Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 130 (2014) 7–12

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

journal homepage: www.elsevier.com/locate/saa

A new pyrene-based Schiff-base: A selective colorimetric and fluorescent chemosensor for detection of Cu(II) and Fe(III)

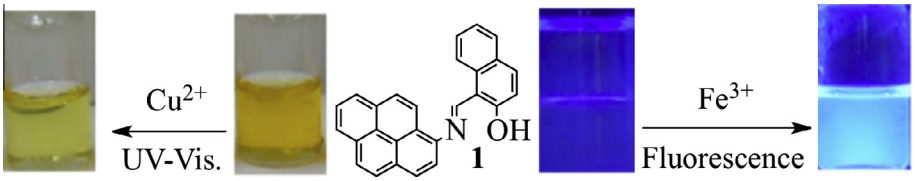
Yeshwant Ramchandra Bhorge [a], Haw-Tyng Tsai [a], Keh-Feng Huang [a], Albert J. Pape [a], Sudhakar Narasimha Janaki [b], Yao-Pin Yen [a,*]

[a] Department of Applied Chemistry, Providence University, 200, Sec. 7, Taiwan Boulevard, Shalu Dist, Taichung City 43301, Taiwan
[b] Graduate Institute of Biomedical Sciences, National Chung Hsing University, 250 Kuo-Kuang Road, Taichung 40227, Taiwan

HIGHLIGHTS

- New Schiff base sensor is selectively detects Cu^{2+} ions by naked eye color change.
- Fe^{3+} ions are also selectively detected by monitoring fluorescence emission.
- The sensing mechanisms observed are binding and hydrolysis, respectively.
- The binding and hydrolysis products were confirmed by ^1H NMR, MS.
- The new sensor has potential future use in biological cell imaging studies.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 20 March 2014
Accepted 29 March 2014
Available online 13 April 2014

Keywords:
Chemosensor
Cu^{2+} and Fe^{3+} ions
Pyrene derivative
Colorimetric
Fluorescence
Cell imaging

ABSTRACT

A new receptor **1** was prepared, for the detection of Cu^{2+} and Fe^{3+} in solutions as a colorimetric and fluorescent sensor, respectively. Receptor **1** shows highly selective and sensitive recognition toward Cu^{2+} and Fe^{3+} by naked eye UV–Vis and fluorescent color changes in aqueous solution (DMSO/H_2O = 8/2, v/v), respectively. The sensitivity toward Cu^{2+} or Fe^{3+} was not interfered with by the presence of other metal ions such as Mg^{2+}, Cd^{2+}, Ag^{+}, Zn^{2+}, Ni^{2+}, Co^{2+}, Mn^{2+}, Cr^{3+}, Ca^{2+}, Na^{+}, Pb^{2+}, K^{+}, Fe^{2+}, Li^{+} and Hg^{2+} ions. Receptor **1** can be used for semi-quantitative recognition of Cu^{2+} ions at ppm level. The fluorescence microscopy experiments showed that the receptor is efficient for detection of Fe^{3+} in vitro, developing a good image of the biological organelles.

Introduction

Chemosensors are a well-known kind of receptor that transduce a chemical signal into action potential through various elements. The development of chemosensors for sensing Cu^{2+} and Fe^{3+} remains an important area in the field of supramolecular chemistry. Currently, there is an active effort to develop systems, which can sense more than one cation even in low concentrations [1–5]. Meanwhile, copper and iron cations are very essential ions because they play important roles in biology, chemistry, and environment. Iron is an important trace element and the most abundant in the cells of all organisms [6,7]. The deficiency of Fe^{3+} causes anemia, hemochromatosis, liver damage, diabetes, Parkinson's disease and cancer [8]. On the other hand, copper is the third most abundant in the human body and plays an important role in many physiological systems in organisms [9,10]. If the blood concentration of copper falls outside the normal range of 15.7–23.3 μM [11], it can cause renal problems and Alzheimer's [12] or

* Corresponding author. Tel.: +886 4 2632 8001x15218; fax: +886 4 2632 7554.
E-mail address: ypyen@pu.edu.tw (Y.-P. Yen).

