

Iminocoumarin-based Hg(II) Ion Probe

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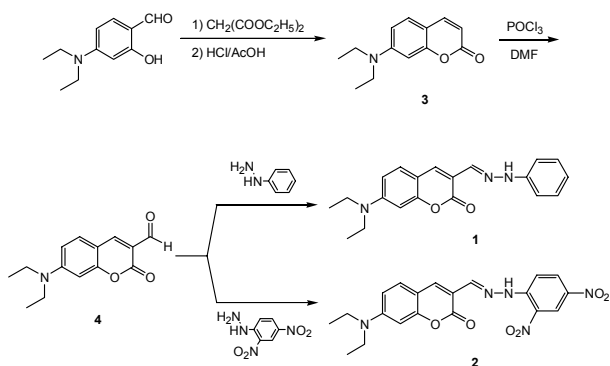
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The design and synthesis of new chemosensors for heavy and transition metal ions (HTM) has been an important subject in the field of supramolecular chemistry due to their fundamental role in biological, environmental, and chemical processes.¹ Particularly, the recognition and detection of Hg²⁺ are of growing interest because the Hg²⁺ is considered highly noxious elements.² Many analytical methods have been applied for this purpose including atomic absorption spectrometry (AAS),^{3a} ion selective electrodes (ISE),^{3b} and flame photometry.^{3c} In addition, for the detection of HTM (heavy and transition metal), colorimetric sensors have also gained interest. The colorimetric sensors have considerable advantages over other molecular sen-

sors because they do not require the use of costly equipment such as spectrophotometers, ISE, or cyclic voltameters.^{3d} So, to develop simple-to-use and naked-eye diagnostic tool, great efforts have been made for the design and synthesis of selective chromogenic sensors for Hg²⁺.

Coumarin derivatives have usually been used as fluorogenic sensors for cations or anions due to their high quantum yields.⁴ However, coumarin chromogenic chemosensors showing color changes upon certain ion complexation are rare.⁵ In this paper, we report new Hg²⁺-selective chromogenic coumarin derivative showing unique UV spectroscopic changes and obvious color changes along with enhanced fluorescence upon Hg²⁺ binding.



Scheme 1. Synthetic routes to **1** and **2**.

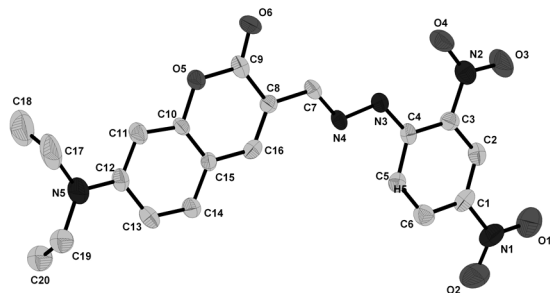


Figure 1. Crystal structure of **2**.

