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ORIGINAL PAPER

Synthesis and Chiral Recognition Properties of Novel Fluorescent Chemosensors for Amino Acid

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Abstract The charge neutral chiral optical sensors **1a~d** containing thiourea and amide groups were synthesized by simple steps in good yields and their structures were characterized by IR, ^{1}H NMR, ^{13}C NMR, MS spectra and elemental analysis. The enantioselective recognition for α-phenylglycine and phenylglycinol was examined by fluorescence emission and UV-vis spectra. The fluorescence and UV-vis spectra changes of **1a** were obvious when the enantiomers of α-phenylglycine anion were added, which exhibited that **1a** has good enantioselective recognition ability towards α-phenylglycine.

Keywords Enantioselective recognition · Chiral chemosensor · Fluorescence · Amino acid

Introduction

The molecular recognition of biologically important anions by simple synthetic receptors is an emerging topic in the field of supramolecular chemistry [1]. It is well-known that the chemical properties and biological activity of chiral matters are strongly dependent on stereochemistry; each enantiomer may have different pharmacological properties in terms of activity, potency, toxicity, transport mechanism and metabolic route [2]. Therefore, great deals of efforts have been devoted to the design and synthesis of receptors for chiral anions [3, 4].

The molecular recognition of amino acids by synthetic receptor molecules has been attracting much attention, due to the frequent use of the basic amino acids (e.g., Lys, Arg, His, Ala) for biological processes and therapeutic drugs made from chiral amino acids intermediates [5–7]. The rational design of receptors with chiral recognition ability for chiral amino acids is still receiving considerable attention, although numerous receptors based on chiral macrocycle and calixarene have been developed for amino acids and amino alcohols [8–11].

Among the various methods used to detect chiral chemosensor operation, an approach based on changes in the chemosensor's fluorescence spectrum has been extensively investigated [12]. Fluorescent sensors for the detection of ions or molecules have attracted considerable interest because of their high sensitivity and potential applications in analytical, biological, and clinical biochemical environments [13–15].

Tryptophan and alanine were often employed as chiral sources in building the desired chiral molecule because of their accessibility and biological relevance [16, 17]. Actually, the indole group of tryptophan, which is a potential hydrogen bond donor, has been exploited extensively in the area of anion sensor development [18, 19]. In this paper, we report four chiral fluorescent chemosensors **1a~d** containing thiourea and amide groups, and their enantioselective recognition towards α-phenylglycine and phenylglycinol was studied by fluorescence emission and UV-vis spectra.

Electronic supplementary material The online version of this article (doi:10.1007/s10895-008-0385-3) contains supplementary material, which is available to authorized users.

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Results and discussion

Synthesis

The synthesis of chiral fluorescent receptors is outlined in Scheme 1. 9-Aminomethyl anthracene was prepared following the published procedure in ref. [20].

The intermediates **3a** and **3b** were obtained by the reaction of 9-aminomethyl anthracene with *N*-boc-L-tryptophan and *N*-boc-L-alanine in the presence of CDI under an inert atmosphere, by treating with trifluoroacetic acid to remove the *tert*-butyloxycarbonyl (Boc) group, then acted directly with *p*-nitrophenylisothiocyanate or *p*-tolylisothiocyanate under triethylamine to obtain receptors **1a~d** in high yields (Scheme 2). All of these compounds were characterized by IR, ^{1}H NMR, ^{13}C NMR, MS and elemental analysis.

Synthetic route for receptors **1a~d**. Reagents and conditions: (1) Hexamethylene tetramine, $CHCl_3$, reflux; (2) CH_3OH, HCl, reflux; (3) *N*-boc-L-tryptophan or *N*-boc-L-alanine, CDI, CH_2Cl_2, rt; (4) CF_3COOH, CH_2Cl_2, rt; (5) *p*-nitrophenylisothiocyanate or *p*-tolylisothiocyanate, triethylamine, CH_2Cl_2, rt.

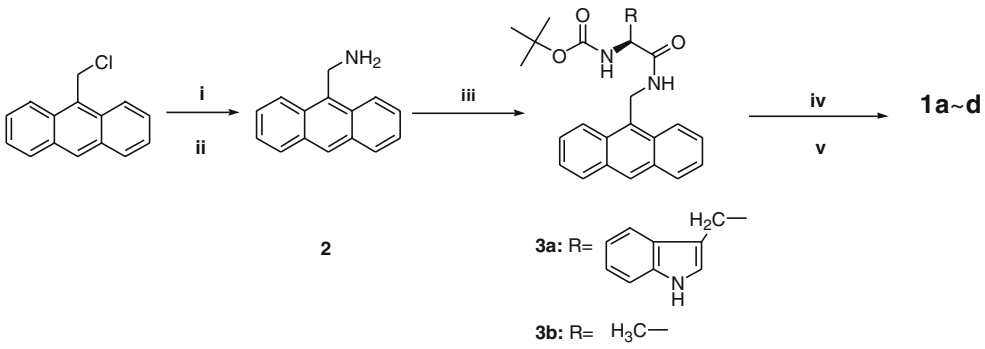
Fluorescence and UV–vis spectra study

The chiral recognition properties of receptors **1a~d** were investigated for the enantiomers of α-phenylglycine (Phe) and phenylglycinol (Phol; Scheme 3). The fluorescence and UV–vis spectra were recorded from a solution of receptors **1a~d** (5.0×10^{-5} mol L^{-1}) in DMSO in the absence or presence of guests, and Phe was in the form of tetrabutylammonium salt.