http://dx.doi.org/10.1016/j.saa.2014.03.110
1386-1425/

Parkinson's [13] diseases. Therefore, the detection of trace amounts of Cu^{2+} [14,15] and Fe^{3+} [16,17] ions is critical. Up to date, many Schiff-base based chemosensors have been reported for metal ions including Hg^{2+} [18], Zn^{2+} [19], Ca^{2+} [20] and Pb^{2+} [21]. However, in many reports most of them showed fluorescence quenching response due to the paramagnetic nature of Fe^{3+} [22,23], which poses a challenge to develop selective and sensitive fluorescence turn on Fe^{3+} receptors. Few dual sensors have been reported for Cu^{2+} and Fe^{3+} [24–26]. To the best of our knowledge, no such chemosensor for Fe^{3+} and Cu^{2+} has been reported.

Our research work involves the design and synthesis of new receptors for selective sensing of various metal ions and anions [27,28]. Recently we reported a new coumarin based Schiff base chemosensor [29] for Mg^{2+} and Fe^{3+} and chemodosimeter [30] for HSO_4^- based on hydrolysis of Schiff base. We have now synthesized a new chemosensor based on hydrolysis of Schiff base with the help of 1-aminopyrene. This behaves as a dual sensor upon chemical inputs of Cu^{2+} and Fe^{3+} cations over other cations.

Experimental section

Reagents

In titration experiments, all the cations in the form of perchlorate salts were purchased from Sigma–Aldrich, USA and stored in a vacuum desiccator. All chemicals were of analytical grade and used as received with the exception of DMSO, which was distilled over calcium hydride.

Instrumentation

Melting points were determined on a Fargo MP-2D melting point apparatus in open capillaries and are uncorrected. ^1H and ^{13}C NMR were recorded at 400 and 100 MHz on a Bruker spectrometer using trimethylsilane (TMS) as an internal standard. The EI Mass spectra were carried out on a JEOL JMS-SX/SX 102A Tandem Mass Spectrometer. UV–Vis spectra were performed in 1 cm path length quartz cell using a Cary 300 UV–Vis spectrophotometer. Fluorescence spectra were measured with a Perkin Elmer LS-50B.

UV–Vis titration experiments

The UV–Vis titrations were carried out at 25 °C and concentration of 5.0×10^{-5} M with DMSO/H_2O (v/v = 8/2, buffered with HEPES, pH = 7.4). Deionized water and a spectroscopic grade of DMSO were used as the solvents for the titration experiments and the cations were diluted to 4.0×10^{-3} M with DMSO. The absorbance was measured from 300 to 600 nm, against a blank in DMSO/H_2O (v/v = 8/2, buffered with HEPES, pH = 7.4) and different cation concentrations were added to the 5.0×10^{-5} M host solution (4 mL) in portions.

Fluorescence titration experiments

The different concentration solutions of cations (4.0×10^{-3} M) were introduced in portions to the host (5.0×10^{-5} M) and the fluorescence spectra were recorded from 400 to 600 nm at room temperature each time (excited at 389 nm, with slit widths: 10 nm/5 nm). Fluorescence quantum yields (Φ_f) were determined by the comparative method using anthracene ($\Phi_f = 0.27$) as reference standard [31].

Cell culture

Human cervical adenocarcinoma cell line HeLa (ATCC® CCL-2™) was used for live cell imaging. The cells were maintained at 37 °C as a monolayer in Eagle's Minimum Essential Medium (MEM) (HyClone) supplemented with 10% fetal bovine serum (HyClone), 100 U/mL of penicillin and 100 μg/mL of streptomycin (HyClone) in a humidified 5% CO_2 incubator. The HeLa cells were seeded on glass slides and allowed to adhere for 36 h.

