

Original Article

Fluorescent Probe for Fe³⁺ Based on a Schiff-base Derivative

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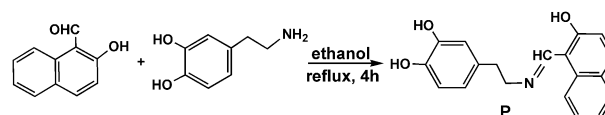
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Abstract - A new probe for Fe³⁺ based on dopamine as a receptor was described. It displayed a highly selective and sensitive fluorescent response toward Fe³⁺ over other metal ions.

Keywords - Fe³⁺, Fluorescent probe, Dopamine.



Scheme 1 The synthetic route of compound P

I. INTRODUCTION

In recent years, considerable efforts have been devoted to developing artificial fluorescent probes to detect biologically and environmentally important species, especially heavy transition-metal (HTM) ions.^[1-3] Among them, the essential role of Fe³⁺ in many biochemical systems became apparent with the identification of Fe³⁺ as a body constituent in oxygen uptake, oxygen metabolism, and electron transfer.^[4] However, excess or deficiency of this ion is toxic or can lead to various diseases, such as Parkinson's disease and Alzheimer's disease.^[5] Therefore, it is important to track and study this biologically important and cytotoxic ion conveniently.

Because of its operational simplicity, low cost, real-time monitoring, and high selectivity, fluorescent detection has become a promising strategy for sensing and bioimaging metal ions, anions, and small molecules in various samples.^[6-10] Based on our previous research on the recognition and separation of important metal ions, it was necessary to choose an efficient fluorophore and consider the geometry of coordination sites for a certain metal ion^[11-15]. The design rationale for the Fe³⁺ probe was explained as follows: 1) naphthalene derivative was chosen as a signal transducer due to its excellent fluorescence properties, such as its large absorption coefficient and high fluorescence quantum yields.^[16-18] 2) Biological iron(III) uptake process utilized some siderophores, such as analogs of ferrichrome.^[19]

With this in mind, in our study, a dopamine moiety was attached to a naphthalene derivative so that the flexibly specific structure could suitably accommodate Fe³⁺ according to the ionic radius, which was similar to the natural tripodal siderophores. The synthesis route of the probe is shown in Scheme 1.

II. EXPERIMENTAL SECTION

A. Reagents and Instruments

All reagents and solvents are of analytical grade and used without further purification. Metal ions species employed were from NaCl, MgCl₂·6H₂O, CdCl₂, HgCl₂, CaCl₂·2H₂O, FeCl₃·6H₂O, CrCl₃·6H₂O, Zn(NO₃)₂·6H₂O, AgNO₃, CoCl₂·6H₂O, MnCl₂·4H₂O, CuCl₂·2H₂O, PbCl₂ and NiCl₂·6H₂O, respectively. Metal ions were dissolved in deionized water.

Fluorescence emission spectra were conducted on a Hitachi 4600 spectrofluorometer. Nuclear magnetic resonance (NMR) spectra were measured with a Bruker AV 400 instrument, and chemical shifts were given in ppm from tetramethylsilane (TMS).

B. Synthesis of P

2-Hydroxy-1-naphthaldehyde (0.1016 g, 0.5907 mmol) and dopamine hydrochloride (0.1386 g, 0.7295 mmol) were mixed in ethanol (30 mL). The reaction mixture was stirred under reflux for 4 h and then cooled to room temperature. The solution was removed under reduced pressure. And then, the mixture was poured into dichloromethane, and the residue so obtained was filtered and washed with ethanol. The final product was dried in a vacuum to afford P as a yellow solid. Yields: 83.4%.

C. General Spectroscopic Methods

All fluorescence spectra were recorded at room temperature (25 °C). Test solutions were prepared by placing 50 μL of the probe stock solution (1 mM) and an appropriate aliquot of individual ion stock solution into a test tube and then diluting the solution with ethanol to 5 mL. The resulting solution was shaken well before recording the spectra. Excitation and emission slit widths for P fluorescent



measurements were 10/10 nm, respectively. The excitation wavelength was 350 nm.

III. RESULTS AND DISCUSSION

A. Fluorescence spectra of P

The fluorescence responses of probe P to respective metal ions (10 equiv) were illustrated in Fig. 1. Na^+ , Mg^{2+} ,

Ca^{2+} , Pb^{2+} , Ni^{2+} , Co^{2+} , Zn^{2+} , Cd^{2+} , Ag^+ , Hg^{2+} , Cr^{3+} , and Al^{3+} caused no obvious fluorescence change; in contrast, upon the addition of Fe^{3+} at the same concentration, fluorescence decrease was observed at 398 nm. These findings indicated that P could recognize Fe^{3+} .

