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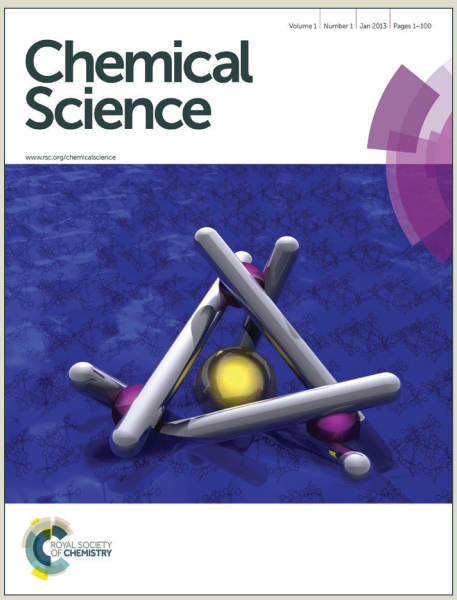

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EDGE ARTICLE

Zn(II) Promoted Dramatic Enhancement in the Enantioselective Fluorescent Recognition of Functional Chiral Amines by a Chiral Aldehyde

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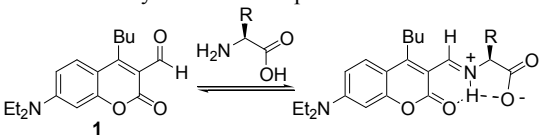
Addition of Zn^{2+} dramatically enhanced the enantioselective fluorescent responses of 3,3'-diformyl-1,1'-bi-2-naphthol toward chiral functional amines in methanol. One enantiomer of the chiral substrates including diamines, amino alcohols and amino acids was found to turn on the emission of this molecular probe at $\lambda > 500$ nm much more greatly than the other enantiomer. This emission signal is greatly red-shifted from most of the other BINOL-based enantioselective fluorescent sensors whose fluorescent signals are generally at 400±50 nm. Thus, a new window is opened for the use of BINOLs to observe the chiral recognition events. The fluorescent responses of the new probe in the presence of Zn^{2+} toward a chiral diamine have also allowed a visual discrimination of these two enantiomers because of their different emitting color and intensity. The mass spectroscopic analyses for the reaction of the probe+Zn^{2+} with the two enantiomers of a chiral diamine have revealed that the chirality match and miss-match between the probe and the substrate have produced different reaction products, generating very different fluorescent responses.

Introduction

Enantioselective fluorescent sensors can potentially provide a real time technique for the rapid determination of the enantiomeric composition of organic compounds. Recently, significant amount of research has been conducted in this area and a number of enantioselective fluorescent molecular probes have been developed.[1-5] Among these, the enantioselective recognition of chiral amines has been actively investigated.[3-5] This research often involves the intermolecular interaction of an organic fluorophore with an amine molecule via hydrogen bonding which causes changes in the fluorescent signal. These interactions, however, limit the application of these probes mostly to the less polar nonprotic solvents because protic solvents can disrupt the hydrogen bonds. Since many functional chiral amines such as amino acids are more soluble in alcohols and water, it is important to develop enantioselective fluorescent sensors in these solvents.

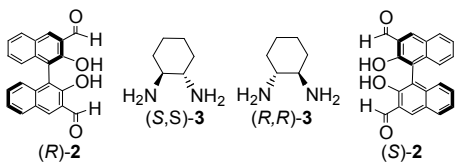
Metal complexes have been used for the recognition of chiral amines[6] and a few were used for enantioselective fluorescent sensing.[6d-f] Compounds such as trifluoromethyl ketones[7-10] and aldehydes[11,12] that contain electrophilic carbonyl groups can form covalent bonds with amines and are found to be useful for amine detection in polar solvents. In 2003, Feuster and Glass reported that the reaction of the aldehyde **1** with amino acids to generate highly fluorescent iminium ions (Scheme 1).[11a] Other aldehydes have also been reported for optical and NMR detections of amines.[11b-d,12] However, almost no aldehyde-based molecular probe was developed for the enantioselective fluorescent recognition of chiral amines.[12-15] Herein, we reported a Zn(II)-promoted greatly enhanced enantioselective fluorescent response to a variety of functional chiral amines in a protic solvent by using a chiral aldehyde.

Scheme 1. An aldehyde fluorescent probe for amino acids.