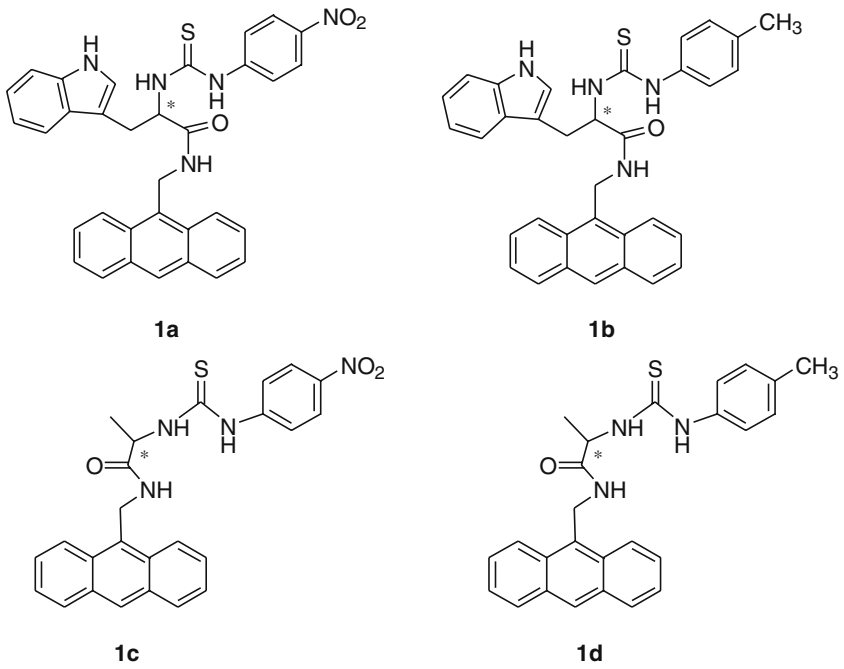
Figure 1a,b show the fluorescence emission spectra of **1a** with different concentrations of L- or D-Phe in DMSO. On increase of the concentration of the anions, the fluorescence emission intensities of **1a** (5.0×10^{-5} mol L^{-1}) gradually enhanced (λ_{ex}=372 nm), which indicates that the complexation happened between **1a** and L- or D-Phe. The phenomenon of the increase of fluorescence intensity upon addition of a guest anion is similar to the anion-induced fluorescence enhancement already reported [21]. In the absence of anion, the photoinduced electron-transfer (PET) process between the anthracene group and the weak electron-withdrawing amide substituents might result in decreased fluorescence intensity. Upon the addition of anions, the interaction of an anion with thiourea NH and indole NH could diminish the PET progress to induce fluorescence retrieval. Therefore anion-induced fluorescence enhancement was observed [22, 23]. The increasing efficiency was about 270% with the addition of four equiv of L-Phe (Fig. 1a), while it was 150% by four equiv of D-Phe (Fig. 1b). The different increasing efficiencies ($\Delta I_L/\Delta I_D$=1.8) indicated that receptor **1a** has a good enantioselective recognition ability between L- and D-α-phenylglycine. In addition, the association constant (K_{ass}) of **1a** with L-Phe is $(2.96\pm0.16)\times10^4$ M^{-1}, while that of **1a** with D-Phe is $(5.26\pm0.25)\times10^3$ M^{-1}, and the enantioselectivity ($K_{ass(L)}/K_{ass(D)}$) is 5.63.

Figure 2a,b show the UV–vis spectra of **1a** with different concentrations of L- or D-Phe in DMSO. As shown in the figures, on gradual increase of the concentration of Phe, the intensity of absorption band at 370 nm was decreased, and a new absorption band appeared with a maximum absorption at 475 nm, which can be explained by expansion of the conjugative system as a result of an intermolecular charge transfer (ICT) process [24, 25]. A discernible isosbestic point at 393 nm was observed, indicating the formation of the host-guest complex. It was particularly noteworthy that adding a small amount of L-Phe (0.5 equiv) made the color of solution of **1a** change from light yellow to orange–red, which could be easily observed by the naked-eyes. When the receptor bound anions, hydrogen bonds were constructed to form stable complexes, and the electron density in the supramolecular system was increased to enhance the charge-transfer interactions between the electron-rich donor nitrogen of the thiourea units and electron-deficient *p*-nitrophenyl moieties, which resulted in a visible color change [26, 27]. The fact that the orange–red solution of **1a** and Phe in DMSO was returned to colorless when protic solvent such as methanol was added. This phenomenon illustrated that the interaction between **1a** and anions was in

Scheme 1 Synthetic route for receptors **1a~d**



Scheme 2 The structures of receptors **1a~d**

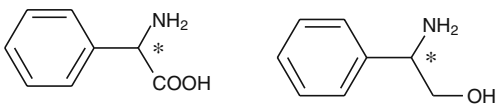


essence hydrogen bonding interactions. As shown in the inset of figures, the satisfactory non-linear fitting curve (R> 0.99) further illuminated the formation of 1:1 complex between **1a** and L- or D-Phe.

