ORGANIC LETTERS

2001
Vol. 3, No. 22
3455−3457

A New Reverse PET Chemosensor and Its Chelatoselective Aromatic Cadmiation

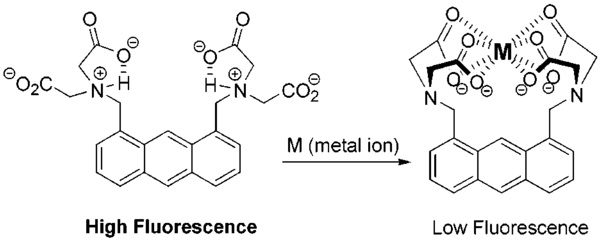
Miwhoa Choi,[†] Mihyang Kim,[‡] Kap Duk Lee,[§] Kuk-Nyo Han,[†] In-A Yoon,[†] Hye-Jin Chung,[†] and Juyoung Yoon*,[†]

Department of New Materials Chemistry and Nanophotonics Research Center,
Silla University, Pusan 617-736, Korea, Department of Food and Nutrition,
Silla University, Pusan 617-736, Korea, and Department of Chemistry,
Dongguk University, Kyungju, Kyungbuk, Korea

jyoon@silla.ac.kr

Received July 5, 2001

ABSTRACT



A new fluorescent chemosensor, anthryl tetra acid, was synthesized and showed large fluorescence quenching effects in 100% aqueous solution with metal ions via photoinduced electron transfer (PET). Chelatoselective fluorescence perturbation was observed with Cd(II) and resulted from electrophilic aromatic cadmiation.

Photoinduced electron transfer (PET) has been widely used as a tool of choice in fluorescent sensor design for protons and metal ions by many groups.[1] In particular for compounds containing the benzylic amine moiety, in the absence of metal ions or proton, fluorescence is quenched via PET from the fairly reducing amine group to the excited singlet state of anthracene. Upon complexation with a suitable metal ion, a large chelation-enhanced fluorescence (CHEF) effect is observed because the chelation abrogates the PET process. This is a typical “*off*−*on*” type of PET chemosensor. On the other hand, Shinkai and co-workers reported a reverse PET chemosensor (on−off type) bearing a (tetraphenylporphyrinato)tin(IV) moiety as a fluorescent site and 2-aminomethylphenylboronic acid group as a sugar-binding site.[2] In this work, diol complexation induced fluorescence quenching due to the inhibition of the B−N interaction.

We report here a new anthracene derivative as a reverse PET chemosensor for metal ions. In the absence of metal ion, fluorescence remains because this compound exists as a zwitterion at pH 7. Metal ion binding induced a PET process by reducing the pK_a of the benzylic amine group, resulting in fluorescence quenching. We also observed a chelatoselective fluorescence perturbation in the presence of Cd(II) caused by the electrophilic aromatic cadmination at the 9-position of anthracene.

[†] Department of New Materials Chemistry and Nanophotonics Research Center, Silla University.

[‡] Department of Food and Nutrition, Silla University.

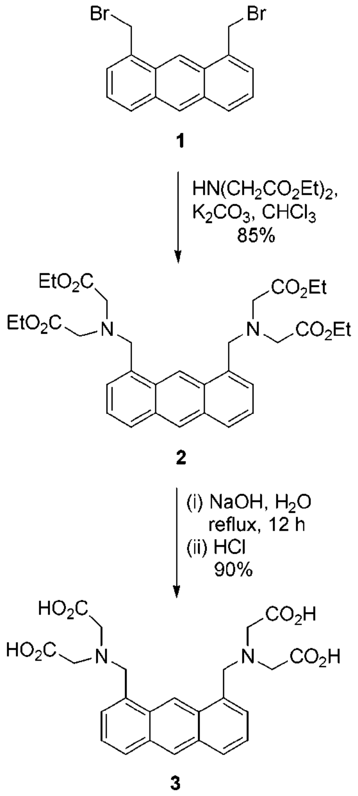
[§] Department of Chemistry, Dongguk University.

