Received: 9 September 2016 | Revised: 23 February 2017 | Accepted: 24 February 2017

DOI: 10.1002/bio.3327

WILEY LUMINESCENCE
The Journal of Biological and Chemical Luminescence

RESEARCH ARTICLE

Novel enantioselective fluorescent sensors for tartrate anion based on acridinezswsxa

Chaoyu Wang[1] | Peng Wang[1] | Xiaoyan Liu[1] | Jiaxin Fu[1] | Kun Xue[2] | Kuoxi Xu[1]

[1] Engineering Laboratory for Flame Retardant and Functional Materials of Henan Province, College of Chemistry and Chemical Engineering, Henan University, Kaifeng, China

[2] Institute of Environmental and Analytical Sciences, College of Chemistry and Chemical Engineering, Henan University, Kaifeng, China

Correspondence
Kuoxi Xu, Engineering Laboratory for Flame Retardant and Functional Materials of Henan Province, College of Chemistry and Chemical Engineering, Henan University, Kaifeng, Henan 475004, China
Email: xukx@henu.edu.cn

Funding Information
National Natural Science Foundation of China, Grant/Award Number: U1404207; The Program for He'nan Innovative Research Team in University, Grant/Award Number: 15IRTSTHN005

Abstract

Novel chiral fluorescence sensors **L-1** and **D-1** incorporating *N*-Boc-protected alanine and acridine moieties were synthesized. The recognition ability of the sensors was studied by fluorescence titration, ^{1}H NMR spectroscopy and density functional theory (DFT) calculations. The sensors exhibited good enantioselective fluorescent sensing ability toward enantiomers of tartrate anion for the selected carboxylate anions and formed 1: 1 complexes by multiple hydrogen bonding interactions.

KEYWORDS

enantioselective recognition, sensor, tartrate anion

1 | INTRODUCTION

Fluorescence sensors can effectively provide a real-time analytical tool for the direct and simple chiral enantiomeric determination of chiral reagents, catalysts, natural products and drugs.[1–3] Because of their sensitivity, selectivity and versatility fluorescence techniques have been used to study the interaction between enantiomers and sensors.[4] The principles for constructing chiral fluorescent sensors are based on studies of biological compounds, among which carboxylic acids are one of the most attractive targets in this field because of their central role in many enzyme activities, DNA regulation, hormone transport, peptide synthesis and intracellular communication.[5–7] The practical, rapid and accurate methods applied in enantioselective recognition of chiral carboxylate are an important analytically in nature and biological processes.[8–11] Our approach to the design of a novel chiral fluorescence sensor relies on the covalent attachment of chiral amino acid substituents to the fluorophore acridine via a short ester linker. Specifically, the chiral amino acid groups provide stereo centers, whereas the oxygen or amino atoms of the sensor form non-covalent interactions with hydroxyl or carboxylate anions of the guest via hydrogen bonding and electrostatic forces.[12–15] Furthermore, when the sensor interacts with the guest, oxygen or nitrogen atoms adjacent to the acridine fluorophore might quench the fluorescence via photo-induced electron transfer.[16–18] Here, we report the study of an acridine derivative as an enantioselective fluorescent sensor for recognition of tartrate anions.

Abbreviations used: DFT, density functional theory; DMSO, Dimethyl sulfoxide; ESI, Electrospray ionization; IR, Infrared; MS, Mass spectrometry; NMR, Nuclear magnetic resonance; TDDFT, Time-dependent DFT; UV, Ultraviolet; Vis, Visible.

2 | EXPERIMENTAL

2.1 | Materials

The reagents used were of commercial origin and were employed without further purification. Purification by column chromatography was carried out over silica gel (230–400 mesh). Optical rotations were undertaken on a Perkin–Elmer Model 341 polarimeter. The infrared (IR) spectra were performed on a Nicolet 670 FTIR spectrophotometer. High-resolution mass spectra were measured on an Agilent 1290LC-6540 Accurate Mass Q-TOF using electrospray ionization (ESI). ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker AV-400 spectrometer. Fluorescence spectra were obtained with an F-7000 FL spectrophotometer. Anions were used as their tetrabutylammonium

salts. 4,5-Bis(bromomethyl)acridine was prepared as described in the literature.[19]