Figure 3a,b exhibit the fluorescence emission and UV-vis absorption spectra change of receptor **1a** with L- or D-Phe. Different responses indicate that **1a** has good enantioselective recognition ability for Phe.

Similar but smaller variations in the fluorescence and absorption spectra were observed when **1a** interacted with L- or D-Phol (see Supplementary data), and the color change was not obvious.

Figure 4a,b show the fluorescence emission spectra of **1b** with different concentrations of L- or D-Phe in DMSO. On increase of the concentration of the anions, the fluorescence emission intensities of **1b** (5.0×10^{-5} mol L^{-1}) at 443 nm (λ_{ex}=372 nm) gradually increased, which indicates that the complexation happened between **1b** and D- or L-Phe. The increasing efficiency was about 150% with the addition of ten equiv of L-Phe (Fig. 4a), while it was 110% by ten equiv of D-Phe (Fig. 4b). The association constant (K_{ass}) of **1b** with L-Phe is $(8.12\pm0.15)\times10^3$ M^{-1}, while that of **1b** with D-Phe is $(3.26\pm0.32)\times10^3$ M^{-1}, and the enantioselectivity ($K_{ass(L)}/K_{ass(D)}$) is 2.49 for Phe. The changes in the absorption spectra of the anthracene moiety were only minor for **1b** in the presence of L- or D-Phe, which implied that a PET process occurred with anion binding (see Supplementary data).



Phenylglycine(Phe) Phenylglycinol(Phol)

Scheme 3 The structures of guests

Figure 5 exhibits the fluorescence change of receptor **1b** with L- or D-Phe.

The continuous variation methods were employed to determine the stoichiometric ratio of the receptor **1a** and **1b** with L/D-Phe. The total concentration of host and guest was constant (1.0×10^{-4} mol L^{-1}) in DMSO, with a continuously variable molar fraction of host ([H]/([H] + [G])). Figure 6 shows the Job plots of receptor **1a** and **1b** with chiral anions. When the molar fraction of the host was 0.50, the fluorescence intensity reached a maximum, which demonstrated that the receptors formed a 1:1 complex with the guests, respectively [28].

Assuming the complex stoichiometry was 1:1, the association constant (K_{ass}) can be calculated by the following equation in Origin 7.0 [29]:

$$X = X_0 + (X_{lim} - X_0)/2c_0 \left\{ c_H + c_G + 1/K_{ass} - \left[(c_H + c_G + 1/K_{ass})^2 - 4c_H c_G \right]^{1/2} \right\}$$

Where X represents the fluorescence intensity, c_H and c_G represent the corresponding concentration of host and guest. The non-linear curve fitting results of the fluorescence intensity of the interaction between **1a~d** and L/D-Phe, L/D-Phol are shown in Table 1.

The data in Table 1 illustrated that the association constants of **1a** and **1c** are always much higher than **1b** and **1d** with the anions. The results demonstrated that the introduction of electron-withdrawing substituent ($-NO_2$)

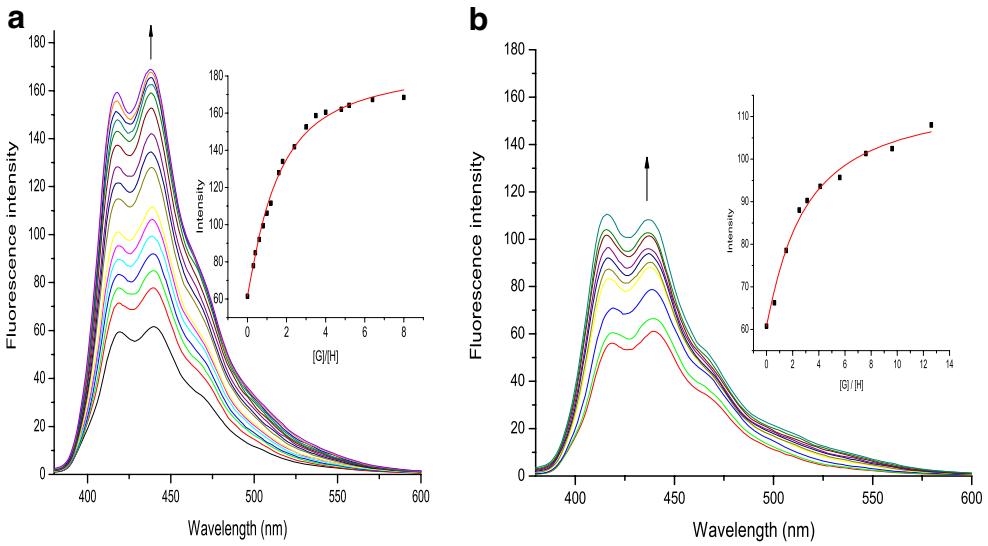


Fig. 1 **a** Fluorescence spectra of receptor **1a** (5×10^{-5} mol L^{-1}) with L-Phe anion in DMSO. Equivalents of anion: 0→8.0. **b** Fluorescence spectra of receptor **1a** (5×10^{-5} mol L^{-1}) with D-Phe anion in DMSO. Equivalent of anion: 0→12.6. λ_{ex}=372 nm. *Inset*: changes of fluorescence intensity of **1a** at 438 nm upon addition of the anion. The *line* is fitting curve

enhance the acidity of thiourea NH, which provided an effective intramolecular charge transfer and enhanced the hydrogen bond ability, resulting in a strong anion binding [24]. While the association constants of **1a** are much higher than **1c** with the anions, which supported the notion that the cooperative act of thiourea and NH of indole group in binding for chiral guests by multiple hydrogen bonding interactions played an important role. So **1a** revealed the highest association constants and the best enantioselective recognition towards the chiral guests.