(1) (a) *Fluorescent Chemosensors for Ion and Molecular Recognition*; Czarnik, A. W., Ed.; American Chemical Society: Washington, DC, 1993. (b) Czarnik, A. W. *Acc. Chem. Res.* **1994**, *27*, 302. (c) Fabbrizzi, L.; Poggi, A. *Chem. Soc. Rev.* **1994**, 197. (d) de Silva, A. P.; Gunaratne, H. Q. N.; Gunnlaugsson, T. A.; Huxley, T. M.; McCoy, C. P.; Rademacher, J. T.; Rice, T. E. *Chem. Rev.* **1997**, *97*, 1515. (e) *Chemosensors of Ion and Molecular Recognition*; Desvergne, J.-P., Czarnik, A. W., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1997.

(2) Kijima, H.; Takeuchi, M.; Robertson, A.; Shinkai, S.; Cooper, C.; James, T. D. *Chem. Commun.* **1999**, 2011.

10.1021/ol016400o CCC: $20.00

Scheme 1. Synthesis of Anthryl Tetra Acid **3**



Our synthesis began with 1,8-bis(bromomethyl) anthracene **1**, produced using the method described by Nakagawa.[3] Treatment of **1** with diethyl iminodiacetate and potassium carbonate in chloroform at 40 °C for 5 h led to the tetraester **2** in 85% yield (Scheme 1). The tetra acid **3** was produced in 90% yield by hydrolysis with potassium hydroxide in water.

Ca(II), Cd(II), Co(II), Cs(I), Cu(II), K(I), Li(I), Hg(II), Mg(II), Mn(II), Na(I), Ni(II), Pb(II), Rb(I), Sr(II), and Zn(II) ions were used to evaluate metal ion binding of compound **3**. Titration studies were conducted at pH 7 (0.1 M HEPES) using a 6 μM concentration of compound **3**. Using these metal ions (6 μM), compound **3** displayed fluorescence quenching effects with Co(II), Cu(II), Hg(II), Mn(II), Pb(II), and Zn(II) ions. Selected fluorescence emission spectra of compound **3** upon the addition of 1 equiv of metal ions are shown in Figure 1. These results are contrary to those obtained with normal PET chemosensors and can be explained as follows. As shown in Scheme 2, in the absence of metal ions, compound **3** displayed significant fluorescent emission intensity even at pH 7. Because of the adjacent carboxylic acid groups, this compound must be a zwitterion, in which each side has two negative and one positive charge. When the metal ion binds, it shields the charge on the carboxylates, and the pK_a of the benzylic amine changes such that it is no longer protonated at pH 7. This explanation can be applied to Co(II), Mn(II), and Zn(II).

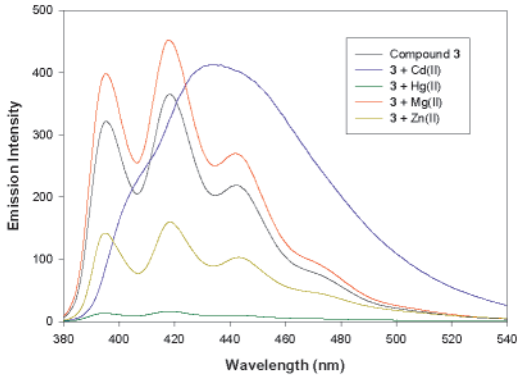
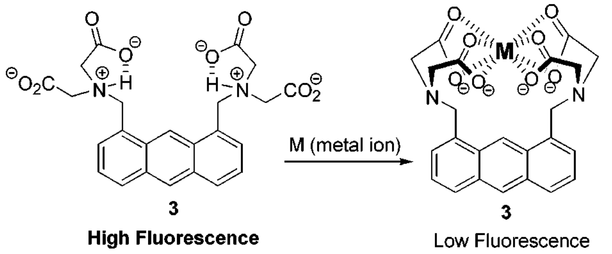


Figure 1. Changes in the fluorescence emission spectra of compound **3** (6 μM) upon the addition of 1 equiv of metal ions at pH 7 (0.1 M HEPES).

Scheme 2. Proposed Mechanism of Fluorescence Emission Change upon the Addition of Metal Ions to Compound **3** at pH 7



Fluorescence quenching effects were maximized with Cu(II) and Hg(II). Since both of these metal ions are known as effective quenching metals (e.g., open-shell, paramagnetic, large or easily reducible cation[4]), it may be difficult to distinguish between the reverse PET mechanism and intracomplex quenching. Interestingly, Ca(II), Mg(II), and Sr(II) ions displayed chelation-enhanced fluorescence (CHEF) effects with compound **3**. These CHEF effects are observed when metal ion binds to the lone pair electrons of nitrogen. We observed similar CHEF effects with these metal ions at pH 11 (0.1 M CAPS) also.