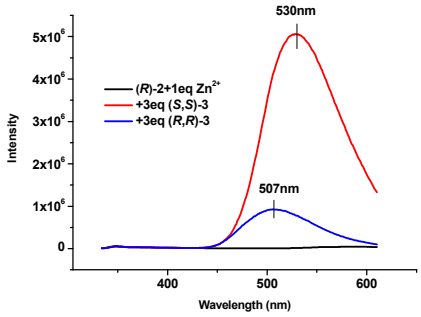
Results and Discussion

The 1,1'-bi-2-naphthol (BINOL)-based chiral dialdehyde (*R*)-**2** is often used in the preparation of many other BINOL derivatives, but its fluorescent property in the presence of chiral amines was not investigated before.[16-19] We prepared this compound from (*R*)-BINOL in three steps.[17] The fluorescent response of this compound toward the two enantiomers of *trans*-1,2-diaminocyclohexane, (*S,S*)- and (*R,R*)-**3**, was then studied. Compound (*R*)-**2** showed only very weak fluorescence in methanol solution. When this solution was treated with 0.2 – 8 equiv of (*R,R*)- or (*S,S*)-**3**, its fluorescence remained to be

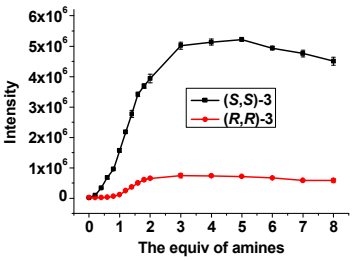


very weak (Figure S1). Thus, this chiral aldehyde cannot serve as an efficient molecular probe for the fluorescent recognition of the amine in the protic solvent.

Since the reaction of a carbonyl compound with amines could be promoted by using a Lewis acid, we tested the interaction of (*R*)-**2** with (*S,S*)-**3** in the presence of $Zn(OAc)_2{\cdot}2H_2O$ in methanol. When (*R*)-**2** was treated with 1 equiv Zn^{2+}, there was almost no change in its weak fluorescence at λ = 368 nm (Figure S2). However, when (*S,S*)-**3** was added to this (*R*)-**2**+Zn^{2+} solution, a dramatic fluorescent enhancement at λ = 530 nm was observed (Figure 1a and S16a). The emissions of various BINOL derivatives were generally observed at λ = 400±50 nm.[1b] Thus, from (*R*)-**2** to its Zn(II) promoted interaction with the amine, there was an unusually large red shift of 162 nm in emission wavelength accompanied with an enormous increase in intensity. We then treated the (*R*)-**2**+Zn^{2+} solution with the diamine enantiomer (*R,R*)-**3**, the fluorescent enhancement at a different wavelength (λ = 507 nm) was observed (Figure 1a and S16b), and the fluorescent intensity was also much weaker than that with (*S,S*)-**3**. When the fluorescence intensity at λ = 530 nm, I_{530}, is plotted against the concentration of the chiral diamine, the resulting Figure 1b displays a high enantioselectivity.



(a)



(b)

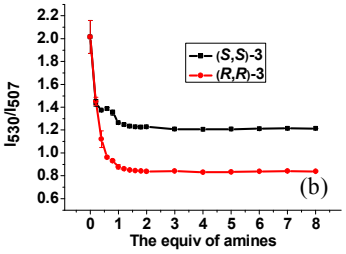
Figure 1. Fluorescence spectra of (*R*)-**2**+Zn^{2+}(1 equiv) (2.0×10^{-5} M in methanol/1% CH_2Cl_2) in the presence of (*S,S*)-and (*R,R*)-**3** (a), and I_{530} nm versus the concentration of the amines (b). (λ_{exc} = 314 nm, slit = 5/5 nm.).

We also prepared (*S*)-**2**, the enantiomer of (*R*)-**2**, and studied the fluorescent responses of its solution with 1 equiv Zn^{2+} in methanol toward (*S,S*)- and (*R,R*)-**3**. The expected mirror image relationship with Figure 1 and S16 was observed which confirmed the observed enantioselective fluorescent recognition (Figure S3).

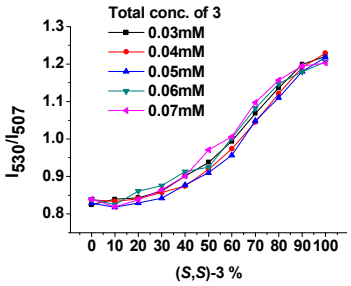
Figure 2 shows the photo images of the (*R*)-**2**+Zn^{2+} methanol solution upon treatment with 2 equiv of (*S,S*)-**3** and (*R,R*)-**3** respectively under a UV lamp irradiation at 365 nm. It shows that the addition of (*S,S*)-**3** converted an almost nonfluorescent solution to one emitting intense yellow color. The addition of (*R,R*)-**3** gave a weaker green emission. Thus, the use of the (*R*)-**2**+Zn^{2+} methanol solution also allowed a visual discrimination of the two enantiomers of the chiral diamine.

Figure 2. From left to right: (*R*)-**2**+Zn^{2+}(1 equiv) (2.0×10^{-5} M in methanol/1% CH_2Cl_2), with 2equiv (*S,S*)-**3**, and (*R,R*)-**3** under a UV lamp irradiation at 365nm.