Conclusion

The anthracene based chiral fluorescent receptors **1a~d** containing thiourea and amide groups were synthesized by simple steps in good yields, and their enantioselective recognition abilities towards phenylglycine and phenylglycinol were evaluated by the fluorescence and UV–vis spectra. Receptor **1a** exhibits the highest association constants and the best enantioselective recognition towards the chiral guests. The receptors' steric effect, structure-complementary with guest and multiple hydrogen binding may be responsible for the enantioselective recognition. Sensitive fluorescence and UV–vis response reveal that **1a** can be used as fluorescent chemosensor for phenylglycine.

Experimental

Materials and methods

CH_2Cl_2 and Et_3N were dried and distilled from CaH_2. All other commercially available reagents were used without further purification. Melting points were determined with a Reichert 7905 melting-point apparatus and are uncorrected.

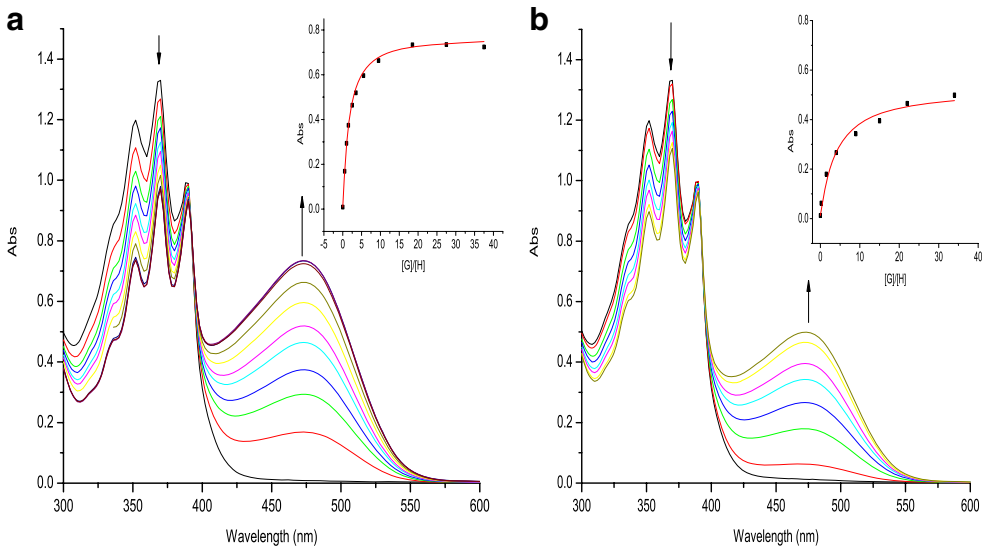


Fig. 2 **a** UV-vis absorption spectra of **1a** (5×10^{-5} mol L^{-1}) upon the addition of various amounts of L-Phe in DMSO. Equivalents of anion: 0→37.5. **b** UV-vis absorption spectra of **1a** (5×10^{-5} mol L^{-1}) upon the addition of various amounts of D-Phe in DMSO. Equivalents of anion: 0→34. *Inset*: changes of absorption of **1a** at 475 nm upon addition of the anion. The *line* is fitting curve

