Tetrahedron Letters 57 (2016) 4898–4904

Contents lists available at ScienceDirect

Tetrahedron Letters

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

A chromone-derived Schiff-base as Al^{3+} "turn-on" fluorescent probe based on photoinduced electron-transfer (PET) and C=N isomerization

Chao-rui Li [a], Si-liang Li [a,b], Zheng-yin Yang [a,*]

[a] College of Chemistry and Chemical Engineering, State Key Laboratory of Applied Organic Chemistry, Lanzhou University, Lanzhou 730000, PR China
[b] School of Petrochemical Engineering, Lanzhou University of Technology, Lanzhou 730050, PR China

ARTICLE INFO

Article history:
Received 13 June 2016
Revised 10 September 2016
Accepted 18 September 2016
Available online 21 September 2016

Keywords:
Chromone
Fluorescent probe
Aluminum ion
Selectivity
Sensitivity

ABSTRACT

In this study, a novel chromone-derived Schiff-base ligand which was called bis(6-hydroxychromone-3-methylidene)-*o*-phenylenediimine (**1**) was designed, synthesized, and evaluated as an Al^{3+} "turn on" fluorescent probe. This probe **1** showed good selectivity and high sensitivity towards Al^{3+} in the presence of most metal ions, and a remarkable enhancement by about 30.91-fold in fluorescence emission intensity at 459 nm was observed with addition of 1 equiv of Al^{3+}, which was attributed to the inhibition of photoinduced electron-transfer (PET) phenomenon and C=N isomerization process at the excited state. Moreover, the fluorescence response of **1** to Al^{3+} was nearly completed within 10 min. Thus, this probe **1** could be utilized for sensing and monitoring Al^{3+} in environmental and biological systems for real-time detection.

Introduction

Aluminum, being the third most abundant of all elements and the most abundant metallic element (approximately 8.3% by weight) in the earth's crust,[1,2] is the most widely existing metal in the environment from the origin of acidic rain and human activities.[3,4] It has been extensively utilized in food additives,[5] water purification,[6] clinical drugs,[7] and packing materials.[8] As a non-essential metal ion for the proper functioning of human body, the wide distribution of Al^{3+} in the air, water, and soil makes people exposed to it.[9] However, when the accumulation of Al^{3+} reaches high levels in human body, it can cause damage to kidney, immune system, and central nervous system,[10–12] leading to various diseases like Alzheimer's disease,[13] Parkinson's disease,[14] encephalopathy,[15] myopathy,[16] osteoporosis,[17] and even to the risk of breast cancer.[18] According to the World Health Organization (WHO) report, the average daily human intake of aluminum is around 3–10 mg with a weekly tolerable dietary intake at 7 mg/kg of body weight.[19] Additionally, the WHO has limited the concentration of Al^{3+} in drinking water to 7.41 mM.[20] Thus, it is highly desirable and necessary to develop a simple and sensitive method for detecting and controlling Al^{3+} concentrations in environmental systems and biological assays.[21]

Because of its visual simplicity, high sensitivity, inexpensive apparatus, instantaneous response, real-time detection, and non-destructive properties compared to traditional analytical methods for the detection of metal ions, fluorescence detection has been widely used in enormous fields, such as analytical chemistry,[22] environmental biology,[23] biochemistry,[24] and medical science.[25] Nevertheless, owing to the poor coordination ability, strong hydration ability, and lack of spectroscopic properties of Al^{3+}, it is more difficult to develop fluorescent probes for sensing Al^{3+} compared with recognizing transition metal ions.[26–28] As a hard acid, Al^{3+} prefers to coordinate with hard-base donor sites like N and O atom.[29,30] Moreover, Schiff-bases are well known as hard bases which can provide nitrogen-oxygen-rich coordination environments for Al^{3+}.[31,32] Therefore, Schiff-bases can be designed and synthesized as Al^{3+} fluorescent probes.[33–35]