We further plotted the concentration of the chiral diamine against the fluorescent intensity ratio I_{530}/I_{507} for the interaction of the (*R*)-**2**+Zn^{2+} methanol solution with (*S,S*)-**3** and (*R,R*)-**3**. As shown in Figure 3a, when more than 1 equiv of the amine was added, I_{530}/I_{507} was independent of the amine concentration. We measured I_{530}/I_{507} versus the enantiomeric composition of the chiral diamine at various total



(a)



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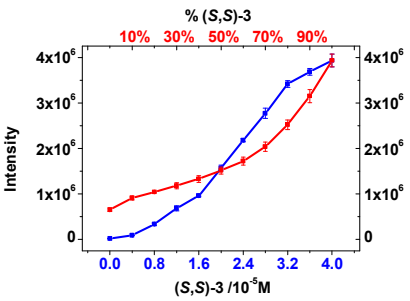


(c)

Figure 3. I_{530}/I_{507} for (*R*)-**2**+Zn^{2+}(1 equiv) (2.0×10^{-5} M in methanol/1% CH_2Cl_2) versus the concentration of (*S,S*)- and (*R,R*)-**3** (a), I_{530}/I_{507}versus the enantiomeric purity of (*S,S*)-**3** at various concentrations (b), and I_{530} versus the enantiomeric purity of (*S,S*)-**3** at a total amine concentration of 4.0 x 10^{-5} M (red curve) and the concentration of the enantiomerically pure (*S,S*)-**3** (blue curve) (c). (λ_{exc}= 314nm, slits: 5/5nm)

concentrations. As shown by Figure 3b, I_{530}/I_{507} could be used to determine the enantiomeric composition of (*S,S*)-**3** in the mixture when the amount of (*S,S*)-**3** was >30%. For the low enantiomeric range [<30% of (*S,S*)-**3**], the composition of (*R,R*)-**3** would be high (>70%) which could be determined by using the enantiomer sensor (*S*)-**2**. The effect of the diamine concentration on the enantiomeric composition determined with I_{530}/I_{507} is less than 10% which should be adequate for high throughput chiral assay.

The red curve in Figure 3c shows I_{530} versus the enantiomeric composition of (*S,S*)-**3** in the mixture with its enantiomer (*R,R*)-**3**. The blue curve in Figure 3c shows I_{530} versus the concentration of the enantiomerically pure (*S,S*)-**3**. The difference between these two curves demonstrates that the enantiomer (*R,R*)-**3** contributes positively when it is >50% and negatively when it is <50% to the fluorescent enhancement of (*R*)-**2**+Zn^{2+} at 530 nm caused by the enantiomeric mixture.

In order to gain a better understanding of the Zn^{2+}-promoted reaction of (*R*)-**2** with the chiral diamine, we conducted a TOF mass spectroscopic (ES+) analysis of the product mixture for the reaction of (*R*)-**2**+Zn^{2+}(1 equiv) with (*S,S*)-**3** (2 equiv) in methanol (Figure S4a). The mass spectrum shows a peak at m/z = 535 (41.6) that could be assigned to (**4**+H)$^+$, a base peak at m/z = 630 (100) that could be assigned to a zinc complex **5**$^+$, a peak at m/z = 841 (27.1) that could be assigned to a macrocycle (**6**+H)$^+$, a peak at m/z = 905 (14.0) that could be assigned to a macrocyclic zinc complex (**6**+Zn+H)$^+$ (*vide infra*), and a peak at m/z = 1395 (6.3) that could be assigned to a trimeric zinc complex (**7**-H)$^+$ (Figure 4).

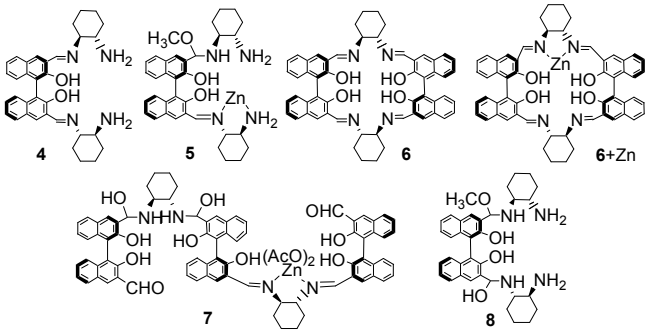


Figure 4. Proposed product structures for the reaction of (*R*)-**2** with (*S,S*)-**3**.