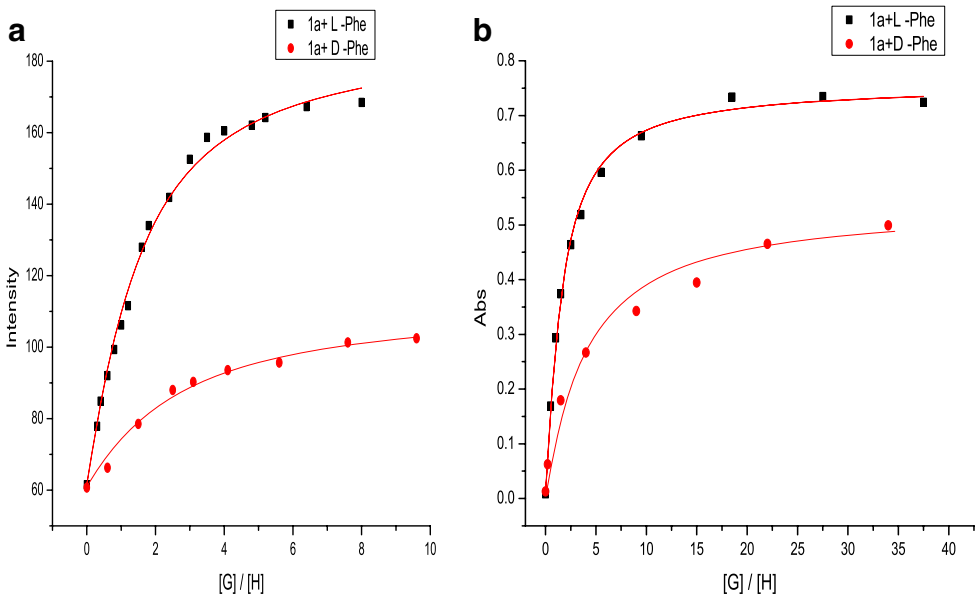


Fig. 3 **a** Fluorescence intensity change of receptor **1a** (5×10^{-5} mol L^{-1}) with L- or D-Phe in DMSO. **b** UV-vis spectra change of **1a** (5×10^{-5} mol L^{-1}) with L- or D-Phe in DMSO. The *line* is fitting curve

Optical rotations were taken on a Perkin–Elmer Model 341 polarimeter. IR spectra were obtained on a Nicolet 670 FT-IR spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were performed on a Varian Mercury VX 300 MHz spectrometer in DMSO-d_6. Mass spectra were recorded on a Finnigan LCQ advantage mass spectrometer. Elemental analysis was determined with a FlashEA 1112 instrument. Fluorescence spectra were obtained on a Schimadzu RF-5301 spectrometer. The UV–vis spectra were performed with a TU-1901 spectrophotometer.

Synthesis

Compounds **3a** and **3b**: To a stirred and ice cooled solution of *N*-boc-L-tryptophan (0.61 g, 2.0 mmol) or *N*-boc-L-alanine (0.38 g, 2.0 mmol) in dry CH_2Cl_2 (10 mL) was added 1, 1'-carbonyldiimidazole (CDI; 0.39 g, 2.4 mmol), and the mixture was stirred for 2 h. Then a solution of 9-aminomethyl anthracene (0.41 g, 2.0 mmol) in 10 mL of dry CH_2Cl_2 was added dropwise. The mixture was stirred under N_2 protection at RT for 24 h. After the starting material had disappeared on TLC, the yellow reaction mixture was washed successively with an aqueous solution of citric acid (10%), sodium hydrogen carbonate (10%) and brine, respectively. The organic layer was collected and dried over anhydrous Na_2SO_4. After filtration, the solvent was evaporated under reduced pressure. The crude product was purified on a column of silica gel (eluent: $CHCl_3$: CH_3OH=100:1) to give the pure product **3a** and **3b**.

Compound **3a**: 0.85 g, 86%. Mp 177–178 °C. [α] 20D=−13.1° (*c* 0.02, DMSO). IR (KBr/cm^{-1}) 3,326, 3,056, 2,975, 2,928, 1,688, 1,644, 1,522, 1,457, 1,392,

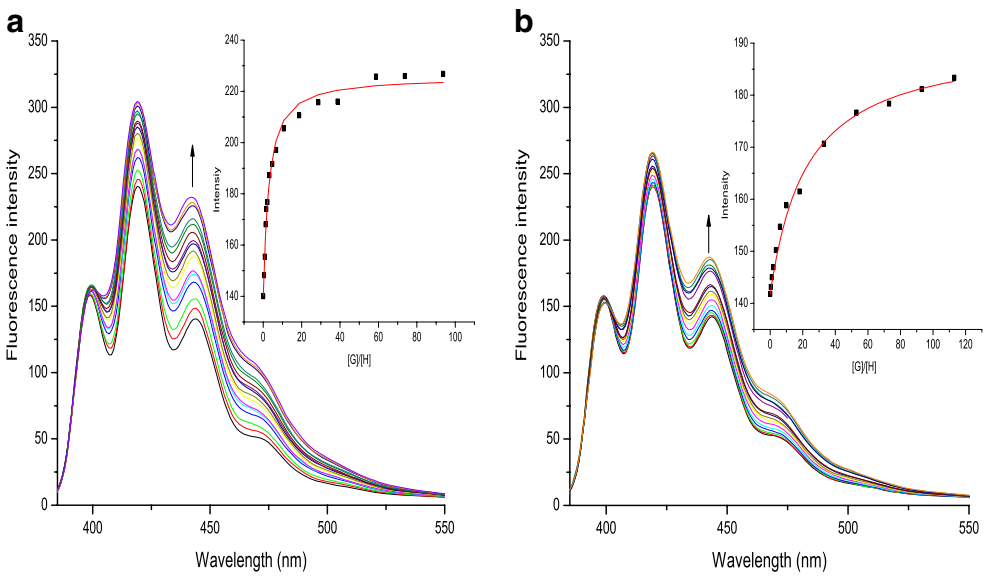


Fig. 4 **a** Fluorescence spectra of receptor **1b** (5×10^{-5} mol L^{-1}) with L-Phe anion in DMSO. Equivalents of anion: 0→93.7. **b** Fluorescence spectra of receptor **1b** (5×10^{-5} mol L^{-1}) with D-Phe anion in DMSO. Equivalent of anion: 0→113. λ_{ex}=372 nm. *Inset*: changes of fluorescence intensity of **1b** at 443 nm upon addition of the anion. The *line* is fitting curve

