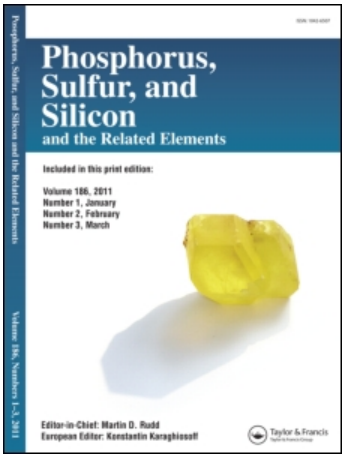

Phosphorus, Sulfur, and Silicon and the Related Elements

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Synthesis and Anion Recognition of Molecular Tweezers Receptors Based on Acyl-Thiourea

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Three title compounds were designed and synthesized in high yields as novel and simple anion receptors. They had a higher selectivity for F^- over AcO^-. The binding properties for anions of the receptors were examined by UV-Vis and ^1H NMR spectroscopy. The spectrographic data indicate that a 1:1 stoichiometry complex is formed between the receptors and the anions through hydrogen bonding interactions in DMSO solution. In addition, these molecular tweezers receptors have more binding points of anions, larger association constant, and better recognition ability. They can be used as better recognition receptors for F^- and CH_3COO^-.

Keywords Anion recognition; Acyl-thiourea; Hydrogen bonds; Molecular tweezers

INTRODUCTION

The sensing and recognition of simple-structure anion receptors have attracted much attention[1–2] because of the important roles of anions not only in biological processes, but also in chemical processes, the possibilities of applying anion receptors in sensors and molecular self-assembly, and even medical or environmental problems.[3–11] Although various receptors containing different functional groups for selective binding of F^- and AcO^- have been reported,[2–16] the anion recognition of the simple-structure molecular tweezers receptors are very few.[1] In recent years, acyl thiourea-based molecular tweezers compounds has received considerable attention in

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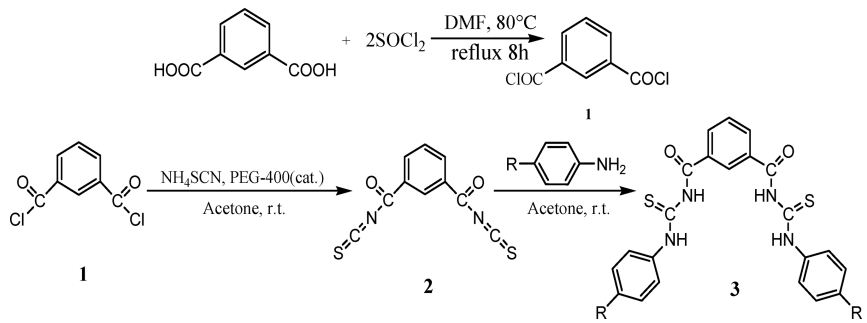
metallamacrocyclic complexes[17,18] because the multiple hydrogen binding interactions of host can induce high recognition selectivity for guest. To the best of our knowledge, however, the anion recognition and sensing of acyl thiourea-based molecular tweezers involving multiple hydrogen-bonding sites has seldom been found in literature.

As far as we know, for construction of anion receptors, it would be crucial to design spacer molecules bearing anion-binding sites. It is well known that binding strength and anion selectivity depend on structures of the spacers, acidity of H-donors, solvents, shape and size of anions.[19] Moreover, receptors bearing two thiourea groups at suitable sites can bind anions through hydrogen bonding interactions and enhance the stability of the resultant complex and recognition selectivity.[20,21] In our previous work, we have had great interest in the research of crown ether and thiosemicarbazide derivatives for anions.[22–28] In view of these facts, and as a part of our work on anion recognition of supramolecular compounds and thiourea-based molecular tweezers receptors, herein we report the synthesis and anion recognition properties of three novel simple and effective molecular tweezers receptors based on acyl-thiourea. The synthetic route of receptors is illustrated in Scheme 1. Isophthalyl chloride (1) was prepared from the reaction of isophthalic acid with thionyl chloride, and it was treated with ammonium thiocyanate under the conditions of solid-liquid phase transfer catalysis using 3% polyethylene glycol-400 (PEG-400) as the catalyst to give isophthalyl isothiocyanate (2). This compound does not need to be isolated and it was treated immediately with substituted aromatic amines to obtain title compounds (3) in good to excellent yields. The recognition properties of receptors have been examined by UV-VisVis absorption and ^{1}H NMR spectroscopy.