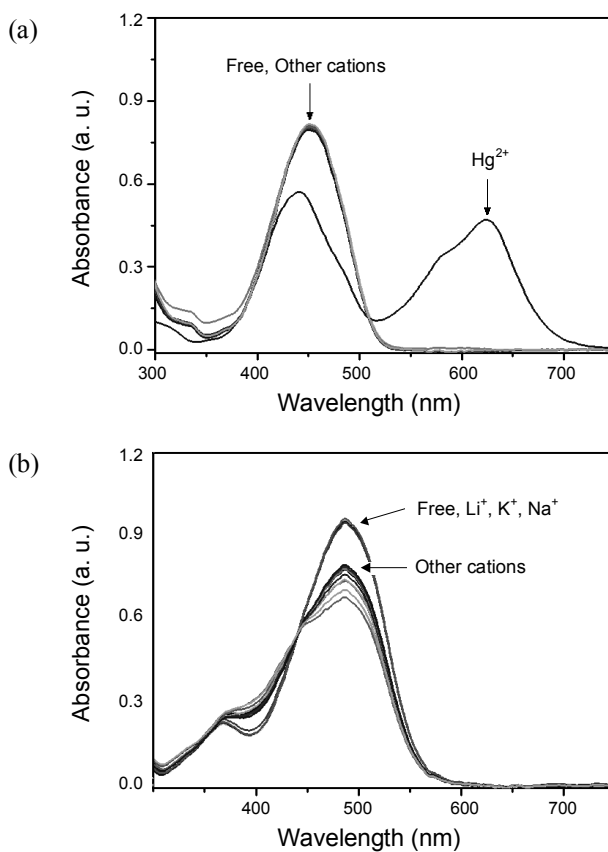


Figure 2. UV/Vis spectra of **1**(a) and **2**(b) (20.0 μ M) upon addition of ClO₄⁻ salts of Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, Cd²⁺, Ag⁺, Pb²⁺, Zn²⁺, Sr²⁺, Ba²⁺, Ca²⁺, Hg²⁺, and Al³⁺ (50 equiv) in CH₃CN.

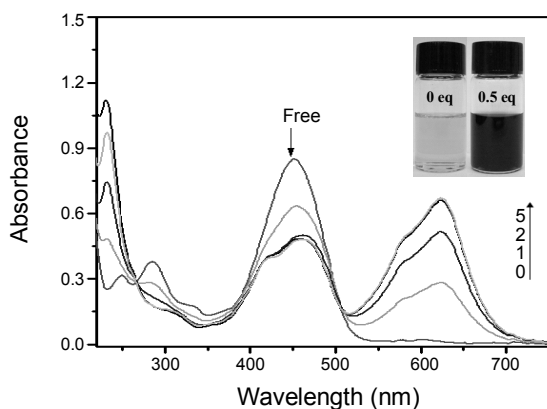


Figure 3. UV/Vis absorption spectra of **1** (20 μM) upon the addition of various amounts of Hg^{2+} in CH_3CN and its color change.

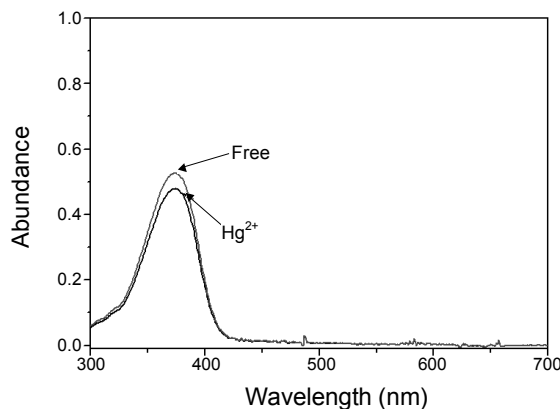


Figure 5. UV/Vis spectra of **3** (20.0 μM) upon addition of ClO_4^- salts of Hg^{2+} (50 equiv) in CH_3CN .

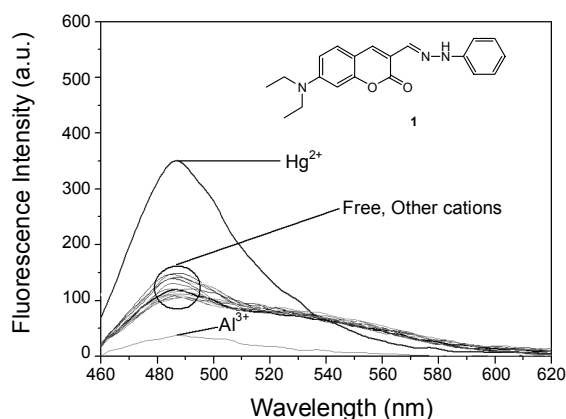
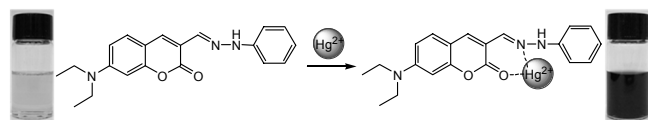


Figure 4. Fluorescence spectra of **1** (6.0 μM) upon addition of ClO_4^- salts of Li^+ , Na^+ , K^+ , Rb^+ , Cs^+ , Cd^{2+} , Ag^+ , Pb^{2+} , Zn^{2+} , Sr^{2+} , Ba^{2+} , Ca^{2+} , Hg^{2+} , and Al^{3+} (50 equiv) with an excitation at 450 nm in CH_3CN .



