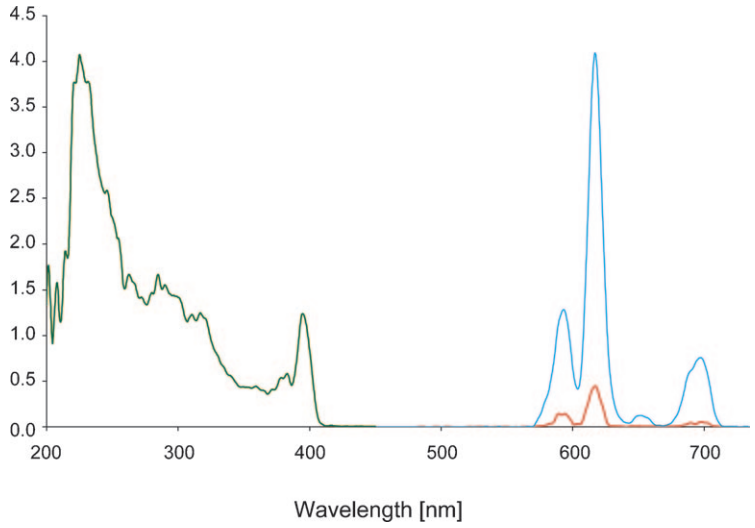


Fig. 4. *Excitation and emission spectra of [Eu_2(**2**)]: note how the excitation spectrum shows bands corresponding to direct excitation* (*e.g.*, at 397 nm), *and the obvious ineffectiveness of sensitised emission for the Eu complex.* The figure also shows the different intensities following direct excitation of the lanthanide (blue line) and chromophore excitation (red line).

Time-resolved luminescence spectroscopy was used to establish the luminescence lifetimes of the complexes, and the hydration number of inner-sphere H_2O molecules in the Yb complexes was determined from the luminescence decay constants in H_2O and D_2O with the formula $q = A(k_{H_2O} - k_{D_2O} - B)$, where q is the number of bound H_2O molecules at each Yb ion, k_{H_2O} and k_{D_2O} are the observed rate constants in H_2O and D_2O, respectively (in ms^{-1}), and A and B are specific to a given lanthanide [20]. The observed values of q imply the binding of one H_2O molecule close to each metal centre for the complexes; they are lower than might be expected for lanthanide complexes with heptadentate ligands but are comparable with those observed for other *N*-benzyl-substituted DO3A derivatives [12][21]. Calculations of q rely on the assumption that

all inner-sphere H_2O molecules are situated at the 'average' distance from the metal centre, but since through-space coupling to the solvent O–H oscillators falls off rapidly with distance, it is possible that these values reflect the presence of two solvent molecules on each centre (both in the inner sphere, but further away than the 'average' separation owing to the hydrophobicity of the benzyl substituent).

The Gd-complexes lend some support to this hypothesis. Inversion recovery measurements of T_1 for the H_2O H-atoms in aqueous solutions containing varying concentrations of the complexes were used to establish the relaxivity (the results of these measurements are plotted in *Fig. 5*). The relaxivities per mol of Gd of both [Gd_2(**1**)] and [Gd_2(**2**)] were measured at 400 MHz and found to be 11.6 $mmol^{-1}$ s^{-1} and 13.8 $mmol^{-1}$ s^{-1}, respectively (*cf.* [Gd(DO3A)] which has a relaxivity of 5.5 $mmol^{-1}$ s^{-1}). These results are broadly comparable with those observed with *p*-xylyl-bridged DO3A complexes [22], and are consistent with the binding of two H_2O molecules to each metal ion and with a slow rotational correlation time for the complex molecules. It is also worth noting that the relaxivity of [Gd_2(**2**)] is marginally greater than that of [Gd_2(**1**)]: the amino-group H-atoms will also be in exchange on the NMR timescale, and may also help facilitate exchange of metal-bound H_2O.

