Anion Recognition by a Simple Colorimetric Benzthiazole-Based Receptor

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A simple colorimetric anion chemosensor based on 2-amino-6-nitrobenzothiazole was synthesized. The addition of tetrabutylammonium (TBA) salts of F^-, CH_3COO^-, and $H_2PO_4^-$ to the solution of receptor **3** caused dramatic and clearly observable color changes from light to dark yellow due to the deprotonation process which is totally different from previously reported receptors based on the same motif. According to the basicity of the anions, the sensitivity of receptor **3** towards various anions decreased in the following order: $CH_3COO^- > F^- > H_2PO_4^-$.

Key Words: Anion sensing, Color change, Deprotonation

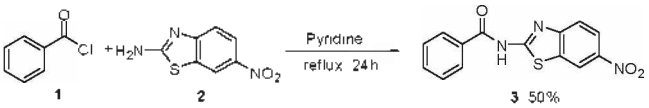
Introduction

The development of chemosensors for anion recognition is rapidly gaining attention in supramolecular chemistry.[1] Colorimetric chemosensors are attractive because they give a direct signal which is easily observed by the naked eye.[2] Most receptors contain NH fragments which act as hydrogen bond donors for the binding of anions such as artificial receptors based on pyrroles, amides, ureas, thioureas, or sulfonamides.[3] Recently, 4-nitrophenyl substituent has been introduced in the structure of the receptors to be as a chromophore fragment for colorimetric signal.[4] The chromophores may contain electron-withdrawing groups that enhance the acidity of the protons of the binding site. Therefore, these acidic protons can be abstracted by the basic anions in the deprotonation process. In some cases, it is difficult to establish a clear difference between a hydrogen bond donor binding process and a deprotonation process. Recently, Jang and co-workers have reported the benzimidazole-based colorimetric chemosensors for binding fluoride and acetate.[5] In this communication, we wish to introduce a novel colorimetric anion chemosensor based on 2-amino-6-nitrobenzothiazole. While this work was in progress, by using the same binding motif, the above authors have reported the benzthiazol-based fluorescent receptor for binding dihydrogen phosphate[6] and more recently it was also reported for binding biotin ester and urea by Ghosh and co-worker.[7] In all above cases, benzthiazol-based receptors are just explored for the binding process. Here, our simple colorimetric mono receptor gave some interesting and different results. The sensing property of our receptor towards various anions was related to the deprotonation process.

Results and Discussion

Receptor **3** was synthesized by the reaction of compounds **1** and **2** in pyridine at 120 °C (Scheme 1). After cooling, the reaction mixture was poured into water and the precipitate was washed with methanol, dichloromethane, and ether to yield a yellow solid product in moderate yield (50%).

The sensing property of receptor **3** was first examined by



Scheme 1. Synthesis of receptor **3**.

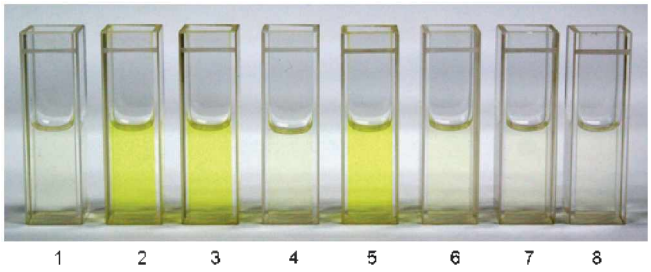


Figure 1. Color changes of receptor **3** (200 μM) observed upon addition of the following 1.0 equiv of guests in CH_3CN: (1) Receptor **3** only, (2) **3** + OAc^-, (3) **3** + $H_2PO_4^-$, (4) **3** + HSO_4^-, (5) **3** + F^-, (6) **3** + Cl^-, (7) **3** + Br^-, and (8) **3** + I^-.

