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## Selective fluorescence turn-on of a prefluorescent azomethine with Zn<sup>2+</sup>

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### Introduction

Azomethine bonds have been incorporated into various areas of chemistry ranging from organic synthesis to functional materials. This is in part owing to the ease with which the bond is formed without the need of stringent reaction conditions. The added advantage of azomethines is that water is the exclusive by-product, making for little- to-no product purification. The most notable feature of azomethines is their reversible formation. This has been exploited for both protecting functional groups in organic synthesis and modular exchange for constitutional component shuffling of dynamic materials.<sup>1-3</sup> Conversely, the azomethine can be rendered robust and resistant to acid hydrolysis, oxidation, and component shuffling when highly conjugated compounds are formed.<sup>4</sup>

We previously made robust azomethines prepared from heterocycles. These compounds exhibited functional materials-like properties including reversible oxidation, electrochromism, and halochromism.<sup>5-7</sup> Although azomethines with opto-electronic properties suitable for use in organic electronic devices are possible, fluorescent azomethines remain elusive.<sup>8,9</sup> In fact, conjugated azomethines do not fluoresce.<sup>10-14</sup> Despite many efforts, only recently have fluorescent azomethines at room temperature been possible. This was achieved by incorporating steric elements into the azomethine compound that suppressed the fluorescence quenching modes occurring by bond-rotation.<sup>15</sup>

### ABSTRACT

A prefluorescent conjugated azomethine (4) was prepared by condensing 8-hydroxyquinoline-5-carbaldehyde with 2-amine thiophene. The fluorescence of the azomethine was guenched in organic solvents including dichloromethane, methanol, DMSO, and DMF. However, the fluorescence of 4 was selectively revived in the presence of zinc and an absolute quantum yield  $\Phi_{\rm fl}$  = 0.15 was measured.

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With our knowledge of azomethine fluorescence deactivation modes, we set forth to prepare an azomethine whose fluorescence could be switched-on at room temperature in the presence of a specific trigger. This would be of interest for selective fluorometric sensors. Since azomethines are known as efficient fluorescence quenchers, a fluorescent azomethine would be possible providing that the fluorophore to which it is connected is highly fluorescent. 8-Hydroxyguinoline (1, Chart 1) is an ideal prefluorescent fluorophore for preparing such an azomethine. This is because its fluorescence is deactivated by excited state intramolecular proton transfer (ESIPT).<sup>16</sup> This deactivation mode can be suppressed with metal coordination, resulting in its fluorescence being switchedon. Fluorescence quantum yields ( $\Phi_{\rm fl}$ ) >0.1 for **1** are possible contingent on the metal.<sup>17</sup> The azomethine **4** was subsequently prepared and investigated as a prefluorescent compound whose fluorescence could be selectively triggered in the presence of zinc.

### **Results and discussion**

Azomethine 4 was targeted because no such derivative was previously prepared. Also, few azomethines have been prepared from the hydroxyquinoline aldehyde **2** and their photophysical properties have not been investigated.<sup>18,19</sup> Both the required aldehyde and amine precursors were prepared according to known methods.<sup>18,20</sup> The desired **4** was obtained by refluxing stoichiometric amounts of the complementary aldehyde (2) and amine (3) in absolute ethanol overnight in the presence of a catalytic amount of trifluoroacetic acid. The desired product precipitated upon cooling the reaction mixture and it was subsequently purified by filtering and washing with cold ethanol.



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Chart 1. Compounds examined.

# Table 1 Spectroscopic properties of 8-hydroxyquinoline derivatives measured in dichloromethane

Compound	$arPhi_{ m fl}{}^{ m a}$	$\lambda_{abs}$ (nm)	$\lambda_{\rm fl}$ (nm)
1	0.10	309	496
$Zn(1)_2$	0.20	379	494
2	0.19	325	480
$Zn(2)_2$	0.45	400	510
4	< 0.01	390	500
$Zn(4)_2$	0.15	446	510

 $^a$  Absolute quantum yield measured with an integrating sphere by exciting at  $\lambda_{\rm max}.$ 

The fluorescence of **4** was measured in various polar protic and aprotic solvents including DMF, DMSO, dichloromethane, acetonitrile, and methanol. The photophysical investigation showed that **4** did not fluoresce ( $\Phi_{\rm fl}$  <0.01) regardless of the solvent, as seen in Table 1. This is not surprising since the azomethine bond is known to efficiently quench the singlet excited state combined with the known ESIPT excited state deactivation of hydroxyquinoline.<sup>11–14,20–24,16,25,26</sup> The higher  $\Phi_{\rm fl}$  of both **1** and **2** relative to **4** confirm that the azomethine bond efficiently quenches any residual hydroxyquinoline fluorescence that is not deactivated by ESIPT.