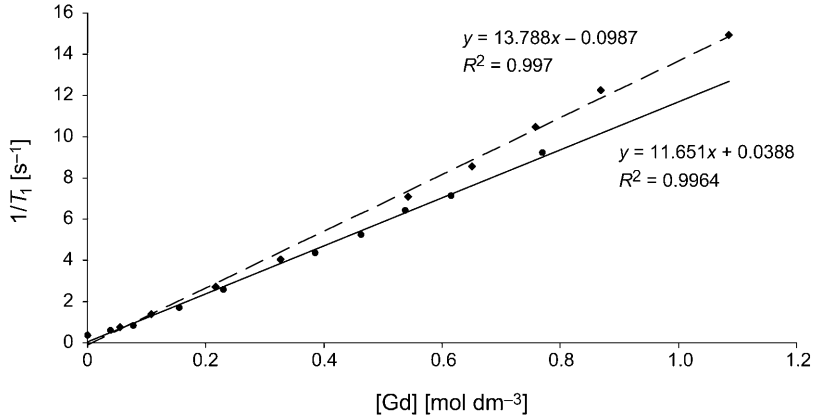


Fig. 5. *Plots of 1/*T_1 vs. *Gd-concentration for [*Gd_2(**1**)*]* (solid line) *and [*Gd_2(**2**)*]* (broken line)

Conclusion. – From these results it is clear that *m*-xylyl-linked systems can be prepared without difficulty, and that they have interesting photophysical and relaxometric properties. Furthermore, the complexes are sufficiently robust to withstand conversion of [Gd_2(**1**)] to [Gd_2(**2**)] by hydrogenation, implying that the amino complex will be an effective building block for more complicated assemblies.

Experimental Part

General. Cyclen (= 1,4,7,10-tetraazacyclododecane) was purchased from *Strem Chemicals*, while other reagents, solvents, and starting materials were obtained from the *Aldrich Chemical Company*. All chemicals were used as supplied. 1,4,7-Tri(*tert*-butyl) 1,4,7,10-tetraazacyclododecane-1,4,7-triacetate was synthesized according to a published procedure [17]. Column chromatography = CC. Absorption

spectra: in H_2O; *T60U* spectrometer (*PG Instruments Ltd.*), fused-quartz cells with a path length of 1 cm; λ_{max} (ε) in nm. FT-IR Spectra: *Equinox-55-FRA106/5* instrument; pressed KBr disks; $\tilde{\nu}$ in cm^{-1}. NMR Spectra: *Bruker-Avance-400* spectrometer, at 400 (^1H) or 100 MHz (^{13}C) for diamagnetic compounds, variable-temp. unit set at 300 K, unless otherwise stated; *Varian-Inova-500* spectrometer, at 500 MHz (^1H) and 295 K for paramagnetic compounds; δ in ppm rel. to Me_4Si as internal standard, J in Hz. MS: *Micromass-Platform-II* spectrometer for pos. electrospray ionization (ESI) in MeCN or MeOH solns.; or *Micromass-TOF-Spec-2E* spectrometer for MALDI with MeOH solns. and an ALPHA maxtrix; in m/z (rel. %). Elemental analyses were performed by the microanalytical services at the University of Manchester with a *Carlo-Erba Instruments CHNS-O EA1108* elemental analyzer (C, H, N, and S analysis) and a *Fisons-Horizon-Elemental-Analysis-ICP-OED* spectrometer for metals and halogens.