Scheme 2. Plausible complexation mechanism of **1** with Hg^{2+} ion.

Chromo-fluorogenic sensors **1** and **2** were prepared by 3-step synthetic route as indicated in Scheme 1. 7-*N,N*-Diethylamino-coumarin (**3**) was prepared by adaptation of reported procedures.⁶ Compound **4** was synthesized in 70% yield by the reaction of **3** with POCl_3 in DMF. Imination of **4** with phenylhydrazine and (2,4-dinitrophenyl)hydrazine in ethanol gave **1** and **2** in 80 and 81% yields, respectively. $^1\text{H-NMR}$, $^{13}\text{C-NMR}$, FR-IR and FAB-MS spectroscopies for **1** and **2** are characterized in detail in the experimental section. Also, the solid-state structure of **2** provided a convincing evidence for its 3-D conformation.

The perchlorate salts of Li^+ , Na^+ , K^+ , Rb^+ , Cs^+ , Cd^{2+} , Ag^+ , Pb^{2+} , Zn^{2+} , Sr^{2+} , Ba^{2+} , Ca^{2+} , Hg^{2+} , and Al^{3+} ions were used to investigate the metal ion binding properties of both **1** and **2** in regard of absorption and emission changes. Figure 2 shows the UV-Vis spectral changes of **1** (20 μM) and **2** (20 μM), respec-

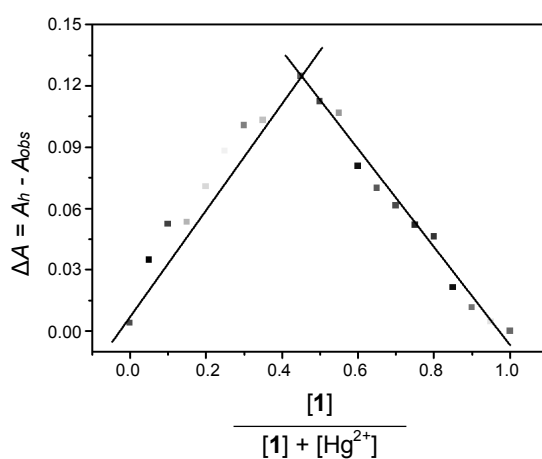


Figure 6. Job plot of **1** with Hg^{2+} in CH_3CN . $\Delta A = A_h - A_{obs}$, where A_{obs} and A_h denote the absorbance at 450 nm upon the Hg^{2+} ion binding and that of free ligand **1**, respectively.

tively, upon the addition of various metal ions in CH_3CN . UV/Vis band of at 450 nm bathochromically moved to 658 nm by 208 nm upon addition of Hg^{2+} ion while no changes with other metal cations are noted. However, spectral changes of **2** having two nitro units are substituted on the aromatic ring were not seen by any other metal ions. As shown in crystal structure in Figure 1, we assume that it is difficult for **2** to encapsulate a metal cation in regard of a geometrical disagreement where the distance between oxygen atom of $\text{C}=\text{O}$ and nitrogen atom of $\text{C}=\text{N}$ group of **2** is too long.

Figure 3 shows a UV/Vis spectral variation of **1** upon the gradual addition of $\text{Hg}(\text{ClO}_4)_2$. A considerable red-shift of absorption spectrum in **1** is presumably due to Hg^{2+} ion binding to carbonyl oxygen of the coumarin along with nitrogen of the $\text{C}=\text{N}$ unit, reflecting an enhanced intramolecular charge transfer (ICT)⁷ process from *N,N*-diethyl unit to carbonyl oxygen group. The variation of fluorescence spectra of **1** upon addition of diverse cations were recorded in CH_3CN and are displayed in Figure 4.