2.2 | Syntheses

To a solution of 4,5-bis(bromomethyl)acridine (0.37 g, 1.0 mmol) in dichloromethane (10 ml), 20% NaOH (10 ml), tetrabutylammonium iodide (0.81 g, 2.2 mmol) and L- or D-*N*-Boc-protected alanine (2.2 mmol) were added consecutively. The mixture was stirred at room temperature for 2 days with monitoring by thin-layer chromatography. After consumption of the starting material, the mixture was poured into a separator funnel over water and extracted with dichloromethane. The combined organic extracts were rinsed with brine, dried over anhydrous Na_2SO_4, and the solvent evaporated under reduced pressure to yield crude products, which were then purified by column chromatography over silica gel using petroleum ether: ethyl acetate (10: 1) as the eluent to obtain the pure products **L-1** or **D-1** as yellow solids.

L-1: 0.23 g, yield, 39.7%; m.p.: 136–138°C; $[\alpha]_D^{20}$ = −52.8 (*c* = 0.50, $CHCl_3$); **D-1**: 0.24 g, yield, 41.5%; m.p.: 137–139°C; $[\alpha]_D^{20}$ = +49.6 (*c* = 0.50, $CHCl_3$); ^{1}H NMR ($CDCl_3$): δ8.73 (s, 1H), 7.94 (d, *J* = 5.4 Hz, 2H), 7.75 (d, *J* = 4.4 Hz, 2H), 7.52 (q, *J* = 5.1 Hz, 2H), 6.08 (d, *J* = 9.2 Hz, 2H), 5.95 (d, *J* = 9.2 Hz, 2H), 5.31 (s, 2H) 5.23 (s, 2H), 1.58 (s, 6H), 1.41 (s, 18H); ^{13}C NMR ($CDCl_3$): 173.40, 155.25, 145.96, 136.29, 134.05, 128.50,126.31, 125.58, 79.81, 63.88, 49.45, 28.37, 18.86; IR (KBr): 3357, 1741, 1689, 1531, 1220, 761 cm^{-1}. ESI-MS calcd for $C_{31}H_{39}N_3O_8$ $[M + Na]^+$ 604.26, found 604.30; elemental analysis calcd (%) for $C_{31}H_{39}N_3O_8$: C 64.01, H 6.76, N 7.22, found: **D-1,** C 63.97, H 6.73, N 7.18; **L-1**: C 63.95, H 6.71, N 7.17.

3 | RESULTS AND DISCUSSION

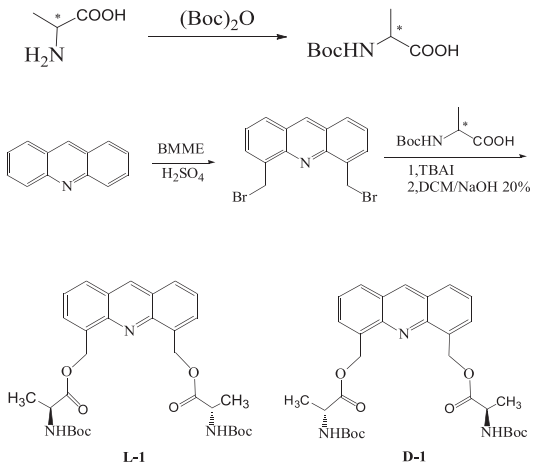
3.1 | Synthesis

Enantiopure chiral L-*N*-Boc-alanine was developed from the cheap and commercially available chiral alanine. The product was further reacted with 4,5-bis(bromomethyl)acridine at room temperature for 24 h to introduce the fluorescence group (Scheme 1). Preparation of compound **D-1**, an enantiomer of **L-1**, was the same as that for **L-1** by starting with D-*N*-Boc-alanine and 4,5-bis(bromomethyl)acridine. The structures of these compounds were characterized by IR, MS, ^{1}H NMR spectra and elemental analysis.