SCHEME 1 **3a**: R = CH_3CO; **3b**: R = H; **3c**: R = CH_3CONH.

RESULTS AND DISCUSSION

UV-Vis Absorption Spectra

UV-Vis spectrometry is associated with the variations of absorption spectra in coordinate systems, and it has been used as an effective and simple measuring method of the association constants of complexes in supramolecular systems.

The UV-Vis absorption spectra of receptors **3a, 3b,** and **3c** (2×10^{-5}mol/L, DMSO) in the presence of various anions (50 times with respect to receptors) showed that the three receptors have the recognition selectivity of F^- and AcO^-, but have not the obvious interactions with other anions such as Cl^-, Br^-, I^-, HSO_4^-, and NO_3^-. In each case the counter cation was tetrabutylammonium. As shown in Figure 1, for example, receptor **3a** has the high recognition selectivity of F^- and AcO^-, but has not the obvious interactions of other anions.

Titration experiments for anion recognition of receptors were performed by UV-Vis spectroscopy in DMSO solution. The UV-Vis absorption spectra were obtained from a solution of these receptors in the absence and presence of F^- and AcO^-. In each case the counter cation was tetrabutylammonium.

As shown in Figure 2a, the UV-Vis absorption spectra of solution of receptor **3a** (2×10^{-5}mol/L) in the course of the titration with different concentrations of anions in DMSO have been observed. During titration with fluoride ions, the intensity of absorption peak, which is from

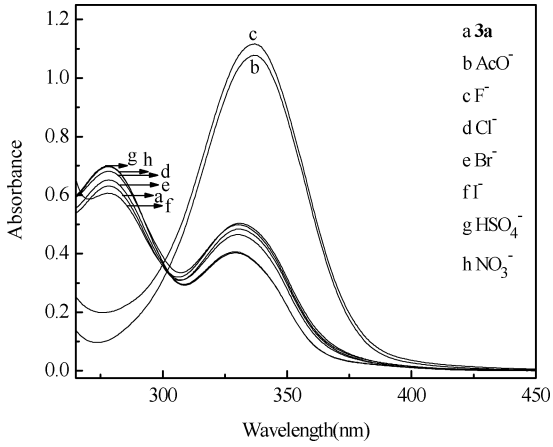


FIGURE 1 UV-Vis absorption spectra of **3a** (2×10^{-5}mol/L, DMSO) in the presence of various anions (50 times with respect to receptor **3a**), which showed that receptor 3a, had the high recognition selectivity of F^- and AcO^-.

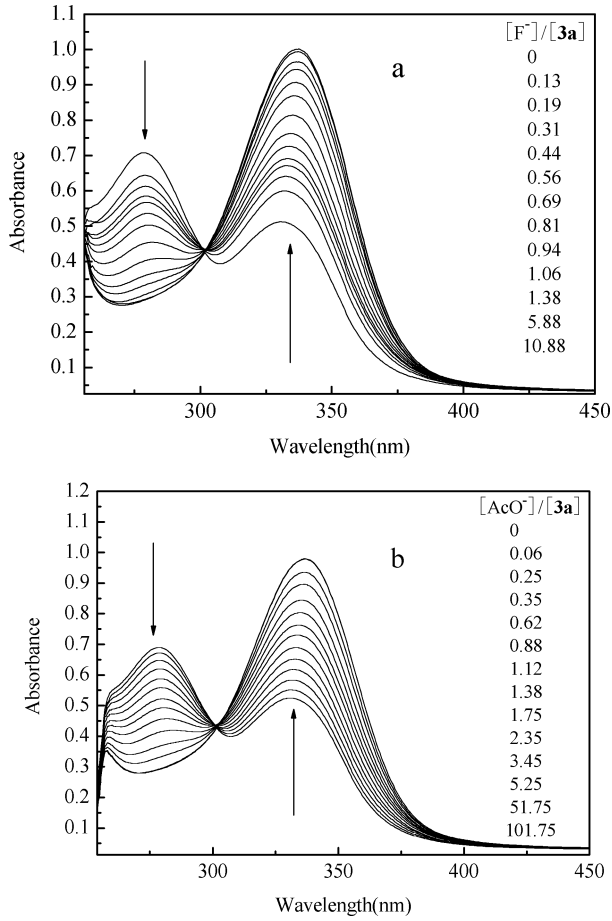


FIGURE 2 (a) The UV-Vis absorption spectra of **3a** (2×10^{-5}mol/L, DMSO) with gradual increasing of the concentration of fluoride ions; (b) The UV-Vis absorption spectra of **3a** (2×10^{-5}mol/L, DMSO) with gradual increasing of the concentration of acetate ions

