Sensors and Actuators B 188 (2013) 735–740

Contents lists available at ScienceDirect

Sensors and Actuators B: Chemical

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

The synthesis, characterization of three isomers of rhodamine derivative and their application in copper (II) ion recognition

Fangjun Huo[a,*,1], Long Wang[a], Caixia Yin[b,**], Yutao Yang[b,1], Hongbo Tong[a], Jianbin Chao[a], Yongbin Zhang[a]

[a] Research Institute of Applied Chemistry, Shanxi University, Taiyuan 030006, China
[b] Key Laboratory of Chemical Biology and Molecular Engineering of Ministry of Education, Institute of Molecular Science, Shanxi University, Taiyuan 030006, China

ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form 25 July 2013
Accepted 26 July 2013
Available online 7 August 2013

Keywords:
Rhodamine derivative
UV–Vis spectra
Copper ion
Fluorescence spectra
Bioimaging

ABSTRACT

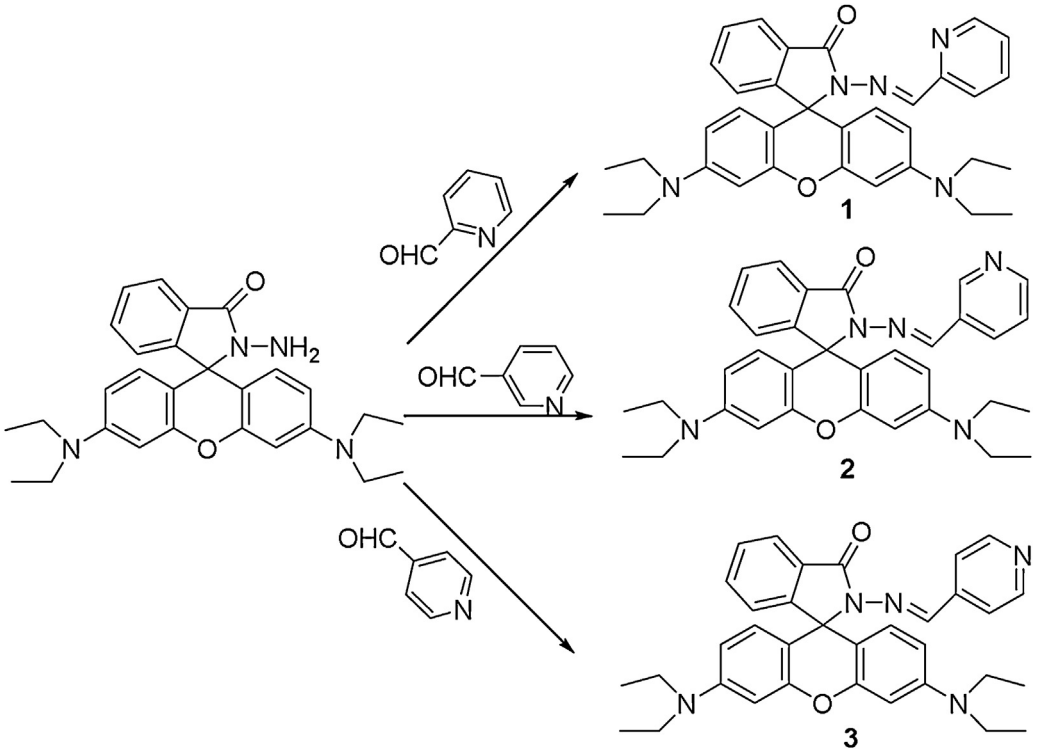
Three isomers of rhodamine derivative, *ortho*-pyridylaldehyde rhodamine hydrazone (**1**), *meta*-pyridylaldehyde rhodamine hydrazone (**2**), and *para*-pyridylaldehyde rhodamine hydrazone (3) were synthesized and characterized. And their recognition abilities for Cu^{2+} were studied by UV–Vis spectra. The result showed that *ortho*-pyridylaldehyde rhodamine hydrazone (**1**) due to having a suitable space coordination structure is a best selective probe for Cu^{2+} over other metal ions in 10 mmol/L HEPES buffer, pH 7.0/CH_3OH (v/v, 1:1), and that it is a quick colorimetric and lagged fluorometric dual-model probe for Cu^{2+}. Because it is a fluorescence turn-on probe, cell experiments show probe can permeate through cell membranes and react to Cu^{2+} within living cells.

