My research has concentrated on the use of cyclen based lanthanide systems for various supramolecular applications. This essay summarises the three principle areas investigated. Work from each area has been accepted for publication.

**Cyclen Based Lanthanide Systems for the Hydrolysis of Phosphodiesters**

The goal of this project was to synthesise a bimetallic, lanthanide, cyclen based complex to cleave the nucleic acid RNA. The focus being the rate enhancement provided by the cooperative action of two metal ions. It is well documented that the presence of a second metal ion can lead to large rate enhancements of phosphodiester hydrolysis over similar mononuclear systems. ¹ This work concentrated solely on binuclear *lanthanide* complexes, which to date, despite large rate enhancements reported for mononuclear lanthanide systems, have gone largely unreported.², ³ The intended synthesis comprised of four steps. Firstly, the spacer would be synthesised. Two cyclen macrocycles would then be attached to the spacer. The macrocycles would then be functionalised with pendant arms, before the final step, the encapsulation of two lanthanide metal ions. The effect of differing metal ions, spacer groups and pendant arms was to be investigated.

The complex’s ability to promote phosphodiester hydrolysis was tested using the phosphodiester HPNP (2-hydroxypropyl-p-nitrophenylphosphate) an RNA model compound. The kinetics of hydrolysis was followed by UV spectroscopy. In all, twelve new bimetallic lanthanide complexes were synthesised, characterised and tested for phosphodiester hydrolysis ability. A variety of factors was seen to effect the activity of the Ln(III) complex cleavage. The choice of pendant arm was an extremely important factor in obtaining greater rate enhancements. The simple acetamide pendant arms showed only moderate rate enhancements, while better enhancements were observed for the more complex arms, such as the pyridine pendant arms. This improvement was assigned to the ability of the pyridine group to function as a general base catalyst.

The choice of spacer group was found to be the central factor in obtaining cooperative enhancements (i.e. > two-fold increase over the corresponding mononuclear complex). The cooperative action sought between the two metals was prevented by the very rigid nature of the original spacer (Figure1). Employing more flexible alkyl chains as bridging groups, led to a modest cooperative rate enhancements (4 fold), in line with similar literature findings. ⁴ The largest rate enhancement was provided by the xlyly bridged Eu(III) system (Figure 2) which reduced the half life of HPNP at pH 7.4, 37 ºC, from 240 days to 28 minutes, a rate enhancement *k*ₕₑₜ of 12,333. This is one of the largest rate enhancements reported under these conditions. It is also 28 times faster than its corresponding mononuclear system. It is believed that this large rate enhancement is due to the cooperative action of the two metal centres working in unison. The complex did not exhibit catalytic turnover and this was attributed to the strong binding of the substrate resulting in poor product release.

![Figure 2: Binucler Eu(III) complex](image)

**Lanthanide Luminescent Sensor for the Detection of aromatic carboxylates**

Lanthanides have great potential as signalling systems for sensors as they can luminesce. However, it is difficult to excite lanthanides directly due to the Laporte forbidden f-f transitions. This drawback can be overcome by attaching ‘antenna’ that can transfer energy to the lanthanide excited state via the antennas triplet state. ⁵ The aim of this project was to design a sensor for aromatic carboxylic acids utilising the antenna effect but with one important difference. The analyte or aromatic carboxylate would also function as the
antenna and upon binding, should lead to a lanthanide emission (Figure 3). The analyte binds to the lanthanide through its carboxyl oxygens by displacing metal bound water molecules. The lanthanide complexes showed no luminescence in aqueous solution prior to addition of the analyte. However, when dimethylaminobenzoic acid (DMABA) was added a Tb(III) emission was observed. The luminescence intensity increased with increasing concentration of DMABA reaching a maximum at 4 equivalents. Salicylic acid, the active form of Aspirin, gave similar results.

A novel binuclear Tb(III) complex, was also synthesised (Figure 4). Lifetime measurement indicated that each Tb(III) ion possesses two metal bound water molecules. As before, this complex exhibited large increases in its luminescence ca. 1000, after the formation of a ternary complex with the DMABA antenna. Lifetime measurements in the presence of the DMABA antenna indicated that each Tb(III) ion was binding one carboxylate anion, as all the metal bound water molecules had been displaced. Furthermore the addition of the bis-carboxylate, terephthalic acid, (TTA) gave rise to even stronger luminescent enhancements. Lifetime measurements in the presence of TTA confirmed that all metal bound water molecules had been displaced. In summary, a new general class of sensor for aromatic carboxylates such as DMABA, salicylic acid, and terephthalic acid, have been successfully developed. They operate under ambient conditions through the formation of self-assembling ternary complexes, which give rise to large increases in the Tb(III) luminescence.

Lanthanide Luminescent Sensor for the Detection of Cu(II).

The aim of this project was the synthesis of a new class of lanthanide luminescent sensor (Figure 5), based upon use of the 1,10 phenanthroline (phen) chromophore, for selective detection of Cu(II), which would operate under physiological conditions (pH 7.4) and in the presence of biologically prevalent cations. The phen ligand was to act as an antenna for populating the excited state of the lanthanide ion, inducing a lanthanide emission.

The beauty of this system is that the antenna should also function as the receptor. It has two nitrogen atoms which can bind a Cu(II) ion. This should interfere with the energy transfer process and quench the luminescence, providing an on-off system. Once synthesised the luminescent properties of the sensor were probed. At pH 4 and below, the Eu(III) luminescence gradually decreased in intensity. This was attributed to the deprotonation of the amide interfering with the energy transfer process and hence quenching the luminescence. At pH 8 and above, there was a gradual decrease in the luminescence intensity. This was ascribed to the protonation of the phen nitrogen interfering with the energy transfer process and quenching the luminescence. Crucially, the system is switched on in the physiological pH range and is almost independent of pH in this range.

We proposed that the binding of Cu(II) to the phen moiety would interfere with the energy transfer process and quench the luminescence. And indeed, upon addition of Cu(II) a gradual decrease in the luminescence was observed (Figure 6), until the luminescence was completely quenched at ~20 μM [Cu(II)]. This is within the blood concentration range for Cu(II) in the average human 12 – 21 μM. It was shown that this process was unaffected by the presence of biologically prevalent cations Na⁺, Ca²⁺, K⁺, Mg²⁺ and Zn(II). The complex was found to respond to Iron, but with a much lower sensitivity, requiring a higher concentration of Iron than found in the body. In conclusion a new luminescent system for the selective detection of Cu(II) has been developed which operates under physiological conditions and in the presence of the biologically prevalent cations.
Publications:


Please find attached my essay for the YOUNG CHEMISTS 2005 competition.

Yours sincerely,

Andrew Harte.