the benzene moiety, decreased at 278 nm, and a new absorption peak was observed at 337 nm. An obvious isobestic point appeared at 302 nm. Figure 2b shows the absorption spectra of receptor **3a** with adding acetate ions, the peak at 278 nm decreased while the new peak located at 337 nm. Isobestic point appeared at 301 nm. The formation of the complexes between receptor **3a** and fluoride, acetate ions was the best reason for inducing these variations.

Similar to receptor **3a**, the absorption spectra of solution of receptor **3b** (2×10^{-5}mol/L) with different concentrations of anions in DMSO

have also obtained. The absorption spectra of receptor **3b** with adding fluoride ions showed the maximal absorption peak decreased at 267nm, the new peak appeared at 321 nm, and the discerned isobestic point was observed at 283 nm. Similarly, the absorption spectra of receptor **3b** (2×10^{-5}mol/L) with acetate ions showed the maximal absorption peak decreased at 266 nm, the new peak appeared at 322 nm, and isobestic point was observed at 284 nm. Therefore, receptor **3b** also has the selective binding ability for fluoride, acetate ions.

Similarly, the variations of the original and new absorption peaks of solution of receptor **3c** with gradual increasing of the concentration of fluoride ions have also obtained. The maximal peak at 275 nm decreased while the new peak located at 325 nm. Obvious isobestic point at 296 nm was observed. Meanwhile, the variations of absorption spectra of receptor **3c** with acetate ions are also observed. The maximal peak at 276 nm decreased while the new peak located at 324 nm. Isobestic point appeared at 291 nm. These observations clearly showed that receptor **3c** has the selective binding ability for fluoride, acetate ions.

The association constants and correlation coefficients of receptors **3a**, **3b,** and **3c** with fluoride, acetate ions.

The degree of binding ability, as further illustrated by non-linear fitting curve,[29] can be seen from Table I. Receptors **3a**, **3b,** and **3c** bind fluoride ions preferentially, acetate ion was the other anion bound stably. The observed selectivity for fluoride ions can be rationally explained based on the anion structures. Because the spherical fluoride ion was bound with receptor more easily, however, acetate ion has two oxygen atoms, it may be bound in a different complex structure, and fluoride ion is bound stronger than acetate ion, as shown in Table I.

Table I also showed that the orders of the association constants *K*s of receptors with fluoride and acetate ions both are **3a**>**3b**>**3c**. These

TABLE I The Association Constants *K*s (mol/L)$^{-1}$ and Correlation Coefficients *R* of Receptors 3a, 3b, and 3c with Fluoride and Acetate Ions in DMSO, as Further Illustrated by Non-Linear Fitting Curve

Anions	3a	3b	3c
F^-			
*K*s	1.7×10^6	7.2×10^4	6.2×10^4
R	0.9971	0.9989	0.9911
AcO^-			
*K*s	7.6×10^4	1.6×10^4	1.4×10^4
R	0.9972	0.9955	0.9994

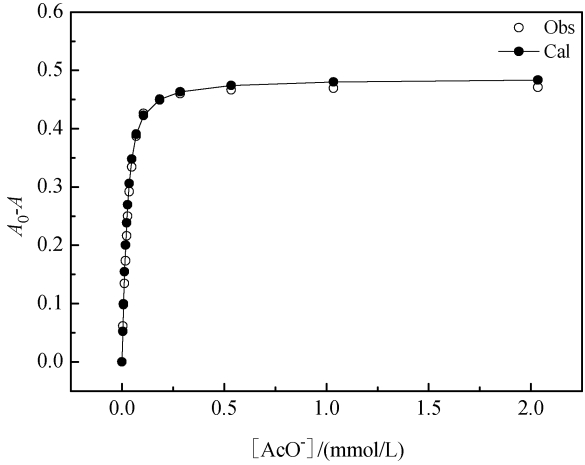


FIGURE 3 The plot of the absorbance of receptor **3a** vs. concentration of acetate ions in DMSO. ([**3a**] = 2×10^{-5}mol/L, λ =336 nm, the correlation coefficient R is 0.9972).

results are likely to be explained that the electron-deficient moieties (p-CH_3CO) can extend the conjugated system and enhance the acidity of –NH protons. In contrast, the electron-rich moieties (p-CH_3CONH_2) can decrease the acidity of NH protons of thiourea groups.