Furthermore, the Cd(II)-**3** complex displays an additional broad, red-shifted band yielding the composite spectrum with λ_{max} 435 nm (Figure 1). The ^{1}H NMR spectrum of the Cd(II)-**3** complex in D_2O solution revealed the presence of more than one chelate; moreover, H-10 was clearly represented by major and minor singlets (ratio = 2:1) (Figure 2). When 1.1 equiv of Cd(II) was added at room temperature, we observed a substantial decrease and broadness of the H-9

---

[3] (a) Akiyama, S.; Misumi, S.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1962**, *35*, 1826. (b) Akiyama, S.; Misumi, S.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1962**, *35*, 1829. (c) Akiyama, S.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1971**, *44*, 3158.

[4] (a) Varnes, A. W.; Dodson, R. B.; Wehry, E. L. *J. Am. Chem. Soc.* **1972**, *94*, 946. (b) Kelmo, J. A.; Shepherd, T. M. *Chem. Phys. Lett.* **1977**, *47*, 158. (c) Formosinho, S. *J. Mol. Photochem.* **1976**, *7*, 13. (d) Akkaya, E. U.; Huston, M. E.; Czarnik, A. W. *J. Am. Chem. Soc.* **1990**, *112*, 3590.

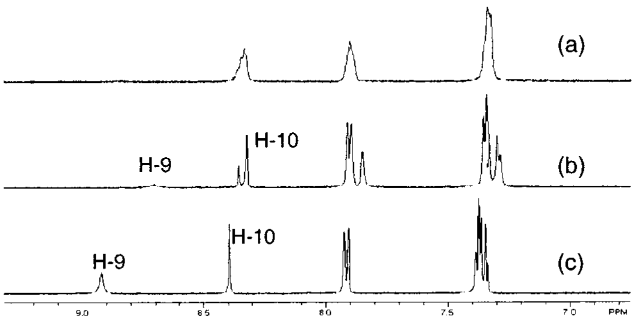


Figure 2. Partial ^{1}H NMR spectra (500 MHz) in D_2O: (a) compound **3** at 25 °C, (b) compound **3** upon the addition of 1 equiv of Cd(II) at 25 °C, and (c) compound **3** upon the addition of 1.1 equiv of Cd(II) at 80 °C.

proton peak. In addition, a gradual coalescing of the aromatic resonances was observed on heating.

A similar result was report by Czarnik and co-workers in 1990.[5] Among few anthryl-azacrown compounds, only (9′-anthrylmethyl)-1,4,7,10,13-pentaazatridecane was reported to exhibit similar aromatic cadmiations at the 1- and 8-positions of anthracene. However, the observed fluorescence, UV, and ^{1}H NMR perturbations of the Cd(II) complex were observed only in water; in methanol, ethanol, and acetonitrile, only unperturbed anthracene spectra were observed. On the other hand, in our case, similar fluorescence and ^{1}H NMR perturbations of the Cd(II)-**3** complex were observed both in water and in ethanol.

A proposed mechanism for these observations is illustrated as follows. The Cd(II)-**3** complex uniquely populates a conformer in which an anthracene-Cd(II) π-d orbital interaction promotes the anthracene-Cd(II) π-complex. This π-complex is then converted to a higher energy species, a σ-complex.

In conclusion, compound **3** can be considered as a new reverse PET chemosensor, which works in a manner that is contrary to that of normal PET chemosensors. Also, the structural basis of chelatoselective fluorescence perturbation with Cd(II) suggests that changes in the species involved in such “nonclassical” selectivity may produce further fluorionophores.

Acknowledgment. This work was fully supported by a grant (2000-1-12300-001-3) from the Basic Research Program of the Korea Science & Engineering Foundation.

Supporting Information Available: Experimental procedures and characterization data for the compounds described. This material is available free of charge via the Internet at http://pubs.acs.org.

OL016400O

---

[5] Huston, M. E.; Engleman, C.; Czarnik, A. W. *J. Am. Chem. Soc.* **1990**, *112*, 7054.