Photophysical Measurements. Luminescence spectra of Eu and Tb complexes were measured on a *Perkin-Elmer-LS55* fluorimeter. In the case of the Nd and Yb complexes, the sample was excited with a pulsed nitrogen laser (*PTI 3301*, 337 nm). Light emitted at right angles to the excitation beam was focussed onto the slits of the monochromator (*PTI 120*), which was used to select the appropriate wavelength. The growth and decay of the luminescence at selected wavelengths was detected with a Ge photodiode (*Edinburgh Instruments*) and recorded with a digital oscilloscope (*Tektronix TDS220*) before being transferred to the computer for analysis. Luminescence lifetimes were obtained by iterative reconvolution of the detector response (obtained by means of a scatterer) with exponential components for growth and decay of the metal-centred luminescence, with a spreadsheet running in *Microsoft* Excel. The time-resolved emission spectra (TRES) of the complexes were obtained by measuring the growth and decay of the luminescence at each of a series of wavelengths.

Crystallography. Data for **6**·2 NaBr·CH_2Cl_2 were collected at 100 K with an *Oxford-Diffraction-XCalibur2* diffractometer equipped with an *Oxford-Cryosystems* low-temp. device [23], by means of MoK_α radiation and ω scans. Data were corrected for *Lorenz* and polarisation factors, and absorption corrections were applied to all data. The structure was solved by direct methods with SHELXS-97 [24]. The structure was completed by iterative cycles of ΔF syntheses and a full-matrix least-squares refinement. Several C-atoms and one N-atom were restrained as approximately isotropic to prevent them from going non pos. definite, and the MeCN and MeOH solvent C-, N-, and O-atoms were refined isotropically. All other non-H-atoms were refined anisotropically. Difference *Fourier* syntheses were employed in positioning idealised H-atoms and were allowed to ride on their parent C- or N-atoms. All refinements were against F^2 and used SHELXL-97 [25].

CCDC-728845 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge *via* http://www.ccdc.cam.ac.uk/data_request/cif.

1,3-Bis(bromomethyl)-5-nitrobenzene (**4**) [15]. The 5-nitrobenzene-1,3-dimethanol (0.9 g, 4.9 mmol) was dissolved in 48% HBr soln. (20 ml) and conc. H_2SO_4 soln. (6.7 ml). The resulting soln. was stirred under reflux for 8 h, and subsequently allowed to cool to r.t. H_2O (40 ml) was added, the pH adjusted to 7 with 1M NaOH, and the resulting orange precipitate washed with brine (3×20 ml). The product was dissolved in $CHCl_3$ (40 ml), the soln. dried ($MgSO_4$) and concentrated, and the yellow solid purified by CC (silica gel, hexane/AcOEt 8:2): **4** (0.98 g, 65%). White powder. Alternatively, purification was achieved by recrystallisation from a hot mixture of hexane/CH_2Cl_2 9:1, that was cooled slowly to between 0 and 5°. UV/VIS (MeOH): 228 (11400, $\pi \rightarrow \pi^*$), 264 (4,300, n $\rightarrow \pi^*$). IR: 1538 (NO_2), 1342 (NO_2), 1254 (CH_2 wagging), 667 (C−Br stretch). ^1H-NMR (400 MHz, $CDCl_3$, 25°): 4.52 (*s*, 2 CH_2Br); 7.75 (*s*, 1 arom. H); 8.18 (*s*, 2 arom. H). ^{13}C-NMR (102 MHz, $CDCl_3$, 25°): 30.6 ($BrCH_2$); 123.7, 135.3 (arom. CH); 140.2, 148.6 (arom. C). ESI-MS (pos., CH_2Cl_2): 309 (5, M^+), 228 (100, $[M - Br]^+$). Anal. calc. for $C_8H_7Br_2NO_2$: C 31.0, H 2.28, N 4.53; found: C 30.83, H 2.17, N 4.23.