Fluorescence imaging

Receptor **1** or $Fe(ClO_4)_3$ were dissolved into a 1.0×10^{-2} M stock in sterile DMSO and 1.0×10^{-2} M HEPES buffer mixed at a ratio of 80:20. To examine the fluorescence activity of receptor **1** in live cells, the HeLa cells were seeded on glass slides and allowed to adhere for 36 h. The cells were treated with MEM containing 2×10^{-5} M $Fe(ClO_4)_3$ for 30 min and then washed with PBS three times. Following washing the cells were loaded with 2×10^{-5} M chemosensor **1** in MEM for another 30 min and washed again with PBS three times to remove the remaining sensor. The fluorescent images of HeLa cells were captured at wavelength excitation 405 nm by using vertical fluorescence microscope (Olympus CKX41).

The pH dependence of Cu^{2+} and Fe^{3+} response by receptor *1* was studied by UV–Vis and fluorescence spectroscopy, respectively

The absorption of receptor **1** (5.0×10^{-5} M) on addition of Cu^{2+} (4.0 equiv.) at 410 nm was measured and plotted as a function of pH. The intensity of fluorescence emission of **1** (5.0×10^{-7} M) at 440 nm on addition of Fe^{3+} (130.0 equiv.) was similarly plotted. Measurements were conducted in DMSO/water solution (v/v, 8:2, 0.002 M buffer). The buffers were prepared in water: pH 1–2, KCl/HCl; pH 3–4, CH_3COOH/KOH; pH 5–7, HEPES/HCl; pH 8–9, Tris/KOH; pH 10–11, $NaHCO_3$/KOH; pH 12, NaCl/KOH.

Synthesis

Synthesis of (E)-1-((pyren-1-ylimino)methyl)naphthalen-2-ol (*1*)

To a stirred solution of 1-aminopyrene **(4)** (0.20 g, 0.92 mmol) in ethanol (10 ml), 2-hydroxy-1-naphthaldehyde **(5)** (0.16 g, 0.95 mmol) was added at room temperature. The reaction mixture was stirred for 12 h. After that, the solid residue was filtered off. The resulting precipitate was collected and the crude product was further washed with ethanol several times to afford the pure product **1.** Yield: 0.17 g (51%). mp: 229–230 °C. ^1H NMR (DMSO-d_6, 400 MHz) δ: 7.20 (d, 1H, J = 9.2 Hz), 7.43 (t, 1H, J = 7.2 Hz), 7.63 (t, 1H, J = 7.2 Hz), 7.88 (d, 1H, J = 7.6 Hz), 8.05 (d, 1H, J = 9.2 Hz), 8.13 (t, 1H, J = 7.6 Hz), 8.20 (d, 1H, J = 9.2 Hz), 8.25 (d, 1H, J = 8.8 Hz), 8.32-8.37 (m, 3H), 8.45 (d, 1H, J = 8.4), 8.51 (d, 1H, J = 9.2), 8.57 (d, 1H, J = 8.0), 8.68 (d, 1H, J = 8.4), 10.02 (s, 1H), 16.58 (s, 1H). ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 110.6, 117.6, 121.6, 121.9, 122.3, 124.1, 124.7, 124.9, 125.4, 126.3, 126.7, 127.1, 127.7, 127.9, 128.0, 128.3, 129.1, 129.4, 130.0, 130.3, 131.5, 132.0, 133.9, 137.7, 139.6, 158.6, 169.6; HRMS (EI) m/z = 371.1308 [M^+], calcd for $C_{27}H_{17}NO$ = 371.1310.

Synthesis of (E)-N-(naphthalen-1-ylmethylene)pyren-1-amine (*2*)

Receptor **2** was prepared by the same procedure as **1** using 1-aminopyrene **(4)** and 1-naphthaldehyde **(6)** in the same molar ratio; yield: 0.17 g (47%). mp: 156–157 °C. ^1H NMR (400 MHz, DMSO-d_6) δ: 7.69 (t, 1H, J = 8 Hz), 7.73–7.79 (m, 2H), 8.05–8.25 (m, 7H), 8.30 (d, 2H, J = 7.6 Hz), 8.39 (d, 1H, J = 8 Hz), 8.43 (d, 1H, J = 7.2 Hz), 8.71 (d, 1H, J = 8.8 Hz), 9.48 (d, 1H, J = 8.4 Hz), 9.53 (s, 1H). ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 117.0, 123.9, 125.0, 125.4,