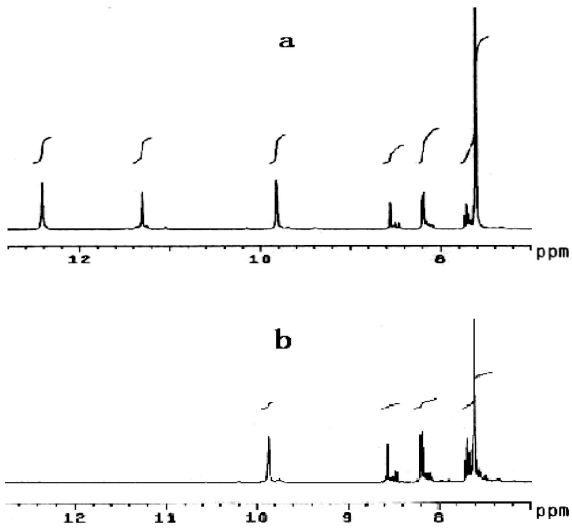
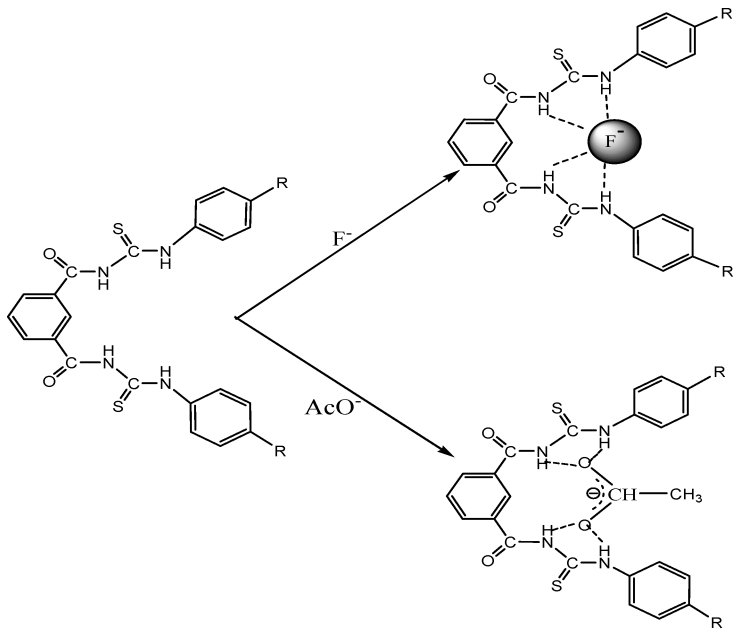


FIGURE 4 ^{1}H NMR spectra of receptor **3c** and the presence of F^- in DMSO-d_6. (a) Receptor **3c**; (b) Receptor **3c** in the presence of F^-.

Meanwhile, the plot of the absorbance of **3a** vs. concentration of acetate ions had been obtained, as shown in Figure 3. The plot of **3a** vs. concentration of fluoride ions had also been obtained from the same step. Similarly, the plots of **3b** and **3c** vs. concentration of fluoride and acetate ions had also been obtained in the same conditions.

^{1}H NMR Study

^{1}H NMR spectroscopy plays an important role in the understanding of receptor-anion interaction and is capable of providing a revealing picture of the details of the interactions between receptors and anions. Therefore it can give convincing evidence for the existence of intramolecular hydrogen bonds between the NH of thiourea group and anions. As shown in Figure 4, for example, the binding ability of the receptor **3c** for fluoride ions is evident in ^{1}H NMR titration experiments in DMSO-d_6. Upon addition of 1 mol equiv. of tetrabutylammonium fluoride to receptor **3c** in DMSO-d_6 caused the complete disappearance of the signals for thiourea NH protons. Figure 4a reported that a partial ^{1}H NMR spectrum of receptor **3c**. Figure 4b showed that upon addition of



SCHEME 2 Possible complexes structures of receptor **3** with fluoride and acetate ions.