1,1′,4,4′,7,7′-Hexa(tert-*butyl*) *10,10′-[(5-Nitro-1,3-phenylene)bis(methylene)]bis[1,4,7,10-tetraazacyclododecane-1,3,7-triacetate]* (**6**). Cs_2CO_3 (1.33 g, 4.09 mmol) was added to a soln. of 1,4,7-tri(*tert*-butyl) 1,4,7,10-tetraazacyclododecane-1,4,7-triacetate (**5**; 1.00 g, 1.68 mmol) in anh. MeCN (25 ml) under N_2. A soln. of **4** (0.253 g, 0.819 mmol) in anh. MeCN (5 ml) was added under stirring to the soln., and the mixture was heated to reflux temp. for 72 h. The soln. was cooled to r.t. and filtered to remove the inorg. salts, and the MeCN was evaporated. The product was dissolved in CH_2Cl_2 (30 ml) and the soln. washed with sat. NaCl soln. (5×30 ml), dried ($MgSO_4$), and concentrated: dark yellow oil. The hexaester was

purified by CC (neutral alumina, CH_2Cl_2, then slowly increasing MeOH/CH_2Cl_2 (0.1 ml per 100 ml). The product was eluted with MeOH/CH_2Cl_2 3 : 97, the solvent evaporated, and the residue triturated in Et_2O followed by hexane: 0.55 g (50%) of **6**·2 NaBr·CH_2Cl_2. Yellow powder. Single crystals suitable for X-ray-analysis were grown by slow vapour diffusion between CH_2Cl_2 and hexane. UV/VIS (MeOH): 204 (8900, $\pi \rightarrow \pi^*$), 262 (4400, n $\rightarrow \pi^*$). IR: 1716 (C=O), 1534 (NO_2), 1368 (NO_2). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 1.35 (*s*, 6 *t*Bu); 2.8–4.4 (br., 48 H, CH_2 ring, CH_2CO, ArCH_2N); 7.9–8.6 (br., 3 arom. H). ^{13}C-NMR (102 MHz, $CDCl_3$, 25°): 27.8, 28.0 (*Me*$_3$); 50.0, 50.2, 50.6, 51.5, 51.7, 55.5, 55.8, 56.1, 56.3, 57.1 (CH_2N); 81.8, 82.2, 82.6, 83.0 (Me$_3$*C*); 124.0, 124.3, 124.7, 139.4, 140.2, 148.5, 148.6 (arom. C); 169.3, 170.0, 172.5, 173.5 (C=O). ESI-MS (pos., MeCN): 1176 (48, $[M+H]^+$), 1198 (42, $[M+Na]^+$), 600 (57, $[M+H+Na]^{2+}$). Anal. calc. for $C_{60}H_{105}BrN_9NaO_{14}\cdot CH_2Cl_2$: C 53.70, H 7.90, N 9.24, Na 1.69; found: C 53.90, H 8.00, N 9.13, Na 1.67.

*1,1′,4,4′,7,7′-Hexa(*tert*-butyl) 10,10′-[(5-Amino-1,3-phenylene)bis(methylene)]bis[1,4,7,10-tetraazacyclododecane-1,3,7-triacetate]* (**7**). To a soln. of hexaester **6**·2 NaBr·CH_2Cl_2 (0.480 g, 0.361 mmol) in MeOH (5 ml), a catalytic amount of Pd/C (0.03 g) was added, and the mixture was heated to 60°. Then $NH_2NH_2\cdot H_2O$ (5 ml, 84 mmol) was added. After 10 h (TLC monitoring), the soln. was cooled to r.t., the excess catalyst removed by filtration through a *Celite* slurry in MeOH, the filtrate concentrated, the yellow oil dissolved in CH_2Cl_2 (30 ml), the soln. washed with brine (8 × 30 ml), dried ($MgSO_4$), and concentrated, and the light yellow solid triturated in Et_2O and then hexane: 0.350 g (75%) of **7**·0.5 NaBr. UV/VIS (MeOH): 244 (12100, sh, $\pi \rightarrow \pi^*$), 295 (5200, n $\rightarrow \pi^*$). IR: 1720 (C=O), 1225 (C–N). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.42–1.47 (*s*, 6 *t*Bu); 2.80–4.42 (*m*, 48 H, CH_2 ring, CH_2CO, ArCH_2N); 6.64–6.93 (*m*, 3 arom. H). ^{13}C-NMR (102 MHz, $CDCl_3$): 26.9, 27.1, 27.2 (*Me*$_3$C); 48.8, 52.6, 54.8, 55.2, 58.6, 64.8 (CH_2N); 80.0, 81.5, 81.8 (Me$_3$*C*); 114.5, 120.7, 137.2, 147.2 (arom. C); 169.6, 171.5, 172.5 (C=O). ESI-MS (pos., MeCN): 574 (98, $[M+2H]^{2+}$), 585 (90, $[M+H+Na]^{2+}$), 597 (11, $[M+H+Na]^{2+}$), 1148 (36, $[M+H]^+$), 1170 (12, $[M+Na]^+$). Anal. calc. for $C_{60}H_{107}Br_{1.5}N_9Na_{1.5}O_{12}$: C 55.40, H 8.29, N 9.69 Na 2.65; found: C 54.31, H 8.54, N 10.17, Na 2.73.