Previously, Brunner and Schiessling reported that (*R*)-**2** reacted with (*S,S*)-1,2-diphenylethylenediamine to generate a (2+2) macrocycle but with (*R,R*)-1,2-diphenylethylenediamine only formed acyclic oligomers.[18] In 2005, we reported that (*R*)-**2** reacted with (*S,S*)-**3** in methylene chloride to form the macrocycle **6** in 2 d at room temperature without using a metal catalyst but with (*R,R*)-**3** did not give a macrocycle.[19] The macrocycle **6** was prepared by modifying our previous procedure.[19b] Analysis of the product mixture of **6**+Zn^{2+}(1 equiv) in methanol with TOF mass spectroscopy (ES+) (Figure S4b) shows peaks at m/z = 841 (12.2) and 905 (5.3) corresponding to (**6**+H)$^+$ and (**6**+Zn+H)$^+$ respectively. This confirms the peak assignment made for the reaction of (*R*)-**2**+Zn^{2+} with (*S,S*)-**3**. The reaction of **6** with Zn^{2+} in methanol also gave a mass peak at m/z = 586 (100) which could be assigned to (**8**+2H)$^+$ (Figure 4), indicating a Zn^{2+} catalyzed partial hydrolysis and alcoholysis of the macrocycle in methanol (not dried).

The reaction of (*R*)-**2**+Zn^{2+}(1 equiv) with (*R,R*)-**3** (2 equiv) was also analyzed by using the TOF mass spectroscopy (ES+) (Figure S5) and it gave remarkably different signals from the reaction with (*S,S*)-**3**. Almost no signal corresponding to the macrocycle **6** and its Zn^{2+} complex **6**+Zn could be observed. The mass spectrum of (*R*)-**2**+Zn^{2+}+(*R,R*)-**3** gave a peak at m/z = 630 (43.6) corresponding to a compound like **5**$^+$, and a base peak at m/z = 586 (100) like (**8**+2H)$^+$. Thus the major difference between the reaction of (*R*)-**2** with (*S,S*)-**3** and (*R,R*)-**3** in the presence of Zn^{2+} should be the ability of (*R*)-**2** to form a (2+2) macrocycle **6** with (*S,S*)-**3** but not with (*R,R*)-**3**, consistent with the previous observations made in the *absence* of Zn^{2+}.[18,19] This difference led to the observed different fluorescence responses of (*R*)-**2**+Zn^{2+} toward the two enantiomers of the chiral diamine.

We studied the fluorescent response of the macrocycle **6** toward Zn^{2+} in methanol. It was found that addition of Zn^{2+} to the methanol solution of **6** led to large fluorescence enhancements at λ = 530 nm (Figure 5a). This further supports the assignment that the observed fluorescent enhancement of (*R*)-**2**+Zn^{2+} in the presence of (*S,S*)-**3** at λ = 530 nm should be due to the formation of the macrocyclic zinc complexes. As shown in Figure 5b, the fluorescent enhancement of **6** reached maximum when about 1 – 2 equiv Zn^{2+} were added. This suggests that the formation of the monozinc complex **6**+Zn and a dizinc complex **6**+2Zn should be responsible for the observed enhancement at λ = 530 nm.[20]

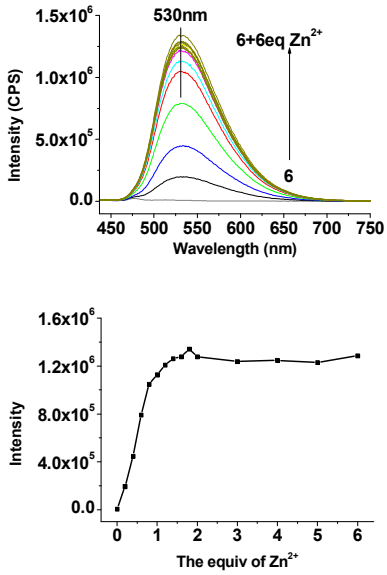
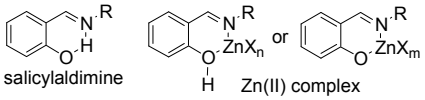


Figure 5. Fluorescence spectra of **6** (1.0 x 10^{-5} M in methanol/1% CH_2Cl_2) in the presence of Zn^{2+} (a), and I_{530} versus concentration of Zn^{2+} (b). (λ_{exc}= 417 nm, slits: 5/5nm).

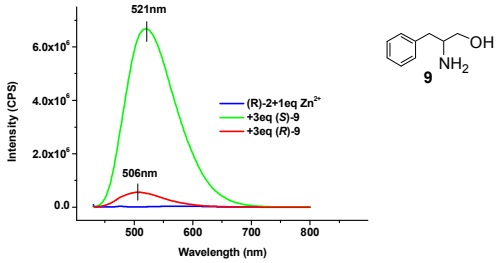
We also conducted ^{1}H NMR analyses for the reaction of (*R*)-**2** with (*S,S*)-**3** and (*R,R*)-**3** in the presence of Zn^{2+}. The NMR spectra showed broad signals with indications of multiple product formation (Figure S6 and S7). The reactions of the two enantiomers gave very different product signal patterns.

