



Dansyl-styrylquinoline conjugate as divalent iron sensor

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ABSTRACT

Synthesis and photophysical studies of a simple and efficient dansyl-styrylquinoline conjugate (DansSQ) which shows excellent selectivity towards Fe²⁺ over other transition metal ions including Fe³⁺ is described. The fluorescent emission of DansSQ at 450 nm was enhanced upon addition of Fe²⁺ in the presence of common interfering metal ions in background. The studies suggest that DansSQ could be used as fluorescent sensor for Fe²⁺.

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Selective detection of metal ions is of fundamental importance in the broad areas of chemistry and biology.¹ Significant advances in the field of fluorescence spectroscopy in this regard has been made particularly due to its several advantages like easy detection, high sensitivity and tunability.² This has been made possible by the progress made in the design and development of fluoroionophores consisting of small molecules with inherent properties of selective binding and sensing of physiologically and environmentally relevant cations.³ Iron, present in both Fe(II) and Fe(III) oxidation states, plays an important role in biology and is a vital element for the survival of all living organisms.⁴ Its presence is essential for a number of vital cell functions like oxygen metabolism,⁵ electron transfer processes,⁶ and formation of DNA and RNA to mention a few.⁷

Compared to numerous reports available in literature that have explored the fluorescence sensing of main group and transition metal ions such as K⁺, Na⁺, Li⁺, Mg²⁺, Ca²⁺, Zn²⁺, Cu²⁺, Hg²⁺, etc., specific examples of fluorescent sensors for the detection of iron ions are less. Further, examples of fluorophores that show enhanced fluorescence in the presence of Fe ions are even more scarce due to paramagnetism of Fe(II) and Fe(III) ions causing quenching of the fluorescence.⁸ Successful fluorescent Fe(III) sensor designs are based on complexation by covalently linked fluorescent dyes, ionizable chelates, and macrocycles with polydentate binding sites.⁹ A typical example of such a sensor molecule consists of a mixed donor atom (N, S, O) macrocycle as receptor unit and 1,3,5-triarylpyrazoline or boron dipyrromethene as signaling units reported by Bricks et al.¹⁰ A rhodamine 6G based sensor molecule was also

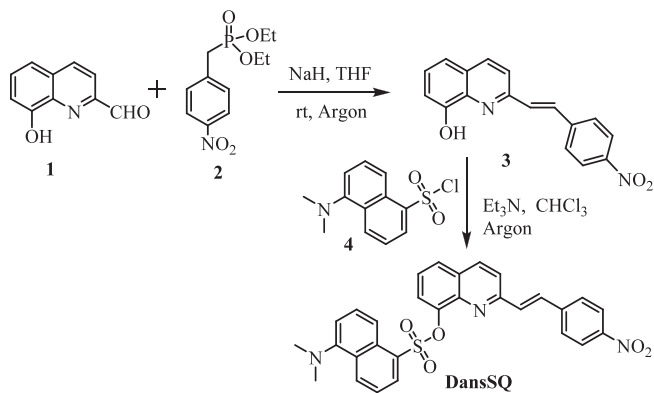
shown to have enhanced fluorescence behavior selective to Fe(III).^{9a} Among iron sensors, it is noteworthy to mention the highly selective and sensitive inorganic/organic hybrid polymer system which exhibited turn on fluorescence for Fe²⁺ ions.¹¹

To be of considerable practical application, organic receptors that evoke optical or electrochemical response on binding with a cation/anion should not only have the inherent property of selective sensing of the analyte among a large number of species that co-exist but also be easily accessible by simple synthetic routes. 8-Hydroxyquinoline is an efficient chelator for cations, and one of the best reagents used as complexing agent after EDTA.¹² It has been employed for OLED materials,¹³ sensitizing lanthanides,¹⁴ solvent extraction,¹⁵ etc. 8-Hydroxy quinoline based fluorescent chemosensors have received increasing interest in recent years by virtue of their high fluorescent properties and ease of modification.¹⁶

Peng et al. have reported a series of 5-dialkylaminomethyl-8-hydroxyquinoline dansylates which exhibited selective quenching of fluorescence in the presence of Fe³⁺. Hydroxyquinoline dansylates as such are highly fluorescent molecules like alkoxy quinolines and upon addition of metal ions the fluorescence is quenched due to an efficient PET process.¹⁷ We in our laboratory have shown that 8-methoxyquinoline with 4-nitrostyryl substituent at the 2-position is a non-fluorescent molecule due to an efficient intramolecular charge transfer process (ICT) upon excitation. With the idea of designing a fluorescent 'turn on sensor' for iron ion, we decided to synthesize a dansyl-styrylquinoline conjugate, since sulphoxide oxygen is known to have an affinity towards iron ions.¹⁸ The results of our investigations are the subject matter of this letter.