1 mol equiv. of tetrabutylammonium fluoride, the signals for the amide NH protons at 11.30 ppm (S, 2H) and 12.41 ppm (S, 2H) of receptor **3c** at 80°C decreased greatly, and completely disappeared, however, signals for the amide NH protons at 9.82 ppm (S, 1H) were still unchanged. These results indicated that receptor **3c** and fluoride ions form 1:1 stoichiometry complex by hydrogen-bonding interaction involving the thiourea NH groups, but the amide NH protons of substitute phenyls have seldom been bound with fluoride ions. The similar results of the signals for receptor **3c** upon addition of 1 mol equiv. of acetate ions can also be observed. Similarly, the variations of the signals for the thiourea NH protons of receptors **3a** and **3b** upon addition of fluoride and acetate ions can be obtained in the same conditions. However, such similar results of signals for receptors **3a, 3b,** and **3c** were not observed upon addition of other anions such as Cl^-, Br^-, I^-, HSO_4^- and NO_3^- in the same conditions. Due to the above facts, possible structures for the complexes of receptor **3** with fluoride and acetate ions are illustrated in Scheme 2. More detailed studies of the hydrogen bonds between thiourea groups of receptors and other anions are under investigation.

CONCLUSION

The novel simple and effective receptors **3a, 3b,** and **3c** were synthesized in good to excellent yields. The UV-Vis absorption spectra and ^1H NMR spectra show that receptors **3a**, **3b,** and **3c** can form 1:1 stoichiometry complexes with F^- and AcO^- by multiple hydrogen-bonding interactions. Receptor **3a** has an excellent ability to recognition with fluoride and acetate ions in comparison with receptors **3b** and **3c**, and these recognition properties of receptor **3a** indicates that receptor **3a** can be considered as an excellent recognition receptor with F^- and AcO^- because of its larger conjugated system. These molecular tweezers receptors have more binding points of anions, larger association constants, and better recognition ability. They can be used as better recognition receptors for F^- and CH_3COO^-.

EXPERIMENTAL

Measurements and Reagents

UV-Vis spectra were obtained on an Agilent-8453 spectrometer. Elemental analyses were performed by a PE-2400 CHN instrument. IR spectra were recorded on a Digilab FTS-3000 FT-IR spectrophotometer (using KBr pellets). ^1H NMR and ^{13}C NMR spectra were measured on a Varian Mercury plus-400 MHz spectrometer; DMSO-d_6 was used as

solvent and TMS as internal standard. Melting points were determined with an X-4 digital melting-point apparatus, which was uncorrected.

Tetrabutylammonium fluoride was commercial product of highest reagent grade and used as received. Tetrabutylammonium acetate was obtained by the neutral reaction of 25% tetrabutylammonium hydroxide and acetic acid, and it dried in P_2O_5 drier. DMSO and acetone were analytical pure.

General Procedure for the Synthesis of Receptors

1,3-isophthalyl chloride (1.1 g, 5 mmol), NH_4SCN (1.2 g, 15 mmol), PEG-400 (0.18 g, 3% with respect to ammonium thiocyanate) and 20 mL of acetone were added in a dried round-bottomed flask containing a magnetic stirrer bar and stirred at room temperature for 2 h to give yellow 1,3-isophthalyl isothiocyanate, then, *p*-acetyl aniline (1.35 g, 10 mmol) was added dropwise. The mixture was stirred at room temperature for 1 h; the precipitate was filtered, washed with acetone to remove residual isothiocyanate, with water to remove inorganic salts, then dried and crystallized from DMF-C_2H_5OH-H_2O to give receptor **3a** as a white powder.

3a

Receptor **3a** was obtained in 92.6% yields (2.36 g). m.p. 250–251°C. IR (KBr): 3417, 3186, 3034 (N-H); 1668 (C=O); 1595, 1527 (C=C); 1269, 1155 (C=S) cm^{-1}. ^1H NMR (DMSO-d_6): δ 12.62 (s, 2H, NHCO), 11.58(s, 2H, NHAr), 7.26–8.61(m, 12H, ArH), 2.55(s, 6H, CH_3). ^{13}C NMR (DMSO-d_6): δ 179.09, 167.21, 159.11, 135.82, 132.85, 128.56, 123.58. Elemental analysis: calcd. for $C_{26}H_{22}N_4O_4S_2$: C, 60.23; H, 4.25; N, 10.81%. Found: C, 60.25; H, 4.28; N, 10.78%.

According to the same synthesis method as before, aniline (0.93 g, 10 mmol) was added dropwise into 1,3-isophthalyl isothiocyanate, and used the above method to give receptor **3b** as a yellow powder.