mixing it with various anions in acetonitrile. The color change of receptor **3** from light to dark yellow upon the addition of F^-, OAc^-, and $H_2PO_4^-$ was easily observed by the naked eye even at low concentration. In contrast, receptor **3** remained almost unchanged in color upon the addition of other anions such as Cl^-, Br^-, I^-, and HSO_4^- (Figure 1). Jang and coworkers have reported that the mono receptor based on 2-aminobenzimidazole[5] and 2-aminobenzthiazole[6] did not recognize anions effectively due to the unsuitable size of the cavity of this receptor compared to the same model dipodal receptor. However, our mono receptor **3** showed dramatic color changes with F^-, OAc^-, and $H_2PO_4^-$ as compared to the above mono receptors. We were unable to improve the sensing property of receptor **3** by synthesizing dipodal and tripodal receptors based on 2-amino-6-nitrobenzothiazole due to the low solubility of these receptors in all solvents. The sensitivity of receptor **3** upon the addition of various anions was also supported by the UV-Vis adsorption spectra (Figure 2). When receptor **3** formed the complexes with F^-, OAc^-, and $H_2PO_4^-$, a new peak appeared at 426 nm. However, the absorption spectra did not exhibit

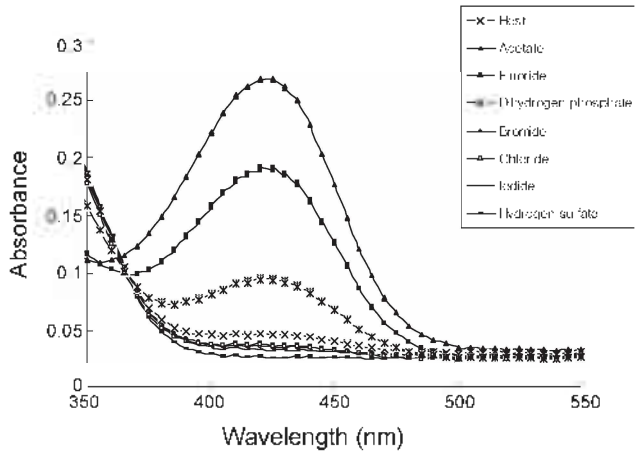


Figure 2. Absorption spectra of receptor **3** (10 μM) upon addition of 1.0 equiv of the TBA salt of various anions in CH_3CN.

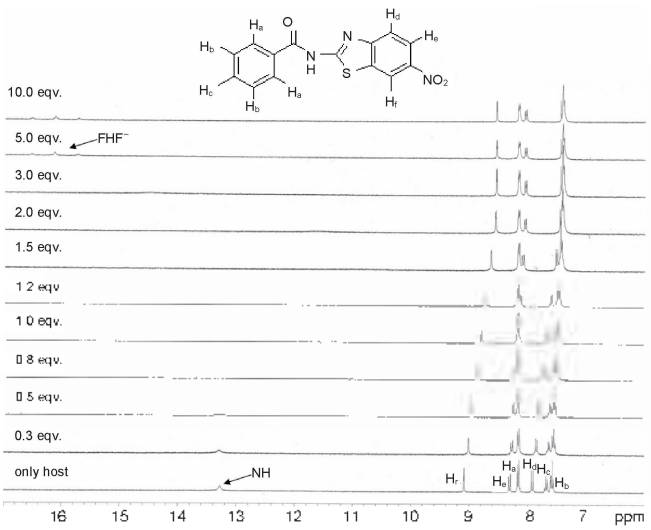


Figure 3. ^{1}H NMR spectra of receptor **3** (4 mM) in DMSO-d_6 upon successive addition of the TBA salt of fluoride.

any changes upon the addition of Cl^-, Br^-, I^- and HSO_4^-. The UV-vis titration data with F^-, OAc^-, and $H_2PO_4^-$ anions are shown in Figures S1-3 (Supplementary data).

The nuclear magnetic resonance (NMR) titration method was used to elucidate the sensing characteristic of receptor **3** with fluoride anion in DMSO-d_6 (Figure 3). Upon the addition of anion fluoride, the H_d, H_c, H_d, H_c, and H_f proton peaks of receptor **3** were shifted to the upfield region while the other proton H_a peak remained almost unchanged. The NH peak of this receptor disappeared and a new triplet peak, attributed to the formation of FHF^-, was observed around 16 ppm.[8] Recently, fluoride anion was reported to be sufficiently basic to deprotonate the NH in colorimetric sensors.[9] The formation of a triplet FHF^- peak suggested the fluoride anion-induced deprotonation of the NH peak of receptor **3**. In addition, the ^{19}F NMR results also supported this deprotonation phenomenon. Upon the addition of 10 equiv. of fluoride anion in DMSO-d_6, the ^{19}F NMR spectrum of receptor **3** showed the