The synthesis of the chemosensor dansyl-styrylquinoline (DansSQ) was carried out as outlined in Scheme 1. The quinoline

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Scheme 1. Synthesis of receptor DansSQ.

carbaldehyde **1** was synthesized as reported.¹⁹ Wittig-Horner reaction of **1** with diethyl 4-nitrobenzyl phosphonate in the presence of NaH yielded 4-nitrostyryl quinoline-8-ol **3**. Subsequent reaction of **3** with dansyl chloride **4** in dry CHCl₃ with Et₃N as base yielded the product in 35% yield. The product DansSQ was characterized by analytical and spectral techniques.²⁰ The UV–vis absorption spectrum of the compound showed two broad bands at 352 nm ($\epsilon = 1.8 \times 10^4 \text{ M}^{-1} \text{ cm}^{-1}$) and 256 nm ($\epsilon = 2.12 \times 10^4 \text{ M}^{-1} \text{ cm}^{-1}$), corresponding to the π – π^* transitions of the quinoline core. To obtain insight into the binding properties of DansSQ towards various metal ions, we initiated our studies with Fe³⁺ and Fe²⁺ ions followed by metal ions like Mn²⁺, Co²⁺, Ni²⁺, Cu²⁺, Zn²⁺, Hg²⁺, Ag⁺, Pb²⁺, Cd²⁺, Na⁺, K⁺, Ca²⁺ and Al³⁺. Among all the metal ions tested, only Fe²⁺ elicited marked changes in the absorption spectrum of DansSQ.

Upon addition of Fe²⁺ (0–5.0 equiv) the absorption band at 256 nm decreased in intensity and the band at 352 nm underwent a bathochromic shift of 22 nm which tailed out up to 450 nm as shown in Figure 1. Appearance of a new absorption band at 302 nm, which increased in intensity upon addition of Fe²⁺ ions and well defined isosbetic points at 272 nm, 319 nm and 352 nm indicate formation of an active Fe²⁺–DansSQ complex.

The fluorescence spectrum of DansSQ ($\lambda_{\text{exc}} = 352$) in acetonitrile (ACN) as well as ACN/H₂O (9:1, v/v) showed highly structured but very weak emission band centered at 450 nm. Upon addition of increasing amounts of Fe²⁺ to a solution of DansSQ, the fluorescent intensity was remarkably enhanced (15-fold) as shown in Figure 2. In acetonitrile and partial acetonitrile solutions, the low quantum yield (Φ_F) of DansSQ is attributed by the ICT from quinoline nitro-

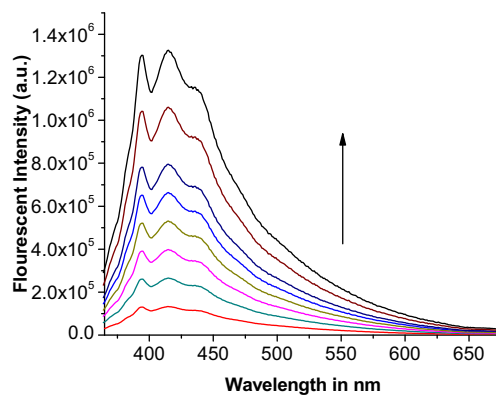


Figure 2. Fluorescence spectra ($\lambda_{\text{exc}} = 352$ nm) of DansSQ (6×10^{-6} M) in acetonitrile with increasing amount of Fe²⁺ (2.4×10^{-4} M) ACN–H₂O (9:1, v/v).

gen to nitrostyryl group upon excitation.²¹ On binding with Fe²⁺, the ICT process is disrupted thereby regaining the fluorescence. The origin of fluorescence in DansSQ is due to quinoline core and not due to dansyl chromophore was further proved by recording excitation spectrum and comparing with literature data.²² The quantum yield (Φ_F) of the Fe²⁺–DansSQ complex was found to be 0.075.²³ Cyclic voltametric studies indicate that no electron transfer takes place from Fe²⁺ to the ligand in the complex, as there is no changes were recorded in the cyclic voltammogram of the ligand upon addition of Fe²⁺.