Upon excitation, salicylaldimines were observed to undergo an excited state intramolecular proton transfer process via the hydrogen bond of the OH···N=C unit.[21] Coordination of Zn^{2+} to these compounds could inhibit this excited state proton transfer process and has been shown to give enhanced fluorescence.[20] A coordination caused restriction of the C=N

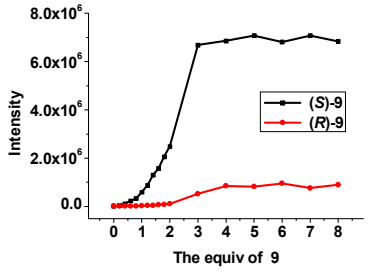
isomerization in the excited state was also proposed to contribute to the fluorescent enhancement of the Schiff base-Zn^{2+} complexes.[20j] These fluorescent responses have been used for Zn^{2+} detection but not for chiral recognition until this work.[22] Our observed enantioselective fluorescent enhancement could thus be attributed to the difference in the emissions of the different salicylaldimine-Zn^{2+} complexes generated from the reaction of (*R*)-**2**+Zn^{2+} with the two enantiomers of the diamine as discussed earlier.



Besides the chiral diamine (*S,S*)- and (*R,R*)-**3**, we found that (*R*)-**2** in combination with Zn^{2+} also exhibited highly enantioselective fluorescent responses to the chiral amino alcohol phenylalaninol (*S*)- and (*R*)-**9**. As shown in Figure 6a, (*S*)-**9** greatly enhanced the fluorescence of the methanol solution of (*R*)-**2**+Zn^{2+} at λ = 521 nm but (*R*)-**9** led to a much weaker fluorescence enhancement at a shorter wavelength of λ = 508 nm. Figure 6b plots the fluorescent enhancement of (*R*)-**2**+Zn^{2+} versus the concentration of (*S*)- and (*R*)-**9** at λ = 521 nm. It was found that the fluorescent intensity ratio I_{521}/I_{508} was also independent of the concentration of the amino alcohol when it is in excess of the sensor (Figure S8).



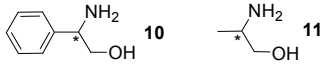
(a)



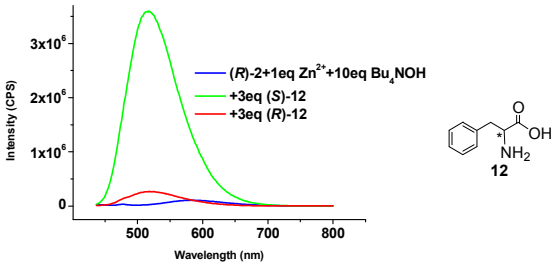
(b)

Figure 6. Fluorescence spectra of (*R*)-**2**+Zn^{2+}(1 equiv) (2.0 x 10^{-5} M in methanol/1% CH_2Cl_2)with (*S*)-and (*R*)-**9** (a), and I_{521} nm versus the amino alcohol concentration (b). (λ_{exc}= 417nm, slits: 5/5nm).

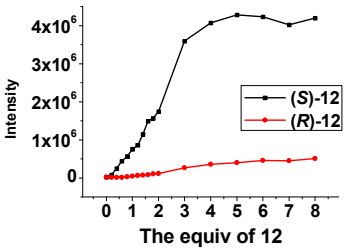
We further found that the methanol solution of (*R*)-**2**+Zn^{2+} exhibited highly enantioselective fluorescent recognition of additional amino alcohols such as phenylglycinol (**10**) and alaninol (**11**) (Figure S9 and S10). In each case, the *S* enantiomer of the amino alcohol led to much greater fluorescent enhancement at λ ~ 530 nm, and the *R* enantiomer caused smaller fluorescent enhancement at a shorter wavelength of λ ~ 500 nm.



The (*R*)-**2**+Zn^{2+}(1 equiv) methanol solution in the presence of excess Bu_4NOH also showed highly enantioselective fluorescent responses toward chiral amino acids. When the methanol solution of (*R*)-**2**+Zn^{2+} was treated with 10 equiv Bu_4NOH, a weak emission signal at λ = 600 nm was observed (Figure 7a). This long wavelength emission could be attributed to the base deprotonated (*R*)-**2** in combination with Zn^{2+}. When this solution was treated with the amino acid phenylalanine (*S*)-**12**, great fluorescent enhancement at λ = 515 nm was observed (Figure 7a and S19a). When the (*R*)-**2**+Zn^{2+}+Bu_4NOH solution was treated with (*R*)-**12**, the fluorescent enhancement was much weaker although still at λ= 515 nm (Figure 7a and S19b). Figure 7b displays the enantioselective fluorescent responses of (*R*)-**2**+Zn^{2+}+Bu_4NOH at various amino acid concentrations.



