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Anthracene derivatives bearing thiourea group as fluoride selective fluorescent and colorimetric chemosensors

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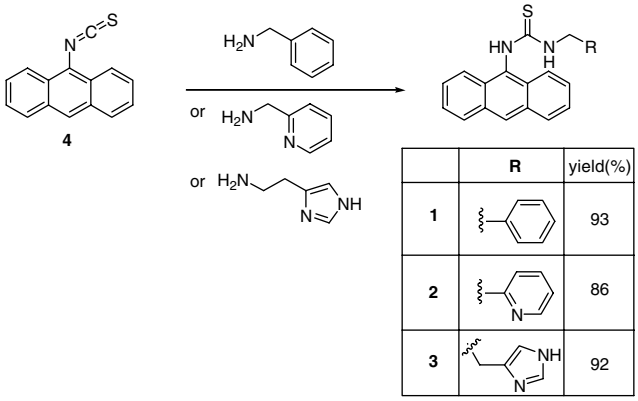
Abstract—New anthracene derivatives bearing thiourea group have been synthesized and characterized including X-ray crystallography. These chemosensors display selective ratiometric changes in their fluorescence spectra upon the addition of fluoride ion.

Considerable efforts have been made to design chemosensors for anions since anions play a fundamental role in a wide range of chemical and biological processes.[1] Sensors based on anion-induced changes in fluorescence appear to be particularly attractive due to the simplicity and high detection limit of fluorescence.[1,2] Particularly, fluoride ions are biologically important anions because of their important role in dental care[3] and in the treatment of osteoporosis,[4] etc.

In this regard, the fluorescent sensing of a fluoride ion has attracted growing attention.[5–7] In most cases, a hydrogen bonding between N–H of urea or pyrrole group and fluoride was used for the recognition. On the other hand, there have been a few reports regarding fluoride ion detection utilizing a unique fluoride–boron interaction.[6] Even though various fluorescent chemosensors for fluoride ion have recently been reported, there has been a paucity of reports of fluoride selective fluorescent chemosensors based on the ratiometric changes.[7] A ratiometric sensor allows a calibration curve, which is independent of the sample conditions, for example, the concentration of the sensor, etc. Furthermore, ratiometric fluorescence measurements can increase the selectivity and the sensitivity of the detection.

Herein, we report anthracene derivatives bearing thiourea group as selective fluorescent chemosensors for fluoride, which display ratiometric changes in their fluorescent spectra upon the addition of fluoride ion. These compounds also display selective colorimetric changes with fluoride ion among the anions we examined (see Scheme 1).

Our synthesis began with anthracen-9-yl isothiocyanate **4**,[8] which was then reacted with benzylamine in chloroform. The crude product was precipitated in chloroform–hexane several times to give analytically pure compound **1** in 93% yield. Compounds **2** and **3** were



	R	yield(%)
1		93
2		86
3		92

Scheme 1. Synthesis of compounds **1**, **2** and **3**.

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synthesized in 86% and 92%, respectively, following a similar procedure.

X-ray crystal structures of **1** and **2** were determined as shown in Figure 1. The X-ray diffraction data for a pale yellow single crystal with $0.01 \times 0.05 \times 0.02\ mm^3$ of compound **1** were collected, and all hydrogen atoms of the molecule were located in the calculated positions. All carbon atoms of the compound **1** were refined isotopically. The crystals **1** and **2** were grown in DMF. There was no interaction (e.g., hydrogen bonding) between DMF and the host compound (Figure 1a). As shown in Figure 1b, the amide hydrogen in compound **2** does not make a hydrogen bond with pyridine nitrogen in its solid state. For the X-ray crystal structure of **3**, the *R* value was not satisfied since X-ray diffraction data were not so good, but we could obtain a well-refined structure of the main anthracene–thiourea–imidazole moiety (Supplementary data).

Figure 2 shows the fluorescence emission changes in compound **1** (3 μM) upon the addition of HSO_4^-, CH_3COO^-, I^-, Br^-, Cl^-, $H_2PO_4^-$ and F^- (100 equiv) in DMSO. The fluorescence spectra were obtained by excitation of the anthracene fluorophore at 368 nm. Both the excitation and emission slits were 5 nm. In the absence of fluoride ion, the maximum fluorescent intensity was observed at 443 nm. As shown in Figure 2, there was a unique change in the emission spectrum upon the addition of fluoride even though similar but lesser change was observed with acetate ion. Upon the addition of the fluoride ion, a new charge transfer peak at 568 nm was observed. As shown in the abstract figure, the blue fluorescence was changed to orange fluorescence upon the addition of fluoride ion. This new peak can be attributed to the intramolecular charge transfer (ICT) process.[5b,7a–c,f–h] Most related papers were

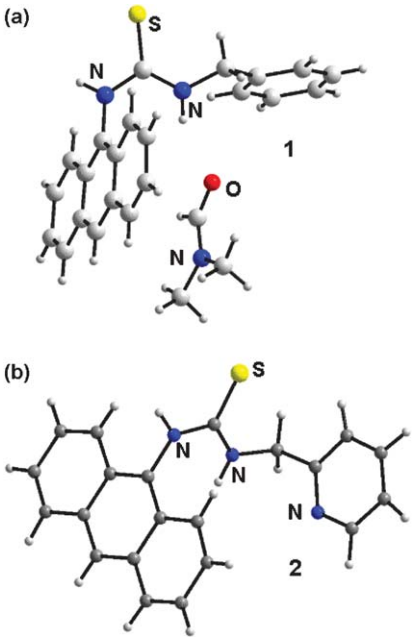

Figure 1. X-ray crystal structures of **1** and **2**.