10,10′-[(5-Nitro-1,3-phenylene)bis(methylene)]bis[1,4,7,10-tetraazacyclododecane-1,4,7-triacetic Acid] ($H_6\cdot$**1**). Hexaester **6**·2 NaBr·CH_2Cl_2 (0.500 g, 0.376 mmol) was dissolved in CH_2Cl_2 (4 ml) and CF_3COOH (4 ml, 54.04 mmol) was added dropwise to the yellow soln. After 48 h stirring at r.t., the mixture was concentrated and the orange oil washed with portions of CH_2Cl_2 (3 × 30 ml) and MeOH (3 × 30 ml). Finally, a white solid was precipitated from a conc. MeOH soln. with Et_2O, isolated by filtration, and dried under reduced pressure: 0.455 g (97%) of $H_6\cdot$**1**·3 $CF_3COOH\cdot 4\,H_2O$. UV/VIS (H_2O): 201 (13900, $\pi \rightarrow \pi^*$), 270 (4800, n $\rightarrow \pi^*$). IR: 1638 (C=O), 1681 (C=O), 1540 (NO_2), 1356 (NO_2). ^{1}H-NMR (400 MHz, (D_6)DMSO, 120°): 2.93 (*t*, $^3J = 4.0$, 4 CH_2 ring); 3.04 (*dt*, 8 CH_2 ring); 3.13 (*t*, $^3J = 4.0$, 4 CH_2 ring); 3.55 (*s*, CH_2CO); 3.60 (*s*, 2 CH_2CO); 4.10 (*s*, 2 ArCH_2N); 7.92 (*s*, 1 arom. H); 8.20 (*s*, 2 arom. H). ^{13}C-NMR (102 MHz, CD_3OD, 25°): 55.2, 56.5, 57.4 (*Me*$_3$C); 66.9 (CH_2N); 113.9, 119.7, 122.6, 127.9 (arom. C); 160.3 (C=O). ESI-MS (pos., H_2O): 840 (32, $[M+H]^+$), 863 (16, $[M+Na]^+$), 431 ($[M+H+Na]^{2+}$), 420 ($[M+2H]^{2+}$). Anal. calc. for $C_{36}H_{57}N_9O_{14}\cdot 3\,CF_3COOH\cdot 4\,H_2O$: C 40.23, H 5.47, N 10.05; found: C 40.30, H 5.12, N 10.22.