The weak emission of solution **1** is presumably due to a non-radiative decay through $\text{C}=\text{N}$ dynamic isomerization as was previously suggested,⁶ whereas the strong emission at 485 nm

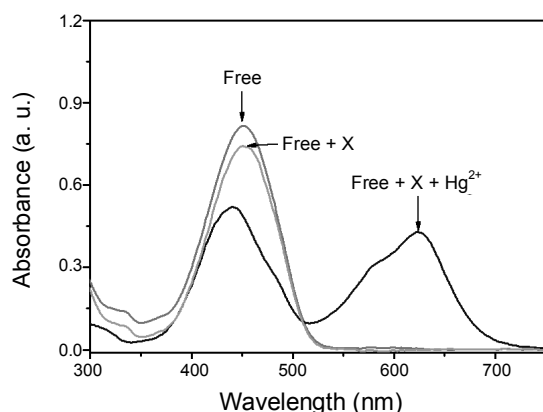


Figure 7. Absorbance spectra of **1** (20.0 μM) in CH_3CN in the presence of the Hg^{2+} ion and miscellaneous cations including Li^+ , Na^+ , K^+ , Rb^+ , Cs^+ , Cd^{2+} , Ag^+ , Mg^{2+} , Ca^{2+} , Sr^{2+} , Ba^{2+} , Zn^{2+} , Pb^{2+} , Co^{2+} , and Al^{3+} (10 equiv, respectively).

in the presence of Hg^{2+} may arise from the blocking of the C=N dynamic isomerization. Similar to previous examples, the complexation and fluorescent sensing mechanism of **1** with Hg^{2+} is depicted in Scheme 2.

To elucidate the complexation mode of **1** with Hg^{2+} ion, we synthesized **3** without the C=N unit as a reference. As expected, upon addition of Hg^{2+} ion, no spectral change was noted as seen in Figure 5. It herewith should be noteworthy again that the C=N group of coumarin **1** plays a crucial role in the complexation for Hg^{2+} ions. A Job plot experiment with **1** supports 1 : 1 complex formation of **1** for Hg^{2+} (Figure 6).

An important feature of **1** is to exhibit its high selectivity towards Hg^{2+} over other competitive species. UV/Vis spectral changes of **1** were investigated with addition of other miscellaneous cations including Li^+ , Na^+ , K^+ , Rb^+ , Cs^+ , Cd^{2+} , Ag^+ , Mg^{2+} , Ca^{2+} , Sr^{2+} , Ba^{2+} , Zn^{2+} , Pb^{2+} , Co^{2+} , and Al^{3+} (Figure 7). We found no changes of UV/Vis and fluorescence spectra of **1**. Competition experiments in the presence of other miscellaneous cations were not found to interfere the Hg^{2+} selectivity of **1**. Therefore, compound **1** is thought to be a Hg^{2+} ion sensor applicable for the industrial and the environmental field.

Experimental Section

Instruments and reagents. All fluorescence and UV-Vis absorption spectra were recorded in RF-5301PC and S-3100 spectrophotometer, respectively. NMR and mass spectra were recorded at Varian instrument (400 MHz) and JMS-700 MStation mass spectrometer, respectively. All cationic compounds such as perchlorate salts of Li^+ , Na^+ , K^+ , Rb^+ , Cs^+ , Cd^{2+} , Ag^+ , Pb^{2+} , Zn^{2+} , Sr^{2+} , Ba^{2+} , Ca^{2+} , Hg^{2+} , and Al^{3+} ions were purchased from Aldrich and used as received. All solvents were analytical reagents and from Duksan Pure Chemical Co., Ltd. CH_3CN for spectra detection was HPLC reagent without fluorescent impurity.

General procedure for fluorescence studies. Fluorescence spectra were recorded with a RF-5301PC spectrofluorophotometer. Stock solutions (1.00 mM) of perchlorate salts were prepared in CH_3CN . Stock solutions of free **1** (0.040 mM) were

prepared in CH_3CN . Excitations were carried out at 450 nm with all excitation slit widths is 3 nm, that of emission is 3 nm.

Job plot experiment. For the Job plot experiment, **1** (20.0 μM) in CH_3CN and perchlorate salts of Hg^{2+} (20.0 μM) in CH_3CN were prepared as stock solutions. The concentrations of each CH_3CN solution were varied, but the total volume was fixed at 4.0 mL. After the mixture was shaken, the absorbance intensity at 450 nm was recorded.

Synthesis.