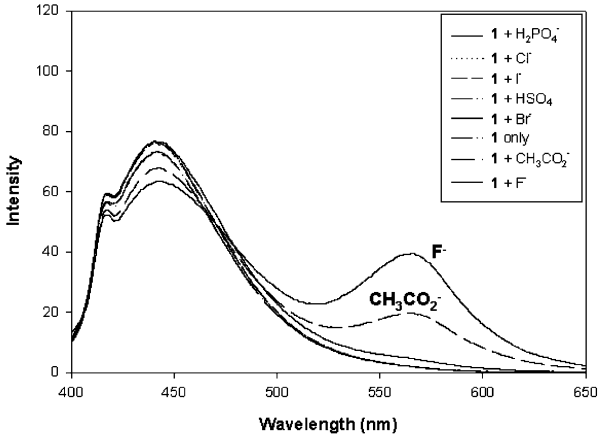

Figure 2. Fluorescence spectra of **1** (3 μM) upon the addition of tetrabutylammonium salts of HSO_4^-, CH_3COO^-, I^-, Br^-, Cl^-, $H_2PO_4^-$ and F^- (100 equiv, 300 μM) in DMSO (excitation at 368 nm).

reported by Nam and Lee et al. in which similar fluorescent changes of a naphthalene derivative bearing two urea groups were observed upon the addition of fluoride ion.[7e,f] In these reports, a distinct peak at 445 nm in the fluorescent spectra was observed while the λ_{max} in the absence of fluoride ion was 379 nm. We also observed that a 1,8-bis(4-nitrophenylurea)anthracene displayed a unique new peak ($\lambda_{max} = 485$ nm) with a red shift of 129 nm upon the addition of fluoride in its UV spectrum.[5b]

Figure 3 explains the fluorescent titration spectra of compound **1** with tetrabutylammonium fluoride in DMSO. As shown in Figure 3, the intensity of a red shifted peak at 568 nm was increased as the amount of fluoride ion was increased. Compounds **2** and **3** displayed similar fluorescent changes with fluoride ion. Figures 4 and 5 explain the fluorescent changes of **2** with various anions and the fluorescent titration spectra of **3** with fluoride ion, respectively. From the fluorescence titration, the association constants of complexes **1**, **2** and **3** were observed to be 2000, 1970 and 2300 M^{-1}, respectively (errors <10%).[9] The association constants were calculated based on the new emission intensities

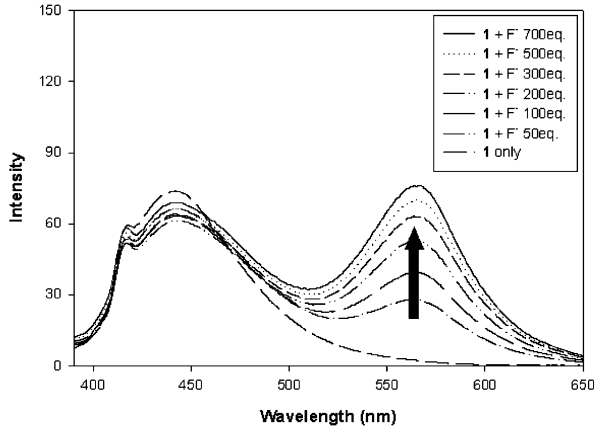

Figure 3. Fluorescent titrations of compound **1** (3 μM) with tetrabutylammonium fluoride in DMSO (excitation at 368 nm).

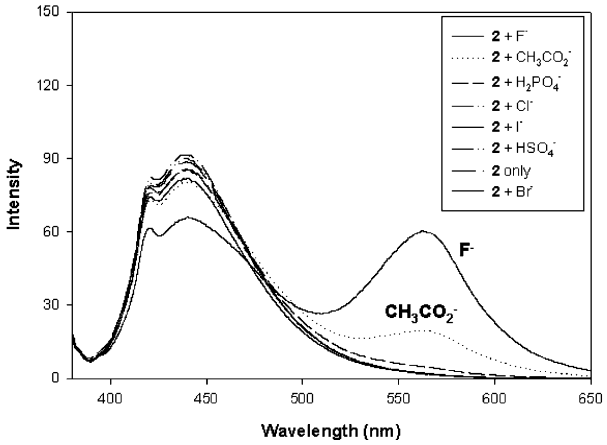

Figure 4. Fluorescence spectra of **2** (3 μM) upon the addition of tetrabutylammonium salts of HSO_4^-, CH_3COO^-, I^-, Br^-, Cl^-, $H_2PO_4^-$ and F^- (100 equiv, 300 μM) in DMSO (excitation at 371 nm).