3.2 | Fluorescence spectroscopic studies

There was almost no change in the UV/vis spectra of sensor **L-1** or **D-1** upon addition of carboxylate anions such as D- or L-dibenzoyl tartrate, benzene lactate, phenylalanine, alanine, mandelate, malate, tartrate (as tetrabutylammonium salts) in acetonitrile, even when the guests were present in excess ([guest]/[**L-1** or **D-1**] = 50; Figure S1). Therefore, enantioselective recognition was investigated using the fluorescence spectra only. The fluorescence spectra of sensor **L-1** were studied in the presence of the above-mentioned enantiomers; we found that other anions produce a slight change in fluorescence, except for tartrate (Fig. 1).

Figure 2 shows the different fluorescence intensity changes when 50 equiv. of L- or D-tartrate anion was added to sensor **L-1**. The



SCHEME 1 Synthesis of compounds **L-1** and **D-1**

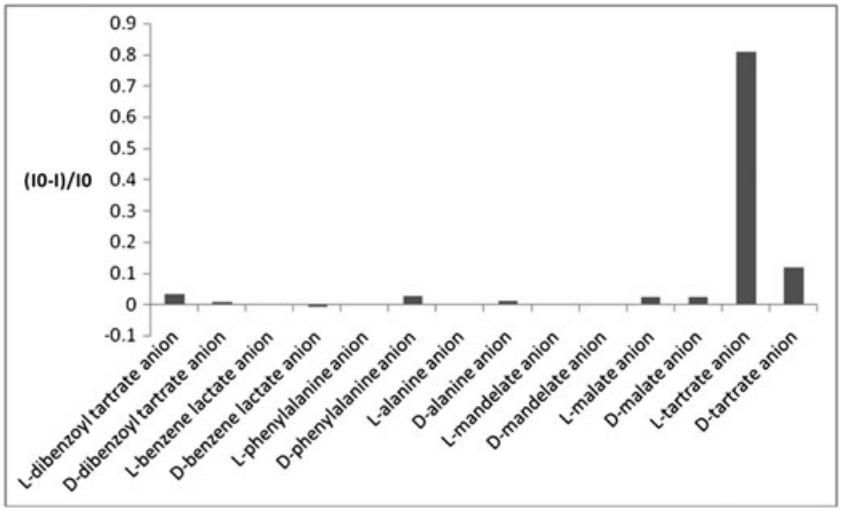


FIGURE 1 Fluorescent spectra changes of sensor **L-1** (3.0×10^{-5} M) measured in CH_3CN upon the addition of 100 equiv. of various anions (λ_{ex} = 356 nm). Fluorescent spectra changes ($(I–I_0)/I_0$) of sensor **L-1** (3.0×10^{-5} M) at 423 nm upon addition of different carboxylic acid anions (as tetrabutylammonium) in CH_3CN at 25°C (50 equiv., 1.5×10^{-3} M). L-Dibenzoyl tartrate anion, D-dibenzoyl tartrate anion, L-benzene lactate anion, D-benzene lactate anion, L-phenylalanine anion, D-phenylalanine anion, L-alanine anion, D-alanine anion, L-mandelate anion, D-mandelate anion, L-malate anion, D-malate anion, L-tartrate anion and D-tartrate anion

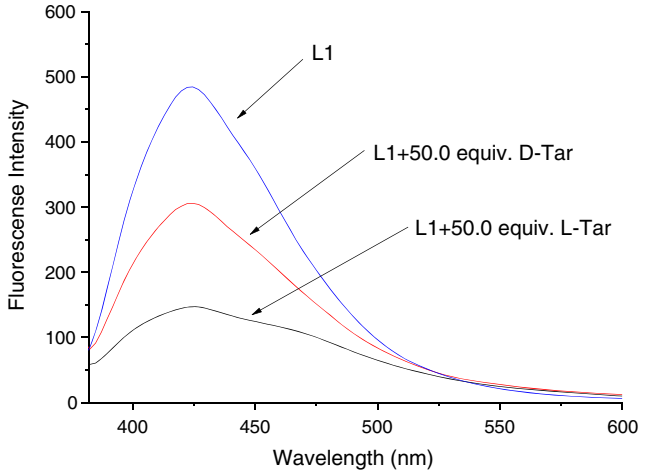


FIGURE 2 Fluorescent spectra of **L-1** (3.0×10^{-5} M) with 50.0 equiv. of L- or D-tartrate anion in CH_3CN (λ_{ex} = 356 nm)