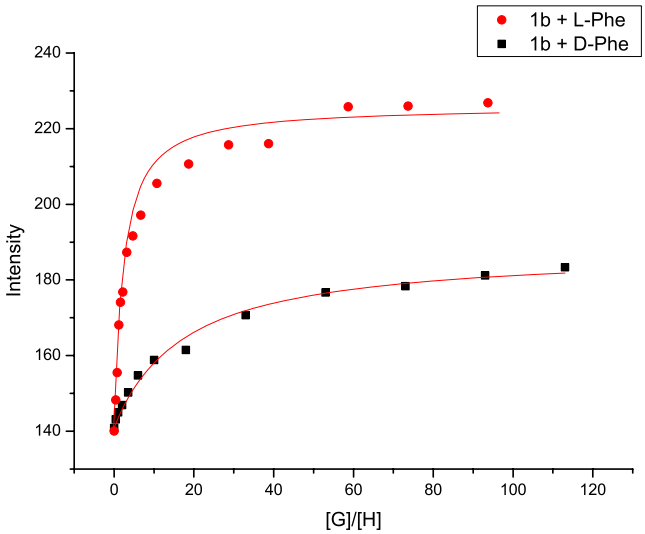


Fig. 5 Fluorescence intensity change of receptor **1b** (5×10^{-5} mol L^{-1}) with L- or D-Phe in DMSO at 443 nm

1,367, 1,340, 1,249, 1,169, 1,048, 743, 660. ^{1}H NMR ($CDCl_3$): δ 8.48 (s, 1H, AnH), 8.00 (s, 1H, Indole), 7.99 (d, J=8.7 Hz, 2H, AnH), 7.93 (d, J=8.7 Hz, 2H, AnH), 7.65 (d, J=7.5 Hz, 1H, Indole), 7.49 (d, J=7.5 Hz, 1H, Indole), 7.42–7.47 (m, 4H, AnH), 7.02–7.19 (m, 2H, Indole), 6.63 (br, 1H, Indole-NH), 5.68 (br, 1H, NH-CO), 5.23 (br, 3H, CH_2-An and *CH), 4.39 (br, 1H, NH-Boc), 3.00–3.08 (m, 2H, Indole-CH_2), 1.32 (s, 9H, Boc-*t*Bu). ^{13}C NMR ($CDCl_3$): δ 166.8, 131.5, 126.8, 125.6, 124.5, 123.4, 122.5, 122.1, 120.7, 119.2, 118.7, 115.3, 114.3, 106.6, 105.9, 50.7, 31.4, 24.4, 23.7. ESI-MS *m/z* (%):

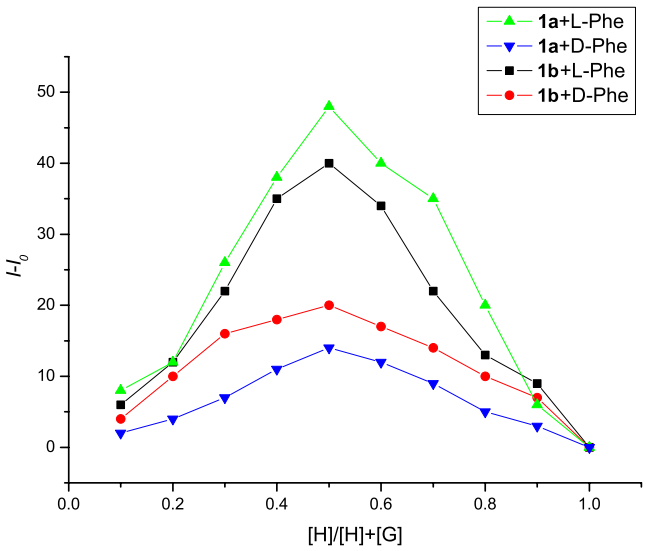


Fig. 6 Job plots of **1a** (at 437 nm) and **1b** (at 443 nm) with L- or D-Phe. The total concentration of the host and guest is 1.0×10^{-4} mol L^{-1} in DMSO. I_0: fluorescence intensity of the host; I: fluorescence intensity of the host in the presence of the guest

Table 1 Association constants (K_{ass}), correlation coefficients (R), enantioselectivities ($K_{ass(L)}/K_{ass(D)}$) for the complexation of receptors **1a~d** with L/D-Phe and Phol in DMSO at 25 °C

Host	Guest	K_{ass} (M^{-1})[a, b]	$K_{ass(L)}/K_{ass(D)}$	R
1a	L-Phe[c]	$(2.96\pm0.16)\times10^4$	5.63	0.9964
1a	D-Phe[c]	$(5.26\pm0.25)\times10^3$		0.9912
1a	L-Phol	$(4.85\pm0.02)\times10^3$	4.29	0.9931
1a	D-Phol	$(1.13\pm0.12)\times10^3$		0.9942
1b	L-Phe[c]	$(8.12\pm0.15)\times10^3$	2.49	0.9901
1b	D-Phe[c]	$(3.26\pm0.32)\times10^3$		0.9918
1b	L-Phol	$(3.32\pm0.16)\times10^2$	2.17	0.9963
1b	D-Phol	$(1.53\pm0.21)\times10^2$		0.9924
1c	L-Phe[c]	$(1.83\pm0.13)\times10^4$	3.53	0.9952
1c	D-Phe[c]	$(5.18\pm0.19)\times10^3$		0.9935
1c	L-Phol	$(3.10\pm0.41)\times10^3$	3.38	0.9916
1c	D-Phol	$(9.17\pm0.32)\times10^2$		0.9928
1d	L-Phe[c]	$(3.86\pm0.25)\times10^2$	2.10	0.9971
1d	D-Phe[c]	$(1.84\pm0.12)\times10^2$		0.9951
1d	L-Phol	–[d]		
1d	D-Phol	–[d]		