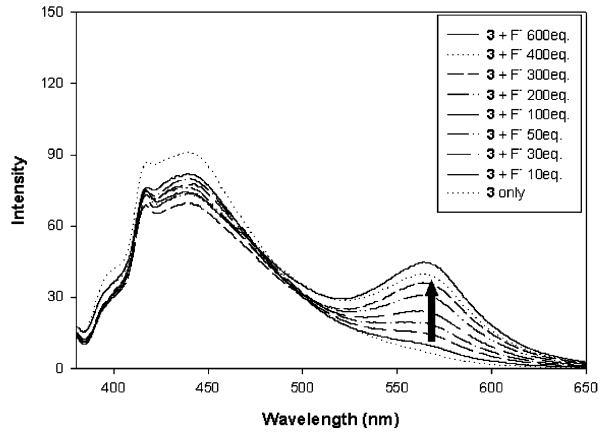

Figure 5. Fluorescent titrations of compound **3** (3 μM) with tetrabutylammonium fluoride in DMSO (excitation at 368 nm).

at around 570 nm. Three different anthracene derivatives display similar selectivities and similar association constants with fluoride ion even though there was a slight increase in the association constant of **3** compared to that of **1**. This can be attributed to the possible additional hydrogen bonding between fluoride and H–N in the imidazole moiety. Unfortunately, we could not observe the ^{1}H NMR evidence of this additional hydrogen bonding of compound **3** with fluoride ion due to the severe broadness of NMR spectra when fluoride ion was added.

As shown in Figure 6, a charge transfer peak was also observed in the UV absorption spectrum of compound **1**. A similar bathochromic shift in an absorption spectrum is explained based on the ICT process between the electron-rich thiourea-bound fluoride ion and the electron-deficient chromophore.[7f] The red shift of fluorescence emission is closely related to the red shift of absorption peak upon the addition of fluoride ion because less excitation energy will induce less emission energy.[7g] Upon excitation of **1** or **2** at around 430 nm, the peak around 570 nm is remarkably enhanced with increasing F^- concentration. We observed that, on the

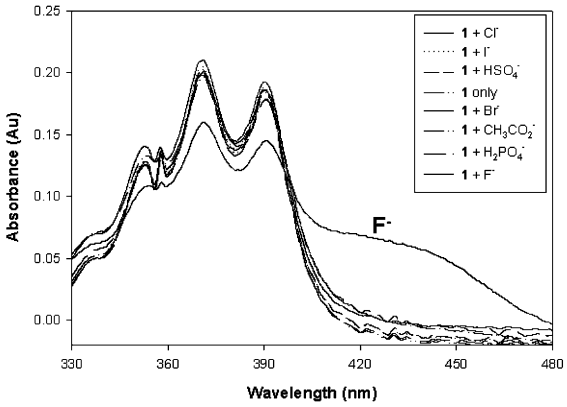

Figure 6. UV spectra of compound **1** (30 μM) upon addition of tetrabutylammonium salts of HSO_4^-, CH_3COO^-, I^-, Br^-, Cl^-, $H_2PO_4^-$ and F^- (100 equiv) in DMSO.

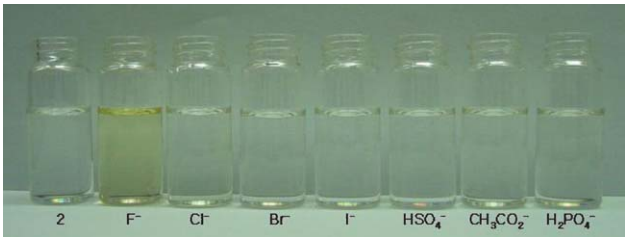

Figure 7. Colour changes compound **2** (30 μM) observed on addition of tetrabutylammonium salts of HSO_4^-, CH_3COO^-, I^-, Br^-, Cl^-, $H_2PO_4^-$ and F^- (100 equiv) in DMSO.

addition of excess anions, the colour of a DMSO solution of **2** turned to yellow only with fluoride ion (Fig. 7).

In conclusion, we synthesized three new anthracene derivatives bearing thiourea group as potential fluorescent and colorimetric chemosensors for fluoride ion. The X-ray crystal structures of compound **1**, **2** and **3** were also determined. These anthracene thiourea derivatives display new peaks at 568 nm in their fluorescent spectra upon the addition of fluoride ion in DMSO.

Acknowledgements

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Supplementary data

Experimental sections including syntheses and characterizations of **1**, **2** and **3**, X-ray crystal structure of **3**, CIF files for **1**, **2** and **3** are available. Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2006.02.147.

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