10,10′-[(5-Amino-1,3-phenylene)bis(methylene)]bis[1,4,7,10-tetraazacyclododecane-1,3,7-triacetic Acid] ($H_6\cdot$**2**). As described for $H_6\cdot$**1**, with hexaester **7**·0.5 NaBr (0.350 g, 0.269 mmol), CH_2Cl_2 (4 ml), and CF_3COOH (4 ml, 54.04 mmol): 0.330 g (96%) of $H_6\cdot$**2**·3.5 $CF_3COOH\cdot 4\,H_2O$. UV/VIS (H_2O): 201 (10000, $\pi \rightarrow \pi^*$), 245 (4600, sh, $\pi \rightarrow \pi^*$), 295 (5000, n $\rightarrow \pi^*$). IR: 1675 (C=O), 1184 (C–N). ^{1}H-NMR (400 MHz, (D_6)DMSO, 120°): 2.95 (*m*, 8 CH_2 ring); 3.11 (*m*, 8 CH_2 ring); 3.45 (*s*, 4 CH_2CO); 3.59 (*s*, 2 CH_2CO); 4.13 (*s*, 2 ArCH_2N); 6.70–6.74 (br., 3 arom. H). MALDI-MS (H_2O): 810 (38, $[M+H]^+$), 832 (6, $[M+Na]^+$). Anal. calc. for $C_{36}H_{59}N_9O_{12}\cdot 3.5\,CF_3COOH\cdot 4\,H_2O$: C 40.32, H 5.55, N 9.84; found: C 39.92, H 4.97, N 10.96.

*{μ-{10,10′-[(5-Nitro-1,3-phenylene)bis(methylene)]bis[1,4,7,10-tetraazacyclododecane-1,4,7-triacetato(3–)-κN^1,κN^4,κN^7,κN^{10},κO^1,κO^4,κO^7]}}dilanthanide Complex [Ln$_2$(**1**)]*. The lanthanide triflate (0.191 mmol) and $H_6\cdot$**1**·3 $CF_3COOH\cdot 4\,H_2O$ (0.100 g, 0.076 mmol) were dissolved in MeOH (2 ml) and stirred for 48 h at 50°. The excess lanthanide salts were removed by dialysis, and H_2O was evaporated. A white solid was obtained by slow diffusion between MeOH and Et_2O. This was isolated by filtration and dried under reduced pressure.

*[Nd_2(**1**)]:* Yield 0.042 g (63%). UV/VIS (H_2O): 205 (22000, $\pi-\pi^*$), 270 (7100, $n\rightarrow\pi^*$). Luminescence: λ_{ex} 337 nm, λ_{em} 1055, 1330 nm. MALDI-MS (H_2O): 1103 (37, $[M-O]^+$), 1119 (52, $[M+H]^+$).

*[Eu_2(**1**)]:* Yield 0.099 g (66%). UV/VIS (H_2O): 204 (19000, $\pi\rightarrow\pi^*$), 270 (6600, $n\rightarrow\pi^*$). IR: 1592 (C=O), 1537 (NO_2), 1351 (NO_2). MALDI-MS (H_2O): 1132 (9, $[M-O]^+$), 1138 (16, $[M+H]^+$). Anal. calc. for $C_{36}H_{51}Eu_2N_9O_{14}\cdot 5\ CF_3SO_3H\cdot 5\ H_2O$: C 24.96, H 3.12, Eu 15.40, N 6.03; found: C 24.28, H 3.37, Eu 14.39, N 6.03.

*[Gd_2(**1**)]:* Yield 0.087 g (62%). UV/VIS (H_2O): 203 (24000, $\pi\rightarrow\pi^*$), 268 (8400, $n\rightarrow\pi^*$). IR: 1591 (C=O), 1535 (NO_2), 1353 (NO_2). MALDI-MS (H_2O): 1130 (7, $[M-O]^+$), 1149 (20, $[M+H]^+$). Anal. calc. for $C_{36}H_{51}Gd_2N_9O_{14}\cdot 3.5\ CF_3SO_3H\cdot 10\ H_2O$: C 25.59, H 4.05, Gd 16.97, N 6.80, S 6.05; found: C 25.58, H 3.80, Gd 13.04, N 6.51, S 5.56.