[a] The data were calculated from results of fluorescence titrations in DMSO.
[b] All error values were obtained by the results of nonlinear curve fitting.
[c] The anions were used as their tetrabutylammonium salts.
[d] The change of fluorescence spectra is minor, so the association can't be calculated.

516 (M + Na^+, 100). Anal. calcd. for $C_{31}H_{31}N_3O_3$: C 75.42, H 6.34, N 8.51; found: C 75.38, H 6.38, N 8.49.

Compound **3b**: 0.61 g, 81%. Mp 184–185 °C, [α]20D=-7.5° (*c* 0.02, DMSO). IR (KBr/cm^{-1}) 3,320, 2,978, 2,931, 1,693, 1,644, 1,525, 1,448, 1,367, 1,250, 1,166, 1,051, 754, 654. ^{1}H NMR ($CDCl_3$): δ 8.46 (s, 1H, AnH), 8.25 (d, J= 8.7 Hz, 2H, AnH), 8.03 (d, J=8.7 Hz, 2H, AnH), 7.46–7.58 (m, 4H, AnH), 6.36 (br, 1H, NH-CO), 5.41 (s, 2H, CH_2), 4.92 (br, 1H, NH-Boc), 4.10 (m, 1H, *CH), 1.34 (d, J= 6.3 Hz, 3H, CH_3), 1.25 (s, 9H, Boc-*t*Bu). ^{13}C NMR ($CDCl_3$): δ 173.2, 155.6, 131.3, 130.4, 126.5, 125.8, 78.6, 50.3, 35.9, 19.1. ESI-MS *m/z* (%): 377 (M^+ −1, 100). Anal. calcd. for $C_{23}H_{26}N_2O_3$: C 72.98, H 6.94, N 7.40; found: C 72.90, H 7.02, N 7.32.

General procedure for the synthesis of receptors **1a~d** TFA (0.5 mL) was added to a solution of compound **3a** (0.49 g, 1.0 mmol) or **3b** (0.38 g, 1.0 mmol) in dry CH_2Cl_2 (10 mL). The mixture was stirred at RT for 30 min to remove the Boc protecting groups. Then the solvent and excess acid was removed in vacuo, giving the TFA salt as green solid, which was used without further purification. The green solid and triethylamine (0.5 mL) were dissolved in dry CH_2Cl_2 (10 mL), then a solution of *p*-tolylisothiocyanate (0.15 g, 1.0 mmol) or *p*-nitrophenylisothiocyanate (0.18 g, 1.0 mmol) in 5 mL dry CH_2Cl_2 was added. The

resulting solution was stirred vigorously overnight under N_2 protection at RT. After the starting material had disappeared on TLC, the mixture was washed by water, and the organic layer was collected and dried over anhydrous Na_2SO_4. The solvent was evaporated and the residue was purified by column chromatography of silica gel (eluent: $CHCl_3$: CH_3OH=200:1) to give yellow solid **1a~d**.

Compounds **1a**: 0.46 g, 80%. Mp 215–217 °C. [α]20D=+ 58.8° (*c* 0.02, DMSO). IR (KBr/cm^{-1}) 3,417, 3,057, 1,643, 1,597, 1,574, 1,509, 1,384, 1,339, 1,302, 1,253, 1,178, 1,112, 850, 734, 602, 544. ^{1}H NMR (DMSO-d_6): δ 10.48 (s, 1H, Indole-NH), 10.39 (br, 1H, NHAr), 8.73 (br, 1H, NHCS), 8.61 (s, 1H, AnH), 8.27 (d, *J*=9.6 Hz, 2H, AnH), 8.22 (d, *J*=8.1 Hz, 1H, NHCO), 8.09–8.14 (m, 4H, ArH), 7.79 (d, *J*=9.6 Hz, 2H, AnH), 7.50–7.58 (m, 5H, AnH and Indole), 7.32 (d, *J*=8.1 Hz, 1H, Indole), 7.01–7.05 (m, 2H, Indole), 6.90 (t, *J*=7.2 Hz, 1H, Indole), 5.09–5.36 (m, 3H, CH_2N and *CH), 3.09–3.14 (m, 2H, *CHCH_2). ^{13}C NMR (DMSO-d_6): δ 183.4, 174.5, 150.2, 145.8, 140.1, 135.0, 134.1, 133.2, 132.8, 131.6, 131.4, 130.2, 129.2, 128.5, 127.9, 124.9, 124.2, 122.6, 122.2, 115.3, 113.1, 61.6, 39.5, 31.9. ESI-MS *m*/*z* (%): 596 (M + Na$^+$, 100). Anal. calcd. for $C_{33}H_{27}N_5O_3S$: C 69.08, H 4.75, N 12.21; found: C 68.92, H 4.82, N 12.18