quenching efficiency was ~70% when L-tartrate was added to the solution of **L-1**, but only ~38% when D-tartrate was added. The fluorescence quenching efficiencies ($\Delta I_L/\Delta I_D$ = 1.90) indicated that sensor **L-1** shows good enantioselective recognition between L- and D-tartrate anions. The decrease in fluorescence was similar to the anion-induced fluorescence quenching previously reported.[20,21] When the guest binds with the host, an electron from the anion transfers to the singly occupied molecular orbital (SOMO) of the excited fluorophore, which in turn prevents the excited-state binaphthyl electron from transferring to the lowest unoccupied molecular orbital (LUMO). Therefore, an anion-induced decrease in fluorescence was observed.[22,23]

To further understand the host–guest interaction, fluorescent titration was carried out. Titration of sensor **L-1** (3.0×10^{-5} M) with 50 equiv. of L- or D-tartrate anion in acetonitrile was undertaken. With the increase in anions, the fluorescence intensity of **L-1** gradually weakened, indicating that a host–guest interaction had happened. The fluorescence quenching efficiency was related to the nonlinear curve fitting (Fig. 3), which was determined by monitoring changes in the fluorescence intensity and applying measurable values to equation (1) below.[24,25] In equation (1) I_0 and I represent the fluorescence intensity of **L-1** in the absence and presence of L- or D-tartrate anion, and C_H and C_G are the concentrations of sensor **L-1** and tartrate anion respectively. C_0 is the initial concentration of **L-1**. Satisfactory nonlinear curve fitting (the correlation coefficient is >0.99) (Fig. 4) confirmed that a 1: 1 complex formed between sensor **L-1** and the L- or D-tartrate anion. For the1: 1 stoichiometry complex, the association constant (K_{ass}) was calculated from equation (1). The values of K_{ass} were 1.15×10^3 M^{-1} for L-tartrate and 2.29×10^2 M^{-1} for D-tartrate. This demonstrated that the interaction of sensor **L-1** with the tartrate anion was highly enantioselective ($K_{ass(L)}/K_{ass(D)}$ = 4.83).

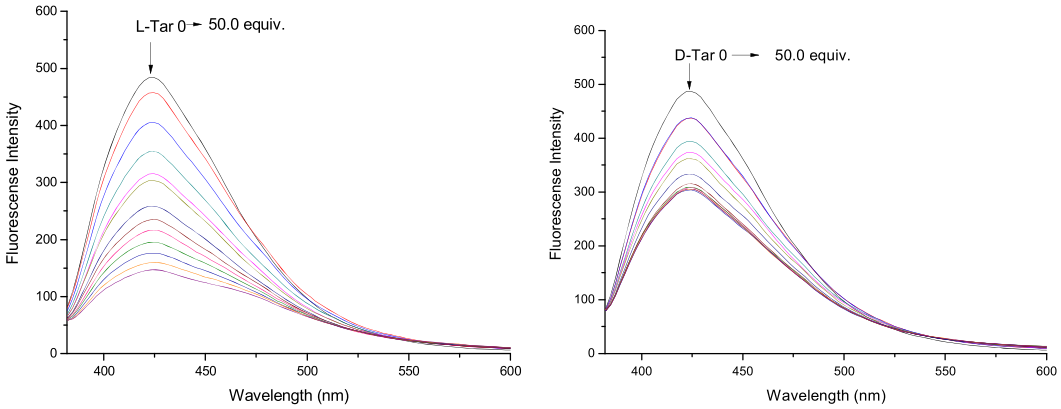


FIGURE 3 (a) Fluorescence spectra of sensor **L-1** (3.0×10^{-5} M) with L-tartrate anion in CH_3CN. Equivalents of anion: 0 → 50.0. (b) Fluorescence spectra of sensor **L-1** (3.0×10^{-5} M) with D-tartrate anion in CH_3CN. Equivalents of anion: 0 → 50.0