*[Tb_2(**1**)]:* Yield 0.138 g (98%). UV/VIS (H_2O): 205 (18000, $\pi\rightarrow\pi^*$), 270 (6600, $n\rightarrow\pi^*$). Luminescence: λ_{ex} 268 nm, λ_{em} 545 nm, τ_{H_2O} 1.60 ms, τ_{D_2O} 2.78 ms, q 1.0. IR: 1632 (C=O), 1532 (NO_2), 1353 (NO_2). MALDI-MS (H_2O): 1151 (98, $[M+H]^+$), 1173 (16, $[M+Na]^+$). Anal. calc. for $C_{36}H_{51}N_9O_{14}Tb_2\cdot 3.5\ CF_3SO_3H\cdot 10\ H_2O$: C 24.50, H 3.41, N 6.27, Tb 15.81; found: C 24.08, H 3.42, N 6.26, Tb 13.65.

*[Yb_2(**1**)]:* Yield 0.076 g (54%). UV/VIS (H_2O): 206 (14000, $\pi\rightarrow\pi^*$), 270 (5900, $n\rightarrow\pi^*$). IR: 1598 (C=O), 1535 (NO_2), 1353 (NO_2). Luminescence: λ_{ex} 337 nm, λ_{em} 980 nm, τ_{H_2O} 1.60 µs, τ_{D_2O} 5.31 µs, q 0.3. ^{1}H-NMR (500 MHz, D_2O): −92.0; −83.9; −77.9; −76.1; −68.8; −66.3; −61.9; −59.5; −40.1; −35.8; −32.3; −21.8; 20.7; 27.9; 32.5; 36.1; 46.3; 51.5; 72.7; 111.8; 127.9; 135.5; 141.0 (only major resolved peaks outside the range +20 to −21 reported). MALDI-MS (H_2O): 1181 (12, $[M+H]^+$), 1203 (3, $[M+Na]^+$). Anal. calc. for $C_{36}H_{51}N_9O_{14}Yb_2\cdot 4\ CF_3SO_3H\cdot 5\ H_2O$: C 25.69, H 3.50, N 6.74, Yb 18.50; found: C 25.24, H 3.70, N 6.37, Yb 14.94.

*{µ-{10,10′-[(5-Amino-1,3-phenylene)bis(methylene)]bis[1,4,7,10-tetraazacyclododecane-1,4,7-triacetato(3−)-κN^1,κN^4,κN^7,κN^{10},κO^1,κO^4,κO^7]}}dilanthanide Complex [Ln_2(**2**)]. Method A.* To a soln. of [Ln_2(**1**)] (0.100 g, 0.054–0.096 mmol) in MeOH (3 ml), a catalytic amount of Pd/C (0.010 g) was added, and the mixture was heated to reflux temp. Then $NH_2NH_2\cdot H_2O$ was added (2 ml, 68 mmol). After 1 h, the mixture was allowed to cool and filtered through a slurry of *Celite* in MeOH to remove the catalyst. The MeOH was evaporated and, through repeated washing with MeOH followed by evaporation, the NH_2NH_2 was removed. A white solid was precipitated from a conc. MeOH soln. by dropwise addition of Et_2O. This was isolated by filtration and dried under reduced pressure.

Method B. As described for [Ln_2(**1**)], with lanthanide triflate (0.115–0.121 g, 0.195 mmol), $H_6\cdot$**2** (0.100 g, 0.078 mmol), and MeOH (2 ml).

*[Nd_2(**2**)]:* Yield 0.110 g (84%). UV/VIS (H_2O): 205 (24000, $\pi\rightarrow\pi^*$), 241 (5100, $\pi\rightarrow\pi^*$), 294 (2400, $n\rightarrow\pi^*$). MALDI-MS (H_2O): 1087 (27, $[M+H]^+$), 1109 (21, $[M+Na]^+$). Anal. calc. for $C_{36}H_{53}N_9Nd_2O_{12}\cdot 4\ CF_3SO_3H\cdot 4\ H_2O$: C 27.22, H 3.71, N 7.14, S 7.27, Nd 16.35; found: C 23.67, H 3.46, N 7.67, S 7.13, Nd 15.25.