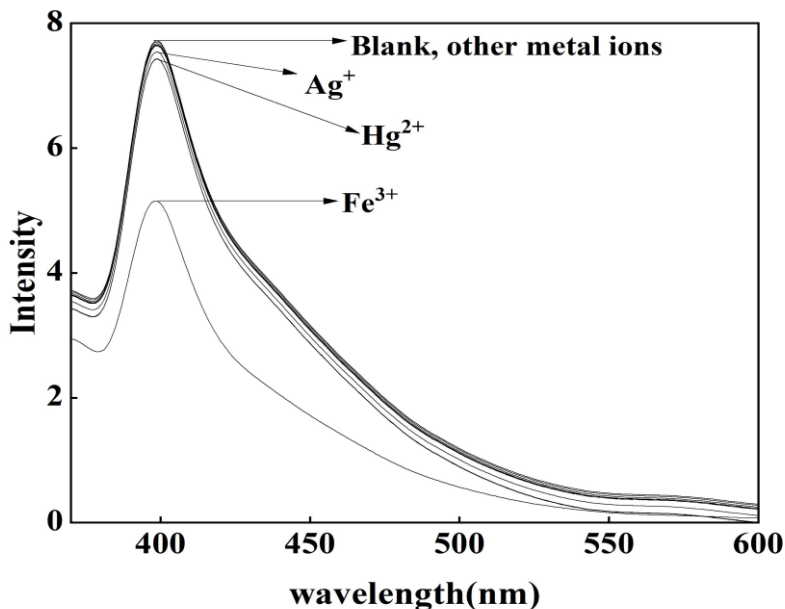


Fig. 1 Fluorescent emission changes of P (10 μM) to different metal ions (100 μM) in ethanol

Achieving high selectivity for the analyte in a complex background of potentially competing species was a challenging task in developing fluorescent probes. Hence, the competition experiments were carried out by adding Fe^{3+} to the P solution in the presence of other metal ions, as illustrated in Fig. 2, which showed that the fluorescence change in the Fe^{3+} -induced reaction with P was not suppressed by excess amounts of other metal ions such as Ca^{2+} , Mg^{2+} , Ag^+ , Hg^{2+} , Cd^{2+} , Cu^{2+} , Pb^{2+} , Zn^{2+} and Cr^{3+} , Al^{3+} . Fluorescence measurements of P with various metal ions revealed excellent selectivity for Fe^{3+} .

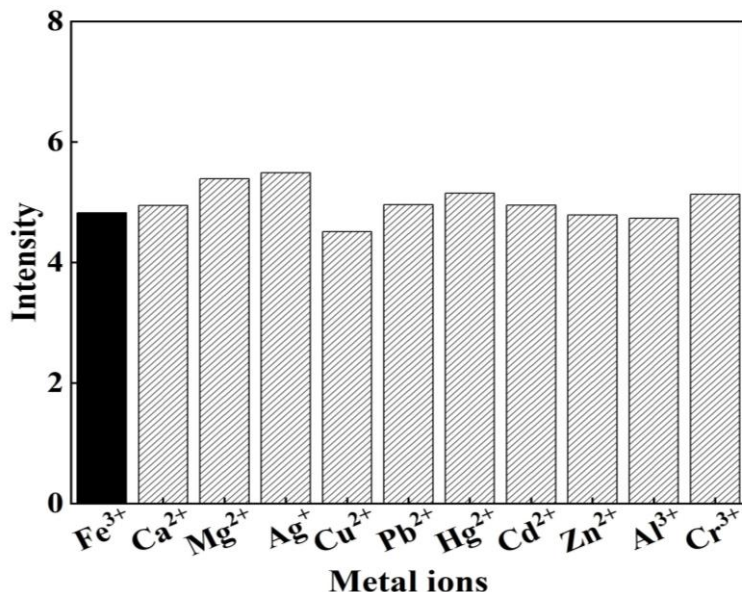


Fig. 2 Effects of different metal ions (100 μM) on the fluorescence spectrum of Fe^{3+} (100 μM) recognized by probe P (10 μM) in ethanol

Fluorescence titrations of P with Fe^{3+} in ethanol were performed (Fig. 3). In its emission spectra, the intensity of the fluorescent peak at 398 nm gradually decreased upon the increase of Fe^{3+} concentration by 350 nm excitation wavelength. A good linear relationship was observed between the fluorescence intensity of the probe at 398 nm and the concentration of Fe^{3+} in the 10 μM -70 μM , and the detection limit of 3.3 μM was obtained (calculated as three times the standard deviation of blank solution) as displayed inset of Fig. 3.