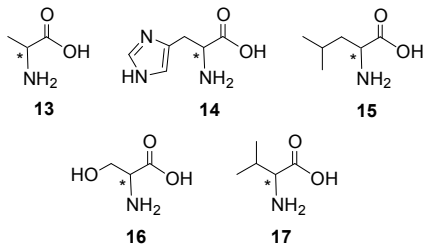
(a)



(b)

Figure 7. Fluorescence spectra of (*R*)-**2**+Zn^{2+}(1equiv) (2.0 x 10^{-5} M in methanol/1% CH_2Cl_2 with 10 equiv Bu_4NOH)with (*S*)- and (*R*)-**12** (a), and I_{515} nm versus the amino acid concentration (b). (λ_{exc}= 417nm, slits: 5/5nm).

Under the same conditions, a series of other amino acids including alanine (**13**), histidine (**14**), leucine (**15**), serine (**16**) and valine (**17**) also caused enantioselective fluorescent enhancements (Figures S11 – S15).



Experimental

General data

^1H NMR, ^{13}C NMR spectra were measured on a Bruker AM400 NMR spectrometer. Proton chemical shifts of NMR spectra were given in ppm relative to internals reference TMS (1H, 0.00 ppm). ESI-MS and HRMS spectral data were recorded on a Finnigan LCQ^{DECA} and a BrukerDaltonics Bio TOF mass spectrometer, respectively. Fluorescent spectra were

obtained using FluoroMax-4 Spectrofluorophotometer (HORIBA JobinYvon) at 298 K. Unless otherwise noted, materials were obtained from commercial suppliers and were used without further purification. All the solvents were dried according to the standard methods prior to use. All of the solvents were either HPLC or spectroscopic grade in the optical spectroscopic studies. $Zn(OAc)_2$-$2H_2O$ was used as the Zn^{2+} source except for the experiments of Figures 5, S6 and S7 where $ZnBr_2$ was used.

Preparation of Samples for Fluorescent Measurement.

For interactions with the diamine and amino alcohols: Stock solutions of 2 mM (*R*)-**2** in CH_2Cl_2 and 2 mM $Zn(OAc)_2{\cdot}2H_2O$ in CH_3OH were freshly prepared for each measurement. For the fluorescent enhancement study, a solution of (*R*)-**2**+Zn^{2+}(1 equiv) (2 mM) was mixed with various equiv of the diamine or amino alcohol solution (1.2 mM or 6 mM in CH_3OH) in a 10 mL test tube. The resulting solution was allowed to stand at room temperature for 1.5 h before being diluted to the desired concentration (0.02 mM). All the fluorescent spectra were taken within 2 h.

For interactions with the amino acids: Stock solutions of 2 mM (*R*)-**2** in CH_2Cl_2, 2 mM $Zn(OAc)_2{\cdot}2H_2O$ in CH_3OH and 6 mM Bu_4NOH in CH_3OH were freshly prepared for each measurement. For the fluorescent enhancement study, a solution of (*R*)-**2**+Zn^{2+}(1 equiv)+Bu_4NOH (10 equiv) (2 mM) was mixed with various equiv of the amino acid solution (1.2 mM or 6 mM in H_2O) in a 10 mL test tube. The resulting solution was allowed to stand at room temperature for 1.5 h before being diluted to the desired concentration (0.02 mM). All the fluorescent spectra were taken within 2 h.

Conclusions

In conclusion, we have discovered that the addition of Zn^{2+} to the methanol solution of a BINOL-based chiral aldehyde (*R*)-**2** leads to dramatically enhanced enantioselective fluorescent responses toward various functional chiral amines. It represents one of the first chiral aldehydes capable of enantioselective fluorescent recognition of chiral amines. The presence of Zn^{2+} turns on the emission signal of (*R*)-**2** at $\lambda > 500$ nm upon interaction with amines in a protic solvent which is greatly red-shifted from most of the other BINOL-based sensors whose fluorescent signals are generally at 400±50 nm. This opens a new and visible window for the use of BINOLs to observe chiral recognition events. The fluorescent responses of (*R*)-**2**+Zn^{2+} toward the chiral diamine (*S,S*)- and (*R,R*)-**3** have allowed a visual discrimination of these two enantiomers because of their different emitting color and intensity. The mass spectroscopic analyses for the reaction of (*R*)-**2**+Zn^{2+} with the two enantiomers (*S,S*)- and (*R,R*)-**3** have revealed that the chirality match and miss-match between the sensor and the substrate have produced different reaction products, generating very different fluorescent responses. In addition, the methanol solution of (*R*)-**2**+Zn^{2+} also showed highly enantioselective fluorescent responses toward a number of amino alcohols and amino acids, demonstrating a broad applicability of this novel sensor system. The mechanisms of these reactions are under further investigation.