1:1 stoichiometry was confirmed for Fe²⁺ and DansSQ by Job's plot (Fig. 3). The stoichiometry of Fe²⁺/DansSQ complex has also been confirmed by mass spectrometric determination. The FAB mass spectrum of this complex showed signals of m/z 779.30, which can be assigned as signals for [Fe(ClO₄)₂+DansSQ+1]⁺. Association constant (K_a) calculated by Benesi-Hildebrand method was found to be $2.837 \times 10^3 \text{ M}^{-1}$. The detection limit was calculated as three times the standard deviation of the background noise and was found to be 3.6×10^{-6} M in ACN–H₂O (9:1, v/v).²⁴

When 1,10-phenanthroline was added to the solution of DansSQ–Fe²⁺ solution, an immediate reversal of the absorbance peak at 374 nm in the UV–vis spectrum was observed with concomitant formation of a new peak at 510 nm which corresponded to the formation of the orange-red Fe²⁺–1,10-phenanthroline complex.²⁵ This experiment brings forth the reversibility of DansSQ as Fe²⁺ sensor (Fig. 4). Similar observations were noticed during the fluorescence studies, when 1,10-phenanthroline was added to DansSQ–Fe²⁺ complex. Fluorescence response of DansSQ on the

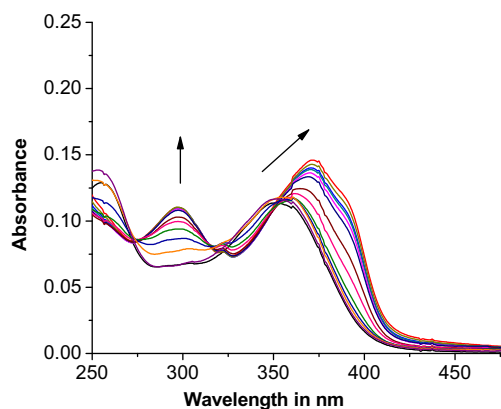


Figure 1. Changes in the absorption spectra of the DansSQ (6×10^{-6} M) with the addition of Fe²⁺ (2.4×10^{-4} M) in ACN–H₂O (9:1, v/v).

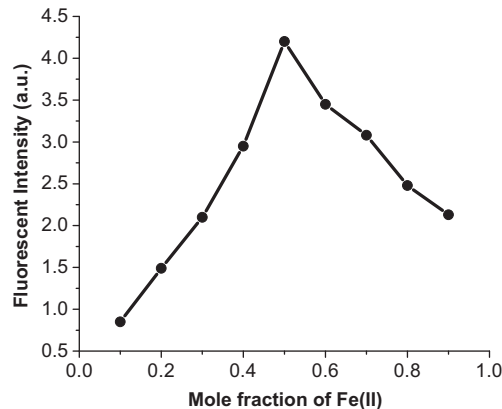


Figure 3. Job's plot of DansSQ (6×10^{-6} M) and Fe²⁺ (6×10^{-6} M), where fluorescent intensity of DansSQ at 450 nm was plotted against the mole fraction of Fe²⁺.

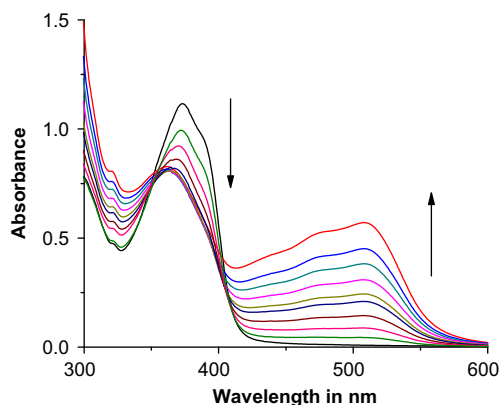


Figure 4. Changes in absorption spectra of Fe^{2+} -DansSQ complex by the addition of 10 equiv of 1,10-phenanthroline (8×10^{-4} M).

addition of other metal ions was also investigated. As shown in Figure 5 only the addition of 5 equiv of Cr^{3+} showed a threefold enhancement in fluorescent intensity.