3b

Receptor **3b** was obtained in 89.3% yields (1.94 g). m.p. 197–198°C. IR (KBr): 3298, 3223, 3173, 3033 (N-H); 1700 (C=O); 1599, 1526(C=C); 1348, 1246, 1145 (C=S) cm^{-1}. ^1H NMR (DMSO-d_6): δ 12.56 (s, 2H, NHCO), 11.60(s, 2H, NHAr), 7.28–8.58 (m, 14H, ArH). ^{13}C NMR (DMSO-d_6): δ 178.98, 167.29, 137.92, 133.28, 131.96, 129.14, 128.77, 126.53, 124.51. Elemental analysis: calcd. for $C_{22}H_{18}N_4O_2S_2$: C, 60.83; H, 4.15; N, 12.90%. Found: C, 60.86; H, 4.18; N, 12.86%.

Similarly, *p*-acetyl amido aniline (1.5 g, 10 mmol) was added dropwise into 1,3-isophthalyl isothiocyanate, and used the above method to give receptor **3c** as a yellow powder.

3c

Receptor **3c** was obtained in 94.3% yields (2.59 g). m.p. >300°C. IR (KBr): 3401, 3143 (N-H); 1663 (C=C); 1400, 1325, 1255, 1159 (C=S) cm^{-1}. ^1H NMR (DMSO-d_6): δ 12.41 (s, 2H, NHCO), 11.30 (s, 2H, NHAr), 9.82 (s, 1H, NHAr), 7.55–8.56 (m, 18H, ArH). ^{13}C NMR (DMSO-d_6): δ 178.42, 167.90, 166.80, 137.26, 132.59, 131.87, 128.11, 124.24, 118.95. Elemental analysis: calcd. for $C_{26}H_{24}N_6O_4S_2$: C, 56.93; H, 4.38; N, 15.33%. Found: C, 56.97; H, 4.41; N, 15.29%.

General Procedure for UV-Vis Spectrometry of Receptors and Anions

The DMSO solution of receptor **3a** (2×10^{-4}mol/L, 1mL) was added in a dry 10 mL colorimetric tubes, the DMSO solution of tetrabutylammonium fluoride (mol/L, 1mL) was added in it, and diluted to 10 mL in DMSO. Similarly, the DMSO solutions of receptor **3a** on respective addition of tetrabutylammonium chloride (mol/L, 1mL), bromide (mol/L, 1mL), iodide (mol/L, 1mL), acetate (mol/L, 1mL), hydrosulfate (mol/L, 1mL) and nitrate (mol/L, 1mL) were obtained, and then detected immediately the UV-Vis spectra of this series of solutions at room temperature. (In this case, the concentration of receptor 3a in DMSO, which is 50 times to the concentration of anions, is 2×10^{-5}mol/L.) According to the above method as before, the spectrometry experiment of receptor **3b** and **3c** with anions can be carried out according to the above method.

General Procedure for UV-Vis Spectrometry Titration of Receptors with Fluoride and Acetate Ions

The DMSO solution of receptor **3a** (2×10^{-5}mol/L, 2mL) was added in a dry colorimetric tube, the DMSO solution of tetrabutylammonium fluoride (1.0 mol/L) in different volumes were respectively added in it, then detected immediately the UV-Vis spectra of this series of solutions at room temperature. (In this case, the concentration of receptor 3a in DMSO invariably is 2×10^{-5}mol/L, the concentration of fluoride ions is changeable.) Similarly, the UV-Vis spectrometry titration of receptor **3a** and acetate ions was carried out. According to the above method as before, the titration experiment of receptor **3b** and **3c** with fluoride ions can be carried out according to the above method.