Compound **1b**: 0.40 g, 75%. Mp 135–137 °C. [α]20D=- 13.1° (*c* 0.02, DMSO). IR (KBr/cm^{-1}) 3,411, 2,924, 2,853, 1,642, 1,513, 1,456, 1,385, 1,238, 1,122, 1,045, 872, 734, 534. ^{1}H NMR (DMSO-d_6): δ 10.80 (s, 1H, Indole-NH), 9.66 (br, 1H, NH-Ar), 8.65 (br, 1H, NH-CS), 8.61 (s, 1H, AnH), 8.26 (d, *J*=8.7 Hz, 2H, AnH), 8.10 (d, *J*=8.7 Hz, 2H, AnH), 7.47–7.58 (m, 6H, AnH and Indole), 7.31 (d, *J*= 8.1 Hz, 1H, indole), 6.90–7.12 (m, 7H, Indole and ArH), 5.07–5.32 (m, 3H, CH_2N and *CH), 3.03–3.21 (m, 2H, *CHCH_2), 2.33 (s, 3H, CH_3). ^{13}C NMR (DMSO-d_6): δ 183.4, 174.9, 140.1, 137.5, 135.1, 134.1, 133.1, 132.9, 131.5, 130.3, 129.3, 128.6, 127.8, 127.2, 124.9, 122.7, 122.3, 115.3, 113.3, 61.7, 39.5, 32.3, 24.5. ESI-MS *m*/*z* (%): 565 (M + Na$^+$, 100). Anal. calcd. for $C_{34}H_{30}N_4OS$: C 75.24, H 5.58, N 10.33; found: C 75.20, H 5.61, N 10.31.

Compounds **1c**: 0.33 g, 72%. Mp 209 to 210 °C. [α] 20D=+ 45.8° (*c* 0.02, DMSO). IR (KBr/cm^{-1}) 3,323, 3,056, 1,655, 1,597, 1,509, 1,329, 1,302, 1,253, 1,180, 1,112, 849, 732, 602, 567. ^{1}H NMR (DMSO-d_6): δ 10.43 (s, 1H, NHAr), 8.76 (s, 1H, NHCS), 8.62 (s, 1H, AnH), 8.38 (d, *J*=9.3 Hz, 2H, AnH), 8.36 (s, 1H, NHCO), 8.16 (d, *J*=8.7Hz, 2H, ArH), 8.12 (d, *J*=8.7 Hz, 2H, ArH), 7.92 (d, *J*=9.3 Hz, 2H, AnH), 7.51–7.60 (m, 4H, AnH), 5.27–5.31 (m, 2H, AnCH_2), 4.80–4.85 (m, 1H, *CH), 1.26 (d, *J*= 6.6 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6): δ 179.5, 172.1, 147.0, 142.6, 131.8, 130.7, 130.2, 129.6, 128.2, 126.9, 125.9, 125.2, 121.0, 53.2, 35.9, 19.7. ESI-MS *m*/*z* (%): 481 (M + Na$^+$, 100). Anal. calcd. for $C_{25}H_{22}N_4O_3S$: C 65.47, H 4.85, N 12.22; found: C 65.23, H 4.10, N 12.04.

Compound **1d**: 0.34 g, 79%. Mp 189–191 °C. [α]20D=+ 40.2° (*c* 0.02, DMSO). IR (KBr/cm^{-1}) 3,284, 2,924, 1,645, 1,514, 1,448, 1,338, 1,242, 1,206, 818, 756, 721, 657, 600, 505. ^{1}H NMR ($CDCl_3$): δ 8.48 (s, 1H, AnH), 8.24 (d, *J*= 8.1 Hz, 2H, AnH), 8.04 (d, *J*=8.1 Hz, 2H, AnH), 7.58 (s, 1H, NH-Ar), 7.48–7.58 (m, 4H, AnH), 7.23 (d, *J*=8.1 Hz, 2H, ArH), 7.05 (d, *J*=8.1 Hz, 2H, ArH), 6.69 (s, 1H, NH-CS), 6.39 (br, 1H, NH-CO), 5.30–5.49 (m, 2H, An-CH_2), 4.91–4.96 (m, 1H, *CH), 2.38 (s, 3H, CH_3-Ar), 1.36 (d, *J*= 7.2 Hz, 3H, *CHCH_3). ^{13}C NMR (DMSO-d_6): δ 179.9, 172.5, 137.2, 134.1, 131.2, 130.5, 129.7, 126.5, 125.8, 123.8, 53.1, 46.4, 36.0, 21.1, 20.1. ESI-MS *m*/*z* (%): 426 (M$^+$ −1, 100). Anal. calcd. for $C_{26}H_{25}N_3OS$: C 73.02, H 5.90, N 9.83; found: C 72.95, H 5.95, N 9.78.

Binding studies

The studies on the binding properties of **1a~b** were carried out in DMSO. The fluorescence titration was performed with a series of 5×10^{-5} mol L^{-1} solutions of receptors **1a~b** containing different amounts of chiral guests. The excited wavelengths were 372 nm. Association constants were calculated by means of a non-linear least square curve fitting method with Origin 7.0 (Origin-Lab Corporation).

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