*[Eu_2(**2**)]:* Yield 0.061 g (72%). UV/VIS (H_2O): 206 ($\pi\rightarrow\pi^*$), 238 ($\pi\rightarrow\pi^*$), 292 ($n\rightarrow\pi^*$). Luminescence: λ_{ex} 268 nm, λ_{em} 617 nm, τ_{H_2O} 0.50 ms, τ_{D_2O} 0.98 ms, q 0.9. IR: 1581 (C=O), 1241 (C−N). MALDI-MS (H_2O): 1108 (26, $[M+H]^+$), 1109 (11, $[M+Na]^+$). ^{1}H-NMR (500 MHz, D_2O): −19.3; −17.1; −15.9; −12.2; −11.6; −9.6; −7.1; 5.5; −2.4; 10.0; 22.4 (only major resolved peaks outside the range +9 to +1 reported).

*[Gd_2(**2**)]:* Yield 0.140 g (84%). UV/VIS (H_2O): 205 (21000, $\pi\rightarrow\pi^*$), 240 (3900, $\pi\rightarrow\pi^*$), 294 (1300, $n\rightarrow\pi^*$). IR: 1581 (C=O), 1239 (C−N). MALDI-MS (H_2O): 1117 (26, $[M+H]^+$), 1109 (10, $[M+Na]^+$). Anal. calc. for $C_{36}H_{51}Gd_2N_9O_{14}\cdot 6\ CF_3SO_3H\cdot 10\ H_2O$: C 22.49, H 3.62, Gd 14.30, N 5.73, S 8.75; found: C 22.29, H 3.21, Gd 15.54, N 5.72, S 7.99.

*[Tb_2(**2**)]:* Yield 0.143 g (96%). UV/VIS (H_2O): 206 (22000, $\pi\rightarrow\pi^*$), 240 (4200, $\pi\rightarrow\pi^*$), 294 (1600, $n\rightarrow\pi^*$). Luminescence: λ_{ex} 242, 291 nm, λ_{em} 545 nm, τ_{H_2O} 1.82 ms, τ_{D_2O} 2.98 ms, q 0.8. IR: 1582 (C=O), 1240 (C−N). MALDI-MS (H_2O): 1122 (75, $[M+H]^+$), 1109 (40, $[M+Na]^+$). Anal. calc. for $C_{36}H_{51}N_9O_{14}Tb_2\cdot 5\ CF_3SO_3H\cdot 5\ H_2O$: C 25.11, H 3.44, N 6.43, S 8.17, Tb 16.21; found: C 20.47, H 3.04, N 6.49, S 8.05, Tb 14.60.

*[Yb_2(**2**)]:* Yield 0.101 g (72%). UV/VIS (H_2O): 207 (27000, $\pi\rightarrow\pi^*$), 240 (5300, $\pi\rightarrow\pi^*$), 294 (2100, $n\rightarrow\pi^*$). Luminescence: λ_{ex} 337 nm, λ_{em} 980 nm, τ_{H_2O} 0.99 ms, τ_{D_2O} 5.83 ms, q 0.1. IR: 1583 (C=O), 1239

(C–N). ^{1}H-NMR (500 MHz, D_2O): –98.5; –82.7; –72.2; –69.5; –643; –59.7; 58.5; –13.8; 10.2; 11.9; 18.3; 21.5; 26.8; 33.1; 35.7; 38.4; 110.3; 124.3; 128.1; 132.9 (only resolved peaks outside the range + 10 to –13 reported). MALDI-MS (H_2O): 1151 (41, $[M+H]^+$). Anal. calc. for $C_{36}H_{51}N_9O_{14}Yb_2 \cdot 4\,CF_3SO_3H \cdot 5\,H_2O$: C 26.11, H 3.67, N 6.85, S 6.97, Yb 18.81; found: C 22.40, H 3.39, N 7.34, S 7.17, Yb 16.14.

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