Acknowledgements

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Notes and references

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1. For reviews on enantioselective fluorescent recognition: (a) Pu, L. *Chem. Rev.***2004**, *104*, 1687–1716. (b) Pu, L. *Acc. Chem. Res*. **2012**, *45*, 150–163. (c) Leung, D.; Kang, S. O.; Anslyn, E. V. *Chem. Soc. Rev*. **2012**, *41*, 448–479. (d) Accetta, A.; Corradini, R.; Marchelli, R. *Top. Curr. Chem*. **2011**, *300*, 175–216. (e) Zhang, X.; Yin, J.; Yoon, J. *Chem. Rev*. **2014**, ASAP.
2. (a) James, T. D.; Sandanayake, K. R. A. S.; Shinkai, S. *Nature* **1995**, *374*, 345–347. (b) Lin, J.; Hu, Q. -S.; Xu, M. H.; Pu, L. *J. Am. Chem. Soc*. **2002**, *124*, 2088–2089. (c) Zhao, J.-Z.; Fyles, T. M.; James, T. D. *Angew. Chem., Int. Ed.* **2004**, *43*, 3461–3464. (d) Zhu, L.; Anslyn, E. V. *J. Am. Chem. Soc.* **2004**, *126*, 3676–3677. (e) Mei, X. F.; Wolf, C. *J. Am. Chem. Soc*. **2004**, *126*, 14736–14737
3. (a) Pugh, V.; Hu, Q. -S.; Pu, L. *Angew. Chem.* Int. *Ed.* **2000**, *39*, 3638–3641. (b) Wang, Q.; Chen, X.; Tao, L.;Wang, L.; Xiao, D.; Yu, X. Q.; Pu, L. *J. Org. Chem*. **2007**, *72*, 97–101. (c) Zheng, Y.-S.; Hu, Y.-J. *J. Org. Chem*. **2009**, 74, 5660–5663.
4. (a) Reetz, M. T.; Sostmann, S. *Tetrahedron* **2001**, *57*, 2515–2520. (b) Prodi, L.; Bolletta, F.; Montalti, M.; Zaccheroni, N.; Huszthy, P.; Samu, E.; Vermes, B. *New. J. Chem.***2000,***24*,781–785. (c) Upadhyay, S. P.; Pissurlenkar, R. R. S.; Coutinho, E. C.; Karnik, A. V. *J. Org. Chem.***2007,***72*, 5709–5714. (d) Mei, X. F.; Wolf, C., *Chem. Commun.***2004,** 2078–2079.
5. (a) Wong, W.-L.; Huang, K.-H.; Teng, P.-F.; Lee, C.-S.; Kwong, H.-L. *Chem. Commun.* **2004**, 384–385. (b) Wang, H.; Chan, W.-H.; Lee, A. W. M. *Org. Biomol. Chem.* **2008**, 6, 929–934.
6. (a) Chin, J.; Lee, S. S.; Lee, K. J.; Park, S.; Kim, D. H. *Nature* **1999**, *401*, 254–257. (b) Holmes, A. E.; Zahn, S; Canary, J. W. *Chirality* **2002**, *14*, 471–477. (c) Folmer-Andersen, J. F.; Lynch, V. M.; Anslyn, E. V. *J. Am. Chem. Soc.* **2005**, *127*, 7986–7987. (d) Corradini, R.; Sartor, G.; Marchelli, R.; Dossena, A.; Spisni, A. *J. Chem. Soc., Perkin Trans. 2* **1992**, 1979–1983. (e) Pagliari, S.; Corradini, R.; Galaverna, G.; Sforza, S.; Dossena, A.; Marchelli, R. *Tetrahedron Lett.* **2000**, *41*, 3691-3965. (f) Yang, X.; Liu, X. C.; Shen, K.; Zhu, C. J.; Cheng, Y. X. *Org. Lett*. **2011**, *13*, 3510–3513.
7. (a) Mohr, G. J.; Tirelli, N.; Lohse, C.; Spichiger-Keller, U. E. *Adv. Mater*. **1998**, *10*, 1353–1357. (b) Mertz, E.; Zimmerman, S. C. *J. Am. Chem. Soc.* **2003**, *125*, 3424–3425.
8. (a) Sasaki, S. –i.; Kotegawa, Y.; Tamiaki, H. *Tetrahedron Lett*. **2006**, *47*, 4849–4852. (b) Sasaki, S.; Monma, G.; Citterio, D.; Yamada, K.; Suzuki, K. *Chimia* **2005**, *59*, 204–208.
9. Ryu, D.; Park, E.; Kim, D. –S.; Yan, S.; Lee, J. Y.; Chang, B. –Y.; Ahn, K. H. *J. Am. Chem. Soc*. **2008**, *130*, 2394–2395.
10. Yu, S. S.; Plunkett, W.; Kim, M.; Pu, L. *J. Am. Chem. Soc*. **2012**, *134*, 20282–20285.
11. (a) Feuster, E. K.; Glass, T. E. *J. Am. Chem. Soc.* **2003**, *125*, 16174–16175. (b) Tanaka, F.; Mase, N.; Barbas, C. F. *Chem. Commun.* **2004**, 1762–1763. (c) Oguri, S.; Mizusawa, A.; Kamada, M.; Kohori, M. *Anal ChimActa***2006**, *558*, 326–331. (d) Kumpf, J.; Bunz, U. H. F. *Chem. Eur. J*. **2012**, *18*, 8921–8924.
12. There was only one report on using a chiral aldehyde for the enantioselective fluorescent recognition of a chiral amino acid: Tang, L.; Wei, G.; Nandhakumar, R.; Guo, Z. *Bull. Korean Chem. Soc.* **2011**, *32*, 3367-3371.