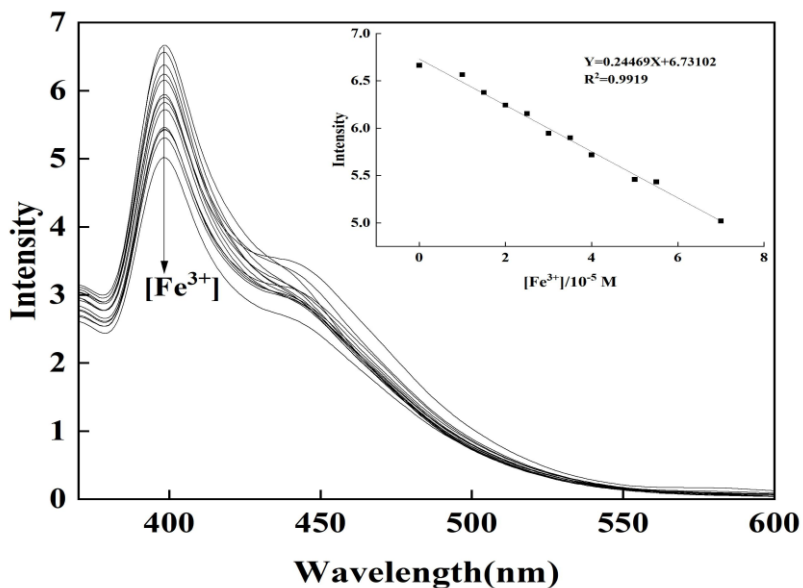


Fig. 3 Fluorescence spectra of P (10 μM) in the presence of different amounts of Fe^{3+} in ethanol. Inset: the fluorescence intensity at 398 nm as a function of Fe^{3+} concentration ($\lambda_{\text{ex}}=350$ nm)

B. Reversibility of P

The EDTA-adding experiments were conducted to examine the reversibility of the probe P (Fig. 4). In addition to Fe^{3+} (10 μM) to the mixture of P (10 μM), fluorescence intensity at 398 nm suffered from attenuation, as shown in Fig. 4b. When upon addition of EDTA (10 μM) and EDTA (100 μM), respectively, the fluorescence intensity at 398 nm was weakly enhanced (Fig. 4c, Fig. 4d), indicating that the EDTA reagent complexed only a small part of Fe^{3+} . And then, the fluorescence intensity at 398 nm decreased significantly after adding Fe^{3+} (100 μM), as seen in Fig. 4e, suggesting that the complexation ability of EDTA to Fe^{3+} was much weaker than that of probe P toward Fe^{3+} .

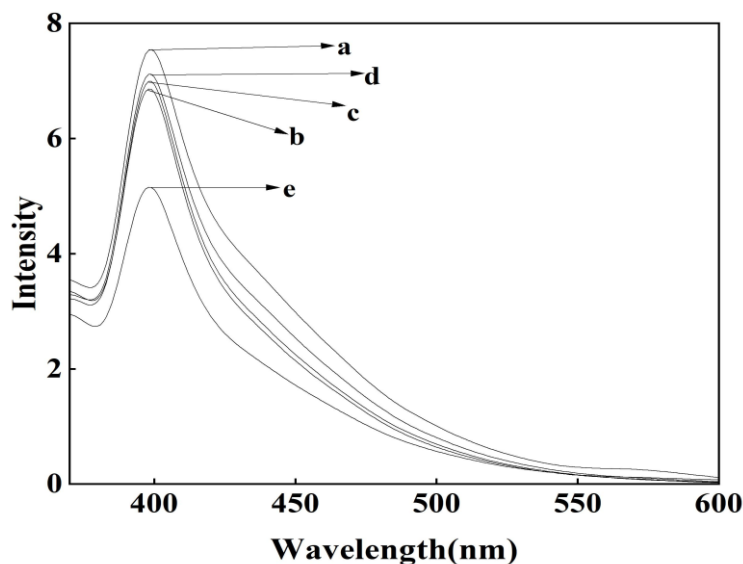


Fig. 4 The reversibility of the P- Fe^{3+} system in ethanol: a. P (10 μM); b. P (10 μM) + Fe^{3+} (10 μM); c. P (10 μM) + Fe^{3+} (10 μM) + EDTA (10 μM); d. P (10 μM) + Fe^{3+} (10 μM) + EDTA (100 μM); e. P (10 μM) + Fe^{3+} (10 μM) + EDTA (100 μM) + Fe^{3+} (100 μM)

C. Proposed Mechanism P with Fe³⁺

Schiff bases can coordinate with various metal ions and form stable complexes, known to be good ligands for metal ions.^[20-25] Based on our research, we expected that upon the addition of Fe³⁺, there was a remarkable fluorescence change because of the chelation of Fe³⁺ with the oxygen atom in the amide group, the oxygen atom in the hydroxy group, as well as nitrogen atom on the dopamine moiety in the probe.

IV. CONCLUSION

A Fe³⁺-selective fluorescent probe derived from naphthalene derivative was constructed, which could specifically detect Fe³⁺ over other metal ions. The conception may expand a promising approach to developing a selective detection method for Fe³⁺.

V. ACKNOWLEDGMENT

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