1. Introduction

The recognition of ions and molecules by chemosensors is important for medical diagnostics, chemistry, and biotechnology [1–5]. While transition-metal ions are important in many different fields, including catalysis, organometallic reactions, and biochemistry, they can be toxic at high concentrations and disrupt normal cell function [6–10]. Among the essential heavy metal ions in the human body, Cu^{2+} is third in abundance after Fe^{3+} and Zn^{2+} and it plays very important roles in several biological processes [11–14]. Deficiency of copper leads to Menkes disease characterized by sparse and coarse hair, growth failure and deterioration of the nervous system. Exposure to high levels of copper on the other hand leads to Wilson's disease, gastrointestinal disorders and kidney damage. A high level of copper is also implicated as causing serious diseases such as Alzheimer's disease and prion disease [15–17]. Consequently, effective detection of Cu^{2+} in water or physiological samples is of toxicological and environmental concern [18–20]. Copper ions can be detected using several instrumental techniques [21–29]. However, these methods are time-consuming and require expensive instrumentation. Chemosensors are powerful molecular tools that can be used to detect many target molecules, such as biological markers and environmental pollutants [30–37]. To design new chemosensors, mechanisms for recognizing target analytes and the signal reporting units must be investigated [38]. Rhodamine dyes were used extensively to construct fluorescent probes because of their excellent spectroscopic properties, such as long absorption and emission wavelengths, high fluorescence quantum yield, large extinction coefficient, and high stability against light [39,40]. Chemosensors using rhodamine derivatives have been designed based on ion induced changes in the fluorescence intensity [41–45]. These sensors are simple to produce and have high detection sensitivities. In recent years, rhodamine-based probes are always our research scope, and we have ever employed a rhodamine-based derivative (CSR) as a dual chemosensor for detecting Cu^{2+} by UV–visible spectroscopy and VO^{2+} using fluorescence spectra [46]. As continuous work, in this paper, three isomers of rhodamine derivative, *ortho*-pyridylaldehyde rhodamine hydrazone (**1**), *meta*-pyridylaldehyde rhodamine hydrazone (**2**), and *para*-pyridylaldehyde rhodamine hydrazone (**3**) were synthesized and characterized (Scheme 1 and Fig. S1). And their recognition abilities for Cu^{2+} were studied. The result showed that *ortho*-pyridylaldehyde rhodamine hydrazone is a best selective probe for Cu^{2+} over other metal ions, furthermore it is a colorimetric and fluorometric dual-model probe for Cu^{2+}. It was also applied in bioimaging.

* Corresponding author. Tel.: +86 351 7018329; fax: +86 351 7018329.
** Corresponding author. Tel.: +86 351 7011022; fax: +86 351 7011022.
E-mail addresses: huofj@sxu.edu.cn (F. Huo), yincx@sxu.edu.cn (C. Yin).
[1] These authors contributed equally to this work.

0925-4005/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.snb.2013.07.102



Scheme 1. The synthesis of the compounds.

2. Materials and methods

2.1. Materials

4-(2-Hydroxyethyl)-1-piperazineethanesulfonic acid (HEPES) was purchased from Sigma–Aldrich (St. Louis, MO). Sodium hydroxide solution (0.1 mol/L) was added to aqueous HEPES (10 mmol/L) to adjust the pH to 7.0. Metal ions salts were purchased from Shanghai Experiment Reagent Co., Ltd (Shanghai, China). All other chemicals used were of analytical grade.