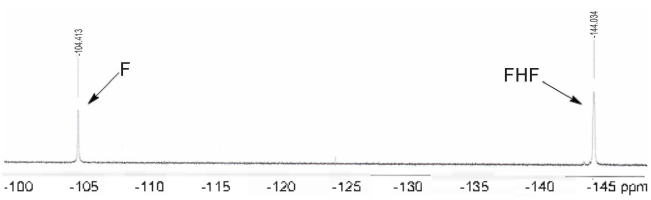


Figure 4. ^{19}F NMR spectra of receptor **3** (4 mM) on the addition of 10 equiv. of the TBA salt of fluoride in DMSO-d_6.

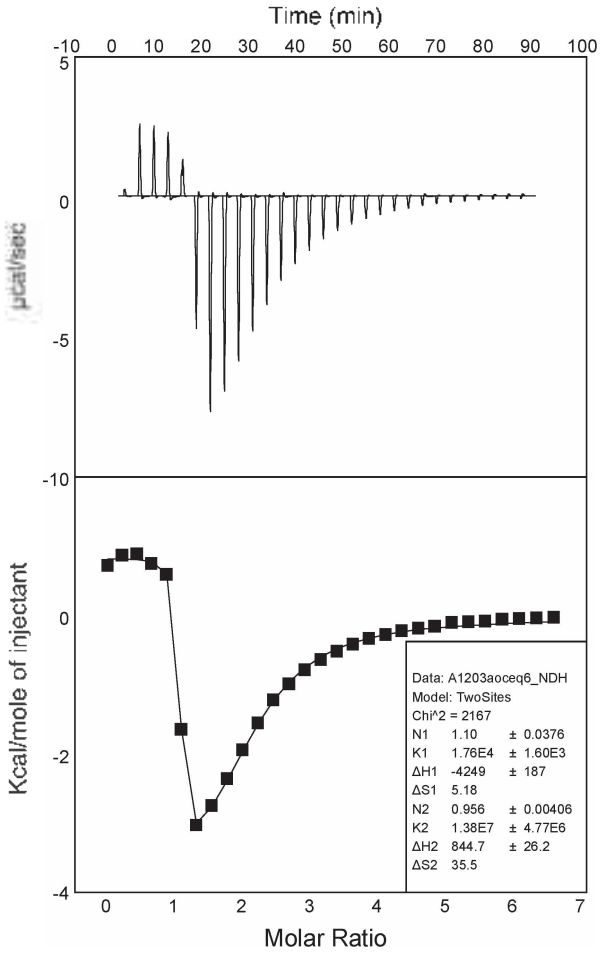


Figure 5. ITC titration data of receptor **3** (0.1 mM) with TBAOAc in CH_3CN at 298 K.

formation of an FHF^- complex peak at −144 ppm (Figure 4).[10] The NMR titration method was also carried out with acetate and dihydrogen phosphate anions (Figures S4 and S5, Supplementary data). A similar effect was observed in the NMR spectrum of receptor **3**: the NH peak disappeared and the other proton peaks were shifted to a similar extent.

For further investigation of the interaction between receptor **3** and various anions, isothermal titration calorimetry (ITC) was used. In all cases, the ITC data (Figure 5 and Figures S6 and S7, Supplementary data) suggested a complex interaction due to the presence of more than one inflection point. Binding and deprotonation processes were involved in tandem as the previous report.[10]

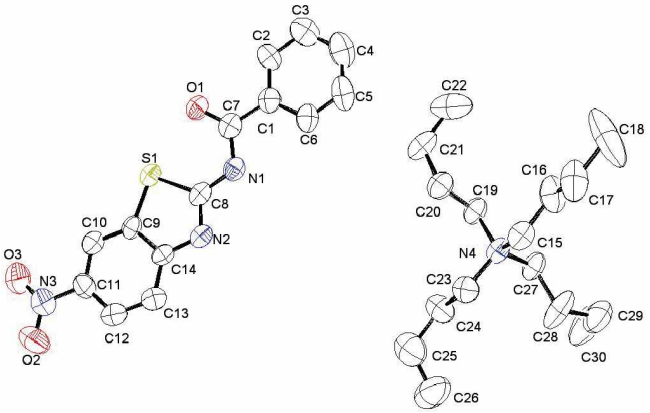


Figure 6. An ORTEP view of the $[Bu_4N]I$ salt.