13. Circular dichroism spectra of an achiral aldehyde in combination with a chiral compound were used to recognize chiral amines: (a) Nieto, S.; Dragna, J. M.; Anslyn, E. V. *Chem. Eur. J*. **2010**, *16*, 227–232. (b) Bentley, K. W.; Nam, Y. G.; Murphy, J. M.; Wolf, C. *J. Am. Chem. Soc*. **2013**, *135*, 18052–18055.
14. BINOL-based monoaldehydes were shown to conduct stereoselective recognition of chiral amino acids by NMR: (a) Park, H.; Kim, K. M.; Lee, A.; Ham, S.; Nam, W.; Chin, J. *J. Am. Chem. Soc*. **2007**, *129*, 1518–1519. (b) So, S. M.; Moozeh, K.; Lough, A. J.; Chin, J. *Angew. Chem. Int. Ed*. **2014**, *53*, 829–832.
15. Reviews of sensors for amines: (a) Mohr, G. J. *Anal BioanalChem***2006**, *386*, 1201–1214. (b) Zhou, Y.; Yoon, J. *Chem. Soc. Rev*. **2012**, *41*, 52–67.
16. Brunner, H.; Schiessling, H. *Bull. Soc. Chim. Belg*. **1994**, *103*, 119–126.
17. Zhang, H. –C.; Huang, W. –S.; Pu, L. *J. Org. Chem*. **2001,** *66,* 481–487.
18. Brunner, H.; Schiessling, H. *Angew. Chem.*, *Int. Ed. Engl*. **1994**, *33*, 125–126.
19. (a) Li, Z. –B.; Lin, J.; Pu, L. *Angew. Chem. Int. Ed.***2005**, 44, 1690–1693. (b) Li, Z. –B.; Lin, J.; Sabat, M.; Hyacinth, M.; Pu, L. *J. Org. Chem*. **2007**, *72*, 4905–4916.
20. Selected reports on the fluorescent enhancement of salicylaldimine-type compounds upon Zn^{2+} coordination: (a) Pathak, R. K.; Ibrahim, S. M.; Rao, C. P. *Tetrahedron Lett*.**2009**, 50, 2730–2734. (b) Royzen, M.; Durandin, A.; Young, Jr., V. G.; Geacintov, N. E.; Canary, J. W. *J. Am. Chem. Soc*. **2006**, *128*, 3854-3855. (c) Hsieh, W. H.; Wan, C. –F.; Liao, D. –J.; Wu, A. –T. *Tetrahedron Lett*. **2012**,*53*, 5848–5851. (d) Majumder, S.; Mandal, L.; Mohanta, S. *Inorg. Chem*. **2012**, *51*, 8739–8749. (e) Wen, H. –R.; Wang, Y.; Chen, J. –L.; Tang, Y. –Z.; Liao, J. –S.; Liu, C. –M. *Inorg. Chem. Comm*. **2012**, *20*, 303–306. (f) Wang, L.; Qin, W.; Tang, X.; Dou, W.; Liu, W. *J. Phys. Chem. A* **2011**, *115*, 1609–1616. (g) Cao, J.; Zhao, C.; Wang, X.; Zhang, Y.; Zhu, W. *Chem. Commun*. **2012**, *48*, 9897–9899. (h) Huang, X. –B.; Miao, Q.; Wang, L.; Jiao, J. –M.; He, X. –J.; Cheng, Y. -X. *Chin. J. Chem.* **2013**, *31*, 195—199. (i) Wang, F.; Moon, J. H.; Nandhakumar, R.; Kang, B.; Kim, D.; Kim, K. M.; Lee, J. Y.; Yoon, J. *Chem. Commun*. **2013**, 49, 7228. (j) A review on fluorescent sensors for Zn^{2+}: Xu, Z. C.; Yoon, J. Y.; Spring, D. R.; *Chem. Soc. Rev*. **2010**, 39, 1996-2006.
21. (a) Barbara, P. F.; Rentzepis, P. M.; Brus, L. E. *J. Am. Chem. Soc.* **1980**, *102*, 2786-2791. (b) A review: Formosinho, S. J.; Arnaut, L. G. *J. Photochem. Photobiol, A: Chem*. **1993**, *75*, 21-48.
22. An achiral Zn(II)-salen complex was used for the fluorescent detection of aliphatic amines: Oliveri, I. P.; Bella, S. D. *J. Phys. Chem. A* **2011**, *115*, 14325–14330.