Owing to their excellent spectroscopic and pharmacological properties, chromone-based compounds have been widely applied in antitumoral agents, cardio cerebrovascular drugs, and fluorophores.[36] In recent years, there have been a great many successful fluorescent probes which are developed for sensing various metal ions based on photoinduced electron-transfer (PET),[37] intramolecular charge transfer (ICT),[38] fluorescence resonance energy transfer (FRET),[39] excited state intramolecular proton transfer (ESIPT),[40] and excimer mechanism,[41] but the ones based on the mechanism of C=N isomerization are relatively few.[42] Bearing these in mind, we have designed and synthesized

* Corresponding author. Tel.: +86 931 8913515; fax: +86 931 8912582.
E-mail address: yangzy@lzu.edu.cn (Z.-y. Yang).

http://dx.doi.org/10.1016/j.tetlet.2016.09.058
0040-4039/

a chromone-derived Schiff-base ligand called bis(6-hydroxy-chromone-3-methylidene)-*o*-phenylenediimine (**1**) that was evaluated as an Al^{3+} fluorescent probe based on PET phenomenon and C=N isomerization mechanism (Scheme 1). On a basis of the experimental results, it was found that this fluorescent probe **1** displayed good selectivity and high sensitivity towards Al^{3+} over other common environmentally and biologically important metal ions, and a significant enhancement in fluorescence emission intensity at 459 nm with a slight blue-shift was observed in the presence of Al^{3+}. Hence, this probe **1** could be utilized for detecting and recognizing Al^{3+} in the presence of most metal ions in the environment.

Experimental

Materials

Hydroquinone, acetic anhydride, concentrated sulfuric acid, aluminum chloride, phosphorus oxychloride, *o*-phenylenediamine, absolute ethanol, *N*,*N*-dimethyl formamide (DMF), dimethyl sulfoxide (DMSO), and cationic salts such as $Al(NO_3)_3$, $Ba(OAc)_2$, $Ca(NO_3)_2$, $Cd(OAc)_2$, $Co(OAc)_2$, $Cr(NO_3)_3$, $Cu(NO_3)_2$, $Fe(NO_3)_2$, $Fe(NO_3)_3$, K(OAc), $Mg(NO_3)_2$, $Mn(NO_3)_2$, $NaClO_4$, $Ni(NO_3)_2$, $Pb(OAc)_2$, and $Zn(NO_3)_2$ were obtained from commercial suppliers, and used as received without further purification. Stock solution of compound **1** (10 mM) was prepared in dimethyl sulfoxide (DMSO). Stock solutions (10 mM) of the salts of Al^{3+}, Ba^{2+}, Ca^{2+}, Cd^{2+}, Co^{2+}, Cr^{3+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, K^+, Mg^{2+}, Mn^{2+}, Na^+, Ni^{2+}, Pb^{2+}, and Zn^{2+} in absolute ethanol were also prepared. Distilled water was used throughout all experiments.