Table 1. Crystal data and structure refinement for complex salt $[Bu_4N]I$.

Empirical formula	$C_{30}H_{44}N_4O_3S$
Formula weight	540.75
Crystal system	Monoclinic
Space group	Cc
Unit cell dimensions	a = 7.9234(7) Å a = 90°
	b = 25.059(2) Å b = 97.699(2)°
	c = 15.4916(14) Å g = 90°
Goodness-of-fit on F2	0.960
Final R indices [I > 2sigma(I)]	R_1 = 0.0690, wR_2 = 0.1402
R indices (all data)	R_1 = 0.1762, wR_2 = 0.1993
Largest diff. peak and hole	0.234 and -0.252 e.Å^{-3}

In addition, the UV spectra and ITC results showed that the sensitivity of receptor **3** with various anions decreased in the following order: CH_3COO^- > F^- > $H_2PO_4^-$. This order fitted with the basicity of the anions. According to the absorbance in the UV spectra (Figure 2), acetate gave a stronger absorbance change than fluoride and dihydrogen phosphate, respectively. Moreover, the ITC titration curves of acetate, fluoride and dihydrogen phosphate were saturated at 4, 8 and more than 8 equiv. of the corresponding anions (Figure 5 and Figures S6 and S7, Supplementary data).

In the most interesting result, the deprotonation process was clearly revealed by examining the X-ray structure of the complex of receptor **3** and the TBAOAc salt. We obtained a crystal of complex $[Bu_4N]$ and receptor **3** by slowly evaporating a solution of receptor **3** and the excess of $[Bu_4N]OAc$ in CH_3CN. The ORTEP diagram of this complex is shown in Figure 6 and the crystal data are presented in Table 1. The proton at the -NH fragment was clearly deprotonated by acetate anion, thereby affording the negative charge at receptor **3** which interacted with the positive charge of tetrabutylammonium (TBA) to form the observed X-ray complex. In addition, the upfield shift protons in NMR titration were attributed to the shielding of the electrons from the resonance effect of the negative charge at the nitrogen of receptor **3**.

In conclusion, we synthesized a novel simple colorimetric anion chemosensor in moderate yield using 2-amino-6-nitrobenzothiazole motif. The receptor effectively recognized fluoride, acetate, and dihydrogen phosphate anions while remaining unaffected by the addition of other anions such as Cl^-, Br^-, I^- and HSO_4^-. The addition of TBA salts of F^-, AcO^- and $H_2PO_4^-$ to the receptor solution dramatically changed the color from light to dark yellow, which facilitated the direct, naked-eye detection of anions. The colorimetric changes were due to the deprotonation of acidic proton of NH of the receptor by the anions. These results are totally different from previously reported receptors based on the same motif.

Experimental Section

Synthesis of *N*-(6-nitrobenzo[d]thiazol-2-yl)benzamide. A solution of 2-amino-6-nitro-benzothiazole (300 mg, 1.54 mmol) and benzoyl chloride (0.148 mL, 1.28 mmol) in pyridine was stirred at 120 °C for 24 h under argon atmosphere. Upon completion of the reaction, the mixture was cooled to 0 °C, and poured into water. The yellow solid was separated out and washed with methanol, dichloromethane, and ether. Pure product **3** was obtained in 50% yield (192 mg): ^{1}H NMR (300 MHz, DMSO-d_6) δ 13.25 (s, 1H), 9.05 (d, 1H, J = 2.4 Hz), 8.29 (dd, 1H, J = 2.4 Hz, J = 9 Hz), 8.16 (d, 2H, J = 7.1 Hz), 7.89 (d, 1H, J = 9 Hz), 7.65 (t, 1H, J = 7.1 Hz), 7.57 (t, 2H, J = 7.1 Hz); ^{13}C NMR (75MHz, DMSO-d_6) δ 119.4, 120.8, 122.1, 128.8, 129.0, 131.8, 132.6, 133.6, 143.4, 153.6, 164.4, 166.8; ESI MS *m z* 300.045 (M^++H).

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Supplementary Data. UV-Vis titration, ^{1}H NMR titration and ITC titration data of receptor **3** with F^-, AcO^- and $H_2PO_4^-$ can be found.

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