A chiroptically enhanced fluorescent chemosensor

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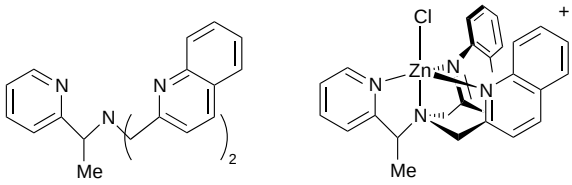
One sensor molecule gives both fluorescence and exciton-coupled circular dichroism signals upon metal ion complexation, suggesting a novel strategy for detection, identification and quantification of multiple analytes.

One important strategy for the design of efficient sensors for the determination of metal ion concentrations in solution utilizes fluorescent chemosensors in which a metal ion binding event is coupled to a change in the luminescence behavior of the ligand upon forming a complex.[1–4] The classic approach to selective metal ion sensor design involves the engineering of selectivity through control of ligand stereoelectronic features including donor atoms and geometry. Sensor arrays with multivariate calibration offer especially exciting potential in this field.[5] Recently, multiple wavelength excitation[6] and ratiometric detection[7] schemes have offered sophisticated analysis of two metal ions with a single ligand. Here, we wish to report a strategy wherein both isotropic and anisotropic absorption signals from the optical response of a single sensory molecule provide not only detection but also differentiation of multiple analytes.



1 α-MeBQPA **2** [Zn(α-MeBQPA)Cl]$^+$

The ligand **1** {α-MeBQPA, bis[(2-quinolyl)methyl][1-(2-pyridyl)ethyl]amine} generates strong signals in exciton-coupled circular dichroism spectra (ECCD) upon formation of complexes with trigonal bipyramidal metal ions (Zn^{II}, Cu^{II}) as shown in Fig. 1.[8] Contrastingly, complexes with octahedral metal ions (Cd^{II}, Fe^{II}) do not give strong CD signals. The physical basis for tripodal ligand ECCD response to metal ion geometry has been discussed.[8,9]

Since quinoline ligands were employed in the development of practical fluorescent sensors for ions such as Ca^{II}, Mg^{II} and Mn^{II},[10,11] we envisioned that **1** might also display useful fluorometric sensory properties. Fig. 1 shows fluorescence spectra of the free ligand and four coordination complexes in aqueous solution at pH = 7.1; the fluorescence intensities of diamagnetic complexes increase relative to the free ligand,[12] with observed enhancements (378 nm, H_2O, pH = 7) of 30 : 1 (Zn^{II}) and 6 : 1 (Cd^{II}). The fluorescence enhancement derives from an N-heterocycle characteristic change from an n–π* electronic transition (leading to phosphorescence)[10,13] to a π–π* transition upon metal ion complexation, resulting in fluorescence.[10,13] The observed binding of Zn^{II} and Cd^{II} to the α-MeBQPA is strong ($K_a > 10^6$ dm^3 mol^{-1}) as expected,[14] which was evidenced by the linear response of the fluorescence enhancement at micromolar concentrations [*e.g.* Fig. 2(*b*)].

The fluorescence and ECCD properties of the complexes result in the interesting situation that the ligand can not only signal the presence of a metal ion, but evaluation of both properties can allow identification of the metal. Detection of both fluorescence enhancement and anisotropic absorption distinguish, for example, Zn^{II} (strong fluorescence and ECCD response), Cu^{II} (strong ECCD but no fluorescence), Cd^{II} (strong fluorescence but no ECCD) and Fe^{II} (neither fluorescence nor ECCD). These results illustrate for the first time the principle that both isotropic and anisotropic detection may be utilized to maximize the information transmitted by a single sensor molecule.

The optical behavior of the ligand upon presentation of Zn^{II} and Cd^{II} mixtures serves to illustrate the approach. The overall ratio of fluorescence signals of the Zn^{II} and Cd^{II} ions at micromolar concentrations is 5 : 1 at 378 nm. However, the circular dichroic responses are more highly differentiated; at 242 nm (H_2O, pH = 7) the ratio of $\Delta\varepsilon(ZnL) : \Delta\varepsilon(CdL)$ is 12 : 1. The relative fluorescence measured follows eqn. (1)

$$I = \chi_{Zn} I_0^{ZnL} + (1 - \chi_{Zn}) I_0^{CdL} \quad (1)$$

$$\theta = A[Zn^{2+}] + B \quad (2)$$

where I_0^{ZnL} and I_0^{CdL} are the intensities for the 1 : 1 M : L complex, and χ_{Zn} the mole fraction of Zn^{II} in the mixture. The CD signal is mainly sensitive to [Zn^{II}]; assumption that Cd^{II}