Apparatus

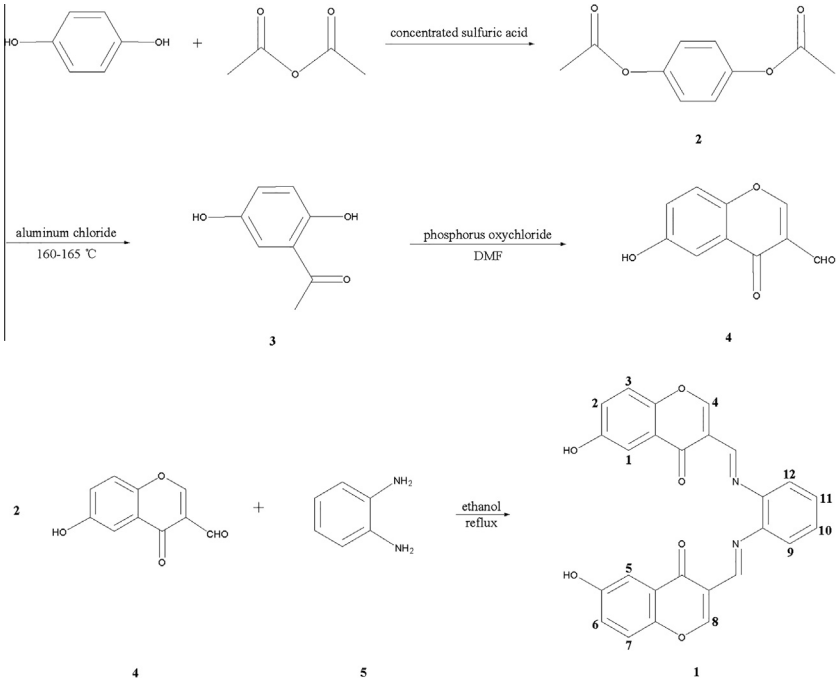
^1H NMR spectra and ^{13}C NMR spectra were recorded on the JNM-ECS instruments at 400 MHz and 100 MHz using TMS (tetramethylsilane) as an internal standard and DMSO-d_6 as a solvent. Mass spectra were obtained on high resolution mass spectrometer (LTQ-Obitrap-ETD) in ethanol. Elemental analyses were performed using a VarioEL Cube V1.2.1 analyzer. UV–vis absorption spectra were collected on a Shimadzu UV-240 spectrophotometer at 298 K. Fluorescence measurements were performed on a Hitachi RF-5301 fluorimeter equipped with quartz cuvettes of 1 cm path length at 298 K. Melting points were determined on a Beijing XT4-100x microscopic melting point apparatus without correction.

Synthesis

Hydroquinone diacetate (**2**), acetylquinol (**3**) and 6-hydroxy-3-formylchromone (**4**) were synthesized according to the methods reported.[43] The synthetic route of compound **1** was shown in Scheme 1.

Synthesis of compound 1 (bis(6-hydroxychromone-3-methylidene)-*o*-phenylenediimine)

A solution of *o*-phenylenediamine (**5**) (0.108 g, 1 mmol) in absolute ethanol (20 mL) was added dropwise to another solution containing 6-hydroxy-3-formylchromone (**4**) (0.380 g, 2 mmol) in absolute ethanol (30 mL) under stirring. The mixture was refluxed for 24 h under stirring, during which time an orange yellow solid was separated out from the solution. After the reaction was completed, the reaction mixture was cooled to room temperature. Then the solid was filtered under reduced pressure, washing five times with absolute ethanol (10 mL). The obtained crude product was recrystallized from absolute ethanol (30 mL) to furnish the desired product **1** as an orange yellow powder (Scheme 1). Yield: 0.10 g (22.12%). Mp at least 300 °C, ^1H NMR (400 MHz, DMSO-d_6) (Fig. S1): δ (ppm): 12.50 (s, 1H, –OH), 10.05 (s, 1H, –OH), 9.28 (s, 1H, H_4), 8.41 (s, 1H, H_8), 7.70–7.60 (m, 4H, $H_{9,10,11,12}$), 7.54 (d, 1H, J = 3.2 Hz, H_1), 7.41 (d, 1H, J = 8.0 Hz, H_3), 7.35–7.15 (m, 5H, $H_{2,5,6,7}$, –CH=N–), 5.19 (s, 1H, –CH=N–). ^{13}C NMR (100 MHz, DMSO-d_6) (Fig. S2): δ (ppm): 175.99, 175.16, 158.13, 156.10, 155.99, 155.56, 155.48, 149.97, 146.11, 143.37, 135.91, 125.12, 125.06, 124.51, 124.32, 120.56, 120.46, 120.13, 119.80, 118.29, 116.41, 113.87, 111.65, 108.60, 108.49, 108.06. HRMS (ESI) (Fig. S3): m/z $[M+H^+]^+$ calcd 453.4024, found 453.1076; $[M+Na^+]^+$



Scheme 1. Synthetic route of compound **1**.