A coumarin based fluorescent photoinduced electron transfer cation sensor

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Abstract

We wish to report 4-[(Bis(pyridin-2-ylmethyl)amino)methyl]-7-methoxychromen-2-one, **1**, as a fluorescent photoinduced electron transfer cation sensor that is capable of indicating the presence of Zn^{2+}, Cd^{2+} and Pb^{2+} ions via a fluorescence signal. The log binding constants, β, for these metal ions have been measured, and were found to be 6.10 ± 0.4, 6.37 ± 0.3, and 5.67 ± 0.3, respectively.
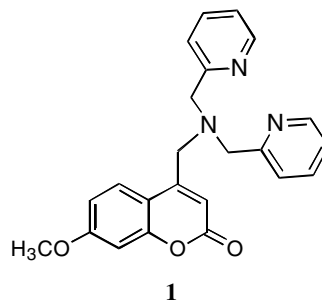
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1. Introduction

There is significant interest in the design and synthesis of fluorescent sensors for detection of physiologically important ions and molecules [1], and for monitoring of harmful pollutants in the environment [2]. The design of small molecules that can behave as sensors for cations has developed significantly over the past three decades [3]. Some of these sensors signal the presence of cations via a fluorescence signal. We are interested in fluorescent sensors that utilize photoinduced electron transfer (PET) to translate a cation binding event into a fluorescence signal. In this paper, we report a fluorescent PET sensor, **1**, designed for transition and post transition metals such as zinc, cadmium and lead.

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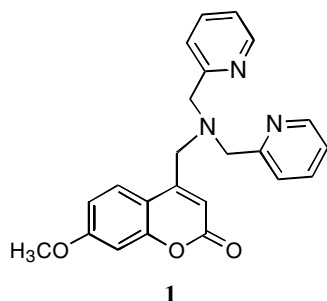
A large number of fluorescent PET sensors that follow the basic design principle of a chromophore-spacer-receptor architecture have been reported to date [4]. The signaling process of these sensors depends on a molecular recognition event to inhibit, or initiate PET between a covalently linked chromophore and a receptor, leading to the generation (off–on), or quenching (on–off) of fluorescence. The role of the saturated spacer unit in these assemblies is to preserve the independence of the chromophore and the receptor in the electronic ground state.

The modular nature of this design has led to the development of a large number of molecules that are capable of functioning as sensors for a variety of cations. We have previously reported a fluorescent PET sensor based on the bis-(2-picolyl)amine receptor, that is capable of generating a fluorescence signal upon binding zinc ions [5]. In this paper we report a new sensor that is based on a coumarin chromohore and the same receptor, and also extend our cation binding studies to several transition and post transition metal ions [6].

The PET process responsible for the signaling in **1**, occurs from the receptor (tertiary amine) to the excited chromophore (coumarin), quenching the fluorescence of the coumarin. The driving force for this process (ΔG_{et}) can be expressed by modified Weller equation as follows:

$$\Delta G_{et} = -E_s - E_{red.chrom} + E_{ox.receptor},$$

where E_s, $E_{red.chrom}$ and $E_{ox.receptor}$ are the singlet energy, reduction potential of the chromophore and the oxidation potential of the receptor, respectively [4]. An increase in the oxidation potential of the receptor, caused by the binding of a cation, will increase the ΔG_{et}, which will decrease and eventually quench the PET process. This in turn will allow the excited chromophore to relax by fluorescence, and will result in the generation of a fluorescent signal in **1** due to cation binding.

2. Experimental

Nuclear magnetic resonance spectra were recorded on a Bruker Avance 300/300MHz FT-NMR Spectrometer. All NMR spectra were obtained in CDCl₃ at room temperature and the chemical shifts are reported in δ values (ppm) relative to TMS. High Resolution mass spectra were obtained at the Mass Spectrometry Service Laboratory at the Department of Chemistry, University of Minnesota.

Elemental analysis was carried out at Robertson-Microlit Laboratories, Madison, New Jersey. Ultraviolet and visible spectra were recorded on Cary 300 Bio UV–Vis Spectrophotometer and Agilent 8453 Spectrophotometers. Excitation and emission spectra were recorded on a Cary Eclipse Fluorescence Spectrophotometer. Cation binding studies were carried out in anhydrous acetonitrile using metal perchlorate salts. Ionic strength of all solutions was maintained at 0.1 M using sodium perchlorate. (*Warning! Metal perchlorate salts are potentially explosive; the isolated salts should never be dried and should not be subjected to shock!*).

2.1. 4-[(Bis(pyridin-2-ylmethyl)amino)methyl]-7-methoxychromen-2-one (**1**)

A mixture of 4-(bromomethyl)-7-methoxycoumarin (1.102 g, 4.095 mmol), 2,2′dipicolylamine (0.808 g, 4.095 mmol), triethylamine (0.816 g, 8.08 mmol) in ethanol (77 mL) was refluxed for two days. After cooling to room temperature, dichloromethane (30 mL) was added and the mixture was washed with 3 M hydrochloric acid (4 × 30 mL). The aqueous layer was neutralized with sodium carbonate and extracted into dichloromethane (50 mL). The organic layer was dried over magnesium sulfate, filtered, and evaporated to give an oily residue. Purification by column chromatography (silica: methanol/ethyl acetate 5:95) gave **1** as a viscous residue (1.01 g, 53%). ¹H NMR (CDCl₃): δ 8.35–8.30 (m, 2H), 7.50–7.25 (m, 5H), 7.00–6.90 (m, 2H), 6.60–6.50 (m, 2H), 6.42 (s, 1H), 3.71 (s, 4H), 3.69 (s, 2H), 3.61 (s, 3H). ¹³C NMR (CDCl₃): δ 161.96, 160.77, 157.89, 154.94, 152.62, 148.63, 136.09, 125.18, 122.63, 121.84, 111.71, 111.44, 110.92, 100.27, 60.01, 55.17, 54.16. HRMS (ESI) for C₂₃H₂₁N₃O₃ (M + Na) calculated 410.1475, found 410.1475. *Anal*. Calc. for C₂₃H₂₁N₃O₃: C, 71.29; H, 5.47; N, 10.85. Found: C, 71.02; H, 6.16; N, 10.87%.

3. Results and discussion

The fluorescence of **1** is quenched due to the thermodynamically favored PET between the tertiary amine and the excited chromophore. Increasing the oxidation potential of the tertiary amine due to cation binding prevents this PET and regenerates the fluorescence of the chromophore [5]. Three metal ions, Zn²⁺, Cd²⁺ and Pb²⁺ show a significant fluorescence enhancement of **1**. No fluorescence enhancement was observed with Hg²⁺, Ag⁺ and Cu²⁺. The Job's plot data indicated that the ligand:metal binding ratio is 1:1 (see Figs. 1 and 2).

Sensor **1**, when dissolved in acetonitrile showed two peaks at 262 and 321 nm on the UV–Vis spectrum. On binding of Zn²⁺, Cd²⁺ and Pb²⁺, the peak at 262 nm remained the same while a small bathochromic shift was observed for the peak at 321 nm. For Cd²⁺ and Zn²⁺, the new peak was observed at 328 nm while for lead it was 331 nm. This indicates the possibility of an interaction