2.2. Instruments

A pH meter (Mettler Toledo, Switzerland) was used to determine the pH. Ultraviolet–visible (UV–Vis) spectra were recorded on a Cary 50 Bio UV-Vis spectrophotometer. Fluorescence spectra were measured on Cary Eclipse fluorescence spectrophotometer. A PO-120 quartz cuvette (10 mm) was purchased from Shanghai Huamei Experiment Instrument Plants, China. ^{1}H NMR, ^{13}C NMR spectra were recorded on a Bruker AVANCE-300 MHz and 75 MHz NMR spectrometer, respectively (Bruker, Billerica, MA). ESI was measured with an LTQ-MS (Thermo) instrument. The ability of **1** reacting to Cu^{2+} in the living cells was also evaluated by laser confocal fluorescence imaging using a Leica TCS SP5 laser scanning microscope. The yellow single crystals of **1** and **2** were mounted on a glass fiber for data collection, respectively. Cell constants and an orientation matrix for data collection were obtained by least-squares refinement of diffraction data from reflections within 1.90–25.05°, 1.55–25.05°, using a Bruker SMART APEX CCD automatic diffractometer. Data were collected at 296 K using Mo Kα radiation (λ = 0.710713 Å) and the ω-scan technique, and corrected for the Lorentz and polarization effects (SADABS) [47]. The structures were solved by direct methods (SHELX97) [48], and subsequent difference Fourier maps were inspected and then refined in *F*2 using a full-matrix least-squares procedure and anisotropic displacement parameters.

2.3. Preparation of *1*–*3*

The synthesis of compounds **1**–**3** are summarized in Scheme 1. They were synthesized by a one-step reaction between rhodamine hydrazine and either of picolinaldehyde (for **1**), nicotinaldehyde (for **2**) and isonicotinaldehyde (for **3**) in methanol containing acetic acid. 0.214 g (2 mmol) picolinaldehyde (for **1**), 0.214 g nicotinaldehyde (for **2**) or 0.214 g (2 mmol) isonicotinaldehyde (for **3**) were added to 0.456 g (1 mmol) of rhodamine hydrazine dissolved in 20 mL of methanol and the reaction solution refluxed in an oil bath for 2 h. A white (**1**), pink (**2**) and purple (**3**) solid appeared was then filtered from each solution. Each crude product was recrystallized in CH_3OH and petroleum ether (v/v, 1/1) to give *ortho*-pyridylaldehyde rhodamine hydrazone (**1**), or *meta*-pyridylaldehyde rhodamine hydrazone (**2**), or *para*- pyridylaldehyde rhodamine hydrazone (**3**) as a white (**1**), pink (**2**) and purple (**3**) powder in 70%, 66% and 55% yields, respectively. An H_2O/CH_3OH solution containing the product was allowed to evaporate slowly at room temperature for several days, and the white and pink crystals (**1** and **2**) that subsequently formed were suitable for X-ray crystallography formed. However, after several attempts, we still cannot obtain good single crystals for **3**.

1: ^{1}H NMR (300 MHz, 25 °C, DMSO-d_6): δ 8.47 (d, 2H), 8.38 (s, N=C–H, 1H), 8.02 (t, 2H), 7.62 (t, 1H), 7.47 (m, 2H), 7.13 (t, 2H), 6.56 (d, 2H), 6.45 (s, 2H), 6.24 (d, 2H), 3.30 (q, 8H), 1.15 (t, 12H,); ^{13}C NMR (75 MHz, DMSO-d_6): δ 166.2, 155.4, 153.6, 149.7, 146.6, 136.8, 134.5, 129.0, 128.3, 124.4, 121.3, 108.7, 106.3, 99.0, 66.5, 45.0, 13.4; ESI-MS *m/z* 546.25 [**1**+H]$^+$; Elemental analysis (calcd. %) for $C_{34}H_{35}N_5O_2$: C, 74.84; H, 6.47; N, 12.83; Found: C, 74.80; H, 6.44, N, 12.75; Crystal data for $C_{34}H_{35}N_5O_2$: crystal size: 0.30 × 0.20 × 0.20, monoclinic, space group $P2_{(1)}/c$ (No. 14). a = 9.507(3) Å, b = 26.137(7) Å, c = 12.113(3) Å, β = 103.856, V = 2922.3(14) Å^3, Z = 4, T = 296 K, θ_{max} = 25.05°, 16 397 reflections measured, 5172 unique (R_{int} = 0.1064). Final residual for 375 parameters and 5172 reflections with $I > 2\sigma(I)$: R_1 = 0.0750, wR_2 = 0.2494 and GOF = 0.991 (Fig. S1).