7-Diethylamino-3-(2-phenylhydrazono)methyl coumarin (1): A portion of **4** (200 mg, 1 mmol) and phenylhydrazine (97 mg, 1.1 mmol) were combined in hot absolute ethanol (20 mL). The solution was stirred at reflux conditions for 4 hours, and the precipitate was filtrated, washed with hot absolute ethanol three times, then recrystallized with $\text{CH}_3\text{Cl}/\text{C}_2\text{H}_5\text{OH}$ (v/v, 1/3) to obtain orange crystal **1** (215 mg) in 80% yield. ^1H NMR (CDCl_3 , 400 MHz) δ 8.19 (s, 1 H, $\text{Ar}_{\text{cou}}\text{H}$), 7.88 (s, 1 H, $\text{Ar}_{\text{cou}}\text{H}$), 7.74 (s, 1 H, $\text{Ar}_{\text{cou}}\text{H}$), 7.36 (d, 1 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 8.84$ Hz), 7.29 (dd, 2 H, ArH , $J = 7.06$ Hz), 7.11 (dd, 2 H, ArH , $J = 7.44$ Hz), 6.87 (t, 1 H, ArH , $J = 7.41$ Hz), 6.61 (dd, 1 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 8.73$ Hz), 6.50 (d, 1 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 2.36$ Hz), 3.43 (q, 4 H, NCH_2CH_3 , $J = 7.10$ Hz), 1.22 (t, 6 H, NCH_2CH_3 , $J = 7.10$ Hz). ^{13}C NMR (CDCl_3 , 100 MHz) δ 161.9 (1 C), 156.0 (1 C), 150.0 (1 C), 145.4 (1 C), 144.3 (1 C), 135.9 (1 C), 135.8 (1 C), 131.7 (1 C), 131.6 (1 C), 129.5 (1 C), 129.3 (1 C), 120.3 (1 C), 112.7 (1 C), 110.2 (1 C), 108.2 (1 C), 97.1 (1 C), 45.3 (2 C), 12.3 (2 C). IR (deposit from CH_2Cl_2 solution on a KBr plate, cm^{-1}): 1698 (C=O br), 1616 (C=N). FAB MS m/z (M^+): calcd, 335.4, found, 335.00.

7-Diethylamino-3-(2-(2,4-dinitrophenyl)hydrazono)methyl coumarin (2): Compound **4** (245 mg, 1 mmol) and (2,4-dinitrophenyl)hydrazine (218 mg, 1.1 mmol) were combined in absolute ethanol (30 mL) and stirred for 4 hours under reflux conditions. The precipitate was filtrated, washed with hot absolute ethanol three times, then recrystallized with CH_3OH to obtain red crystal **2** (344.6 mg) in 81% yield. ^1H NMR (CDCl_3 , 400 MHz) δ 11.40 (s, 1 H, NH), 9.16 (d, 1 H, ArH , $J = 2.58$ Hz), 8.35 (dd, 1 H, ArH , $J = 9.22$ Hz), 8.33 (d, 2 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 11.51$ Hz), 8.07 (d, 1 H, ArH , $J = 9.58$ Hz), 7.42 (d, 1 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 8.90$ Hz), 6.67 (dd, 1 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 8.90$ Hz), 6.53 (d, 1 H, $\text{Ar}_{\text{cou}}\text{H}$, $J = 2.34$ Hz), 3.47 (q, 4 H, NCH_2CH_3 , $J = 7.14$ Hz), 1.26 (t, 6 H, NCH_2CH_3 , $J = 7.11$ Hz). ^{13}C NMR (CDCl_3 , 100 MHz) δ 161.7 (1 C), 157.5 (1 C), 152.1 (1 C), 144.7 (1 C), 143.4 (1 C), 139.8 (1 C), 138.3 (1 C), 130.8 (1 C), 130.1 (1 C), 129.5 (1 C), 123.9 (1 C), 116.8 (1 C), 112.5 (1 C), 110.2 (1 C), 109.0 (1 C), 97.6 (1 C), 45.4 (2 C), 12.7 (2 C). IR (deposit from CH_2Cl_2 solution on a KBr plate, cm^{-1}): 1715 (C=O br), 1586 (C=N), 1517 (N-O). FAB MS m/z (M^+): calcd, 425.39, found, 425.00.

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