Zinc was selected for triggering the fluorescence of the hydroxyquinoline derivatives because it does not undergo MLCT with the ligands.<sup>27</sup> Therefore, the fluorescence exclusively from the ligand can be observed when selectively exciting the hydroxyquinoline. As seen in Table 1, the  $\Phi_{\rm fl}$  of **1**, **2**, and **4** significantly increased in the presence of zinc. In fact, the emission of both 1 and 2 doubled with the addition of zinc. Similarly, the quenched fluorescence of 4 was switched-on with zinc. It is noteworthy that the  $\Phi_{\rm fl}$  are absolute values measured with an integrating sphere. The fluorescence quantum yields therefore are accurate and are independent of a reference actinometer. The latter normally limits the excitation and emission wavelengths in addition to the magnitude of fluorescence that can be used for  $\Phi_{\rm fl}$  measurements. The fluorescence enhancement with metal coordination is further evident from the photographs in the inset of Figure 1. Interestingly, no absolute quantum yields have previously been reported for such compounds.

The fluorescence enhancement of **4** with the addition of zinc is evident from Figure 1. The fluorescence increased with the addition of zinc with the maximum fluorescence being observed with 0.5 equiv of the divalent cation. This provides indirect evidence that metal coordination occurs via the hydroxyquinoline moieties and not via the azomethine bond. Further evidence for the  $ZnL_2$ complex is had from the NMR spectra (see Supplementary data).

Although fluorescence is a more sensitive technique than absorbance, the stoichiometry cannot be accurately determined by this method because of changes in the absorbance of **4** with zinc addition. The zinc/hydroxyquinoline stoichiometry was therefore quantitatively determined from absorbance measurements. This



**Figure 1.** Top: fluorescence increase of **4** with the addition of 0–2 equiv of zinc acetate in dichloromethane. Bottom: fluorescence increase of **4** monitored at 498 nm in dichloromethane with the addition of zinc acetate. Inset: photographs of **1** (A), **2** (B), and **4** (C) without (left) and with zinc (right) in dichloromethane irradiated with a UV lamp.



**Figure 2.** Change in absorbance of **4** in dichloromethane with increasing amounts of zinc acetate ranging from 0 to 1 equiv. Inset: Job plot of **4** with various mole fractions of zinc acetate measured in dichloromethane and monitored at 490 nm.

was possible because significant changes in the absorbance occurred with the addition of zinc, as seen in Figure 2. In fact, the Zn/**4** complex absorbs at 450 nm while **4** absorbs at 390 nm. A 2:1 **4**/zinc stoichiometry was derived from the Job plot in the inset of Figure 2. Furthermore, the isobestic point observed in Figure 2 confirms the interdependence of the two species such that **4** is converted directly to the  $Zn(\mathbf{4})_2$  without passing through another intermediate.



Figure 3. Absorbance (top panels) and fluorescence (bottom panels) pictures of 2 (A) and 4 (B) in dichloromethane with various divalent metals. The fluorescence pictures were taken by irradiating the samples with a UV lamp. From left to right: Mg<sup>2+</sup>, Al<sup>2+</sup>, Fe<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Cu<sup>2+</sup>, Cd<sup>2+</sup>, Zn<sup>2+</sup>, Hg<sup>2+</sup>.

The fluorescence turn-on was further investigated with various divalent metals. As seen in Figure 3, the fluorescence of 2 could be triggered by Mg<sup>2+</sup>, Al<sup>2+</sup>, Zn<sup>2+</sup>, Cd<sup>2+</sup>, Hg<sup>2+</sup> and Pb<sup>2+</sup>. Conversely, the fluorescence of **4** could selectively be turned-on with Zn<sup>2+</sup>and to a certain degree with Cd<sup>2+</sup> at room temperature. Coordination of 4 with various metals also caused bathochromic shifts in the absorbance relative to the native 4.

### Conclusion

Room temperature fluorescence of a conjugated thiophenehydroxyquinoline azomethine was found. The fluorescence was selectively triggered by metal coordination of the hydroxyquinoline moiety with Zn<sup>2+</sup>. The absolute fluorescence quantum yield of the  $Zn(4)_2$  complex was 15% in solution and represents the first example of measurable fluorescence of conjugated azomethines at room temperature. The selective fluorescence triggered with zinc makes the azomethine an interesting fluorescent sensor for potential use in biological systems, where zinc plays a major role in many biochemical processes. Tailoring the fluorescence turn-on towards different cations in addition to modulating the emission wavelength is currently being pursued.

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#### Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2011.06.003.

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