REFERENCES

[1] W. Z. Yang, Z. M. Yin, J. Q. He, and J. P. Cheng, *Chem. J. Chinese Universities*, **25,** 2269–2272 (2004).
[2] J. D. Amilan, K. D. Krishna, G. Bishwajit, and D. Amitava, *Org. Lett.*, **6,** 3445–3448 (2004).
[3] H. Y. Lu, W. Xu, D. Q. Zhang, C. F. Chen, and D. B. Zhu, *Org. Lett.*, **7,** 4629—4632 (2005).
[4] P. C. John, J. A. Alan, B. J. Jean, L. S. Adam, M. Germinal, M. P. P. Nieves, N. L. Timothy, S. Rameshwer, D. S. Bradley, and P. D. Anthony, *J. Am. Chem. Soc.*, **127,** 10,739–10,746 (2005).
[5] L. Nie, Z. Li, J. Han, X. Zhang, R. Yang, W. X. Liu, F. Y. Wu, J. W. Xie, Y. F. Zhao, and Y. B. Jiang, *J. Org. Chem.*, **69,** 6449–6454 (2004).
[6] J. L. Wu, Y. B. He, Z. Y. Zeng, L. H. Wei, L. Z. Meng, and T. X. Yang, *Tetrahedron*, **60,** 4309–4314 (2004).
[7] S. Y. Liu, L. Fang, Y. B. He, W. H. Chan, K. T. Yeung, Y. K. Cheng, and R. Yang, *Org. Lett.*, **7,** 5825–5828 (2005).
[8] S. Duraisamy, S. Nallathambi, K. Muthusamy, G. A. Paduthapillai, and V. Devadoss, *Tetrahedron Lett.*, **46,** 7255–7258 (2005).
[9] Y. Yuan, G. Gao, Z. L. Jiang, J. S. You, Z. Y. Zhou, D. Q. Yuan, and R. G. Xie, *Tetrahedron*, **58,** 8993–8999 (2002).
[10] H. Tong, G. Zhou, L. X. Wang, X. B. Jing, F. S. Wang, and J. P. Zhang, *Tetrahedron Lett.*, **44,** 131–134 (2003).
[11] X. H. Qian and F. Y. Liu, *Tetrahedron Lett.*, **44,** 795–799 (2003).
[12] N. Seiichi, R. Philippe, I. Masatoshi, and U. Yoshio, *Tetrahedron Lett.*, **36,** 6483–6486 (1995).
[13] K. Ryo, N. Seiichi, H. Takashi, and T. Norio, *Tetrahedron Lett.*, **42,** 5053–5056 (2001).
[14] K. S. Kim and H. S. Kim, *Tetrahedron*, **61,** 12,366–12,370 (2005).
[15] G. Thorfinnur, E. K. Paul, J. Paul, T. Juliann, D. P. A. Haslin, and M. H. Gillian, *J. Org. Chem.*, **70,** 10,875-10,878 (2005).
[16] B. Liu and H. Tian, *Chem. Lett.*, **34,** 686–687 (2005).
[17] K. R. Koch, S. A. Bourne, A. Coetzee, and J. Miller, *J. Chem. Soc. Dalton Trans.*, 3157–3161 (1999).
[18] S. A. Bourne, O. Hallale, and K. R. Koch, *Crystal Growth & Design*, **5,** 307–312 (2005).
[19] K. Shin-ichi, N. Masanori, and Y. Yumihiko, *Tetrahedron Lett.*, **44,** 8801–8804 (2003).
[20] Q. M. Mu, Y. Peng, Z. G. Zhao, and S. H. Chen, *Chin. J. Org. Chem.*, **24,** 1018–1028 (2004).
[21] F. Y. Wu, Z. C. Wen, and Y. B. Jiang, *Progress in Chem.*, **16,** 776–784 (2004).
[22] Y. M. Zhang, J. D. Qing, Q. Lin, and T. B. Wei, *J. Fluorine Chem.*, **127,** 1222–1227 (2006).
[23] T. B. Wei, Q. Lin, Y. M. Zhang, and H. Wang, *Synth. Commun.*, **34,** 2205–2213 (2004).
[24] T.B. Wei, Q. Lin, Y.m. Zhang, and W. Wei, *Synth. Commun.*, **34,** 181–186 (2004).
[25] T. B. Wei, Y. Q. Zhou, and Y. M. Zhang, *J. Chem. Res. Synop.*, **4,** 302 (2004).
[26] Q. Lin, Y. M. Zhang, T. B. Wei, and L. M. Gao, *Chin. J. Org. Chem.*, **25,** 290–294 (2005).
[27] Y. M. Zhang, W. X. Xu, M. L. Li, and T. B. Wei, *Chinese J. Inorg. Chem.*, **21,** 1815–1820 (2005).
[28] Y. M. Zhang, W. X. Xu, Y. Q. Zhou, H. Yao, and T. B. Wei, *Acta Chim. Sinica*, **64,** 79–84 (2006).
[29] Y. Liu, B. Li, and B. H. Han, *J. Chem. Soc. PerKin Trans.*, 563–568 (1999).