The fluorescence response of DansSQ towards Fe^{2+} in the presence of 50 equiv each of alkali, alkaline earth and transition metal ions mentioned above were also investigated and it was found that there was no interference of any of these metal ions at the above concentrations (Fig. 6). However, addition of more than 200 equiv of Cu^{2+} , Hg^{2+} , Fe^{3+} or Cr^{3+} was found to cause significant fluorescent enhancement to DansSQ, hampering the selectivity.

Further evidences for metal complexation were obtained from IR spectral studies. In the FTIR spectrum, the medium sized band at 1177 cm^{-1} corresponding to symmetric stretching of S=O bond became fairly weak after coordination with Fe^{2+} (Fig. 7). A broad peak with three shoulders was observed between 1190 cm^{-1} and 1030 cm^{-1} in the Fe^{2+} bound DansSQ complex. Also characteristic stretching of ClO_4^- visible at 622 cm^{-1} further supports the coordination event.²⁶ It can be anticipated that selectivity of DansSQ towards Fe^{2+} arises from the S=O group and the quinoline nitrogen in the vicinity creating in a congenial environment for the complexation event.

In conclusion, we have devised a new fluorogenic chemosensor, by conjugating the well known 8-hydroxyquinoline and dansyl group. The prepared ionophore showed selective and sensitive OFF-ON type fluorescent behaviour and gives a 15-fold fluorescence enhancement upon addition of Fe^{2+} . The chemosensor shows a detection limit which is sufficiently low to allow fluorogenic detection of submillimolar concentrations of Fe^{2+} . The selective

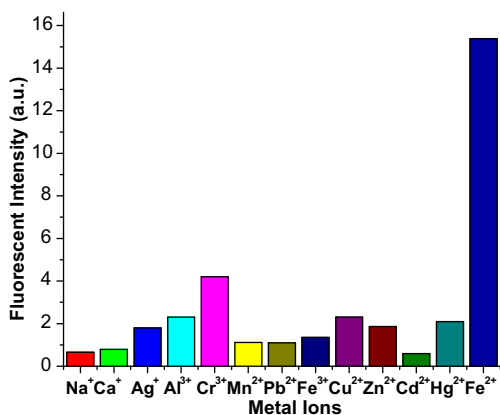


Figure 5. Fluorescent intensity of DansSQ (6×10^{-6} M) in $\text{ACN-H}_2\text{O}$ (9:1, v/v) upon addition of 5 equiv of alkaline and alkaline earth and transition metals.

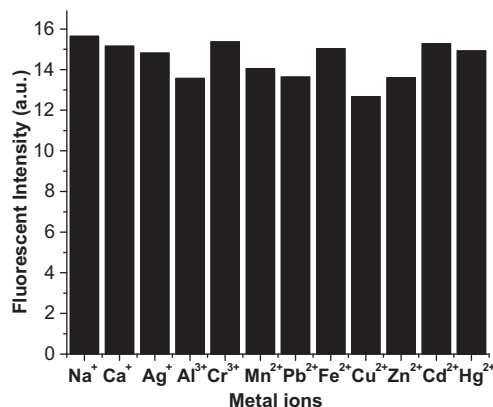


Figure 6. Competitive selectivity of the receptor DansSQ towards Fe^{2+} in the presence of other metals (50 equiv).

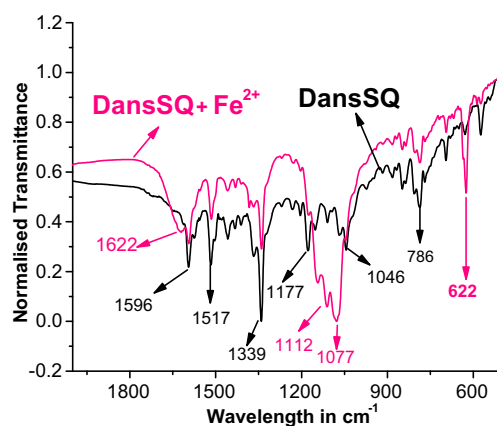


Figure 7. IR spectrum of DansSQ and solid complex of DansSQ- Fe^{2+} in the region $2000\text{--}600 \text{ cm}^{-1}$.

detection of the Fe^{2+} over other bio relevant cations and the possibility of its direct quantification using an unsophisticated fluorescent sensor DansSQ are especially significant. Further studies designed to increase the fluorescent intensity and water solubility are in progress.

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