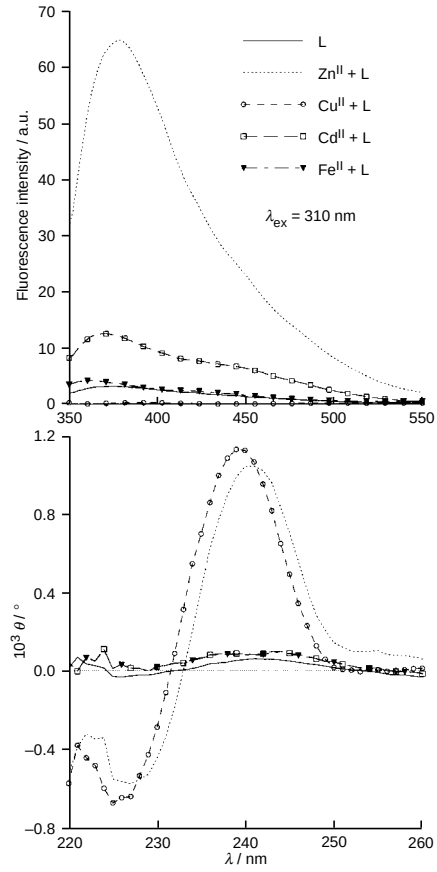


Fig. 1 Fluorescence and circular dichroism spectra of (*R*)-α-MeBQPA (5.1 μM) and complexes with $Zn(ClO_4)_2$ (5.1 μM), $Cd(NO_3)_2$ (5.1 μM), $Cu(ClO)_4)_2$ (5.2 μM) and $FeCl_2$ (5.0 μM) in aqueous HEPES buffer (0.1 M), pH = 7.09, 25 °C (λ_{ex} = 310 nm)

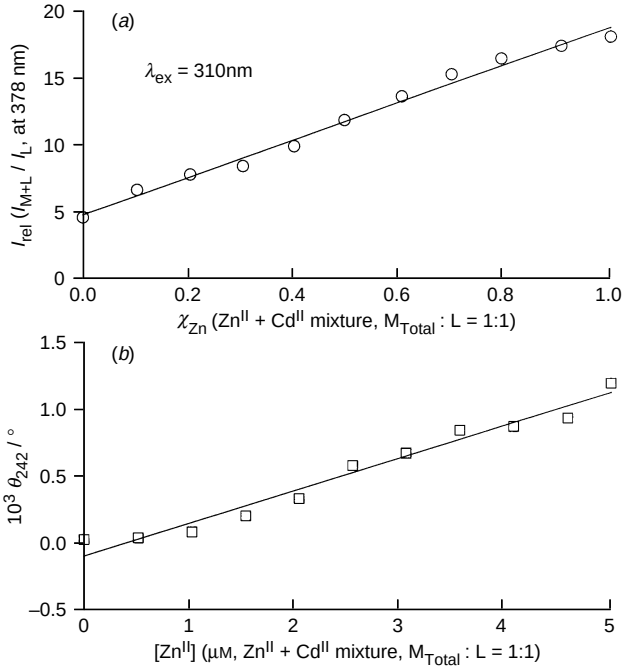


Fig. 2 Change in fluorescence intensity (378 nm, r = 0.995) and CD signal (242 nm, r = 0.984) of a 5 μM solution of (*R*)-α-MeBQPA in water (0.1 M HEPES, pH = 7.09)

does not contribute gives eqn. (2). Rearranging eqn. (1) into linear form and combining with eqn. (2) we obtained eqn. (3) which will give the [Cd^{II}] as a function of the two observables.

$$[Cd^{2+}] = \left(\frac{I_0^{ZnL} - I}{I - I_0^{CdL}}\right)\left(\frac{\theta - B}{A}\right) \quad (3)$$

Based on this chemistry, a device measuring both isotopic and anisotropic absorbance would permit the calculation of the concentrations of two species. This may be done by measurement of light absorption (UV–VIS and CD) or emission (*e.g.*, fluorescence and fluorescence-detected CD) since all four responses are proportional to absorption of the light.

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Footnote and References

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