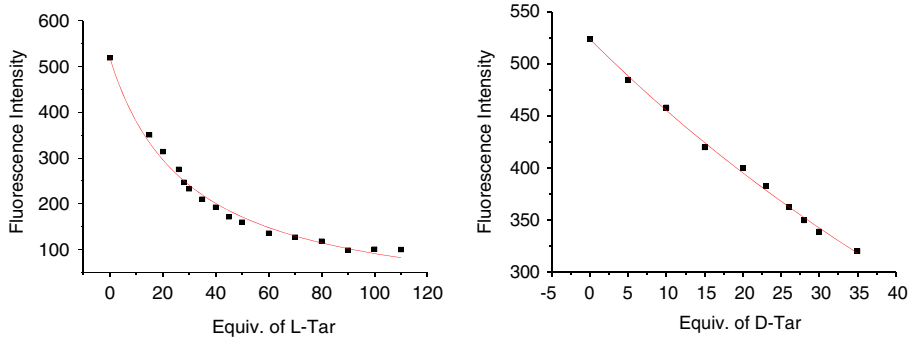


FIGURE 4 (a) Changes in the fluorescence intensity of **L-1** at 423 nm upon addition of L-tartrate anion. The line shown is a non-linear fitted curve. The correlation coefficient (*R*) of the non-linear curve fitting is 0.9949. (b) Changes in the fluorescence intensity of **L-1** at 356 nm upon addition of D-tartrate anion. The line shown is a non-linear fitted curve. The correlation coefficient (*R*) of the non-linear curve fitting is 0.9988

$$I = I_0 + (I_{lim} - I_0)/2C_0 \left\{ C_H + C_G + 1/K_{ass} - \left[(C_H + C_G + 1/K_{ass})^2 - 4\, C_H\, C_G \right]^{1/2} \right\} \quad (1)$$

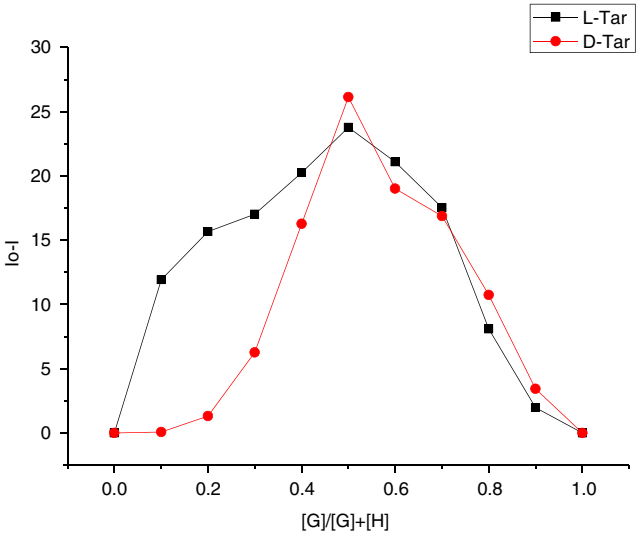


FIGURE 5 Job's plot for **L-1** and L-tartrate and D-tartrate anion in CH_3CN. The total amount of substance of **L-1** and L-tartrate or D-tartrate anion is 1.0×10^{-4} M. I_0 = fluorescent intensity of sensor **L-1** and I = fluorescent intensity of sensor **L-1** in the presence of tartrate anion

The binding characteristics of **L-1** towards D- or L-tartrate anions were further examined using Job's plot (Fig. 5). A maximum change in fluorescence was observed when the molar fraction of sensor **L-1** vs. [**L-1**] + [tartrate anion] was 0.5, indicating1: 1 binding stoichiometry between **L-1** and D- or L-tartrate anions.[26,27]

To ascertain whether the change in fluorescence of **L-1** toward the enantiomers of tartrate anion was due to enantioselective recognition, we investigated use of the enantiomeric compound **D-1**. It was found that the fluorescence intensity of **D-1** was slightly quenched upon addition of L-tartrate, but D-tartrate had a much greater fluorescence quenching effect on D-tartrate anions under the same conditions (Figures 6 and 7). Values of the association constant (K_{ass}) and correlation coefficient (R) obtained by nonlinear least squares analysis are listed in Table 1. The values of K_{ass} were 2.86×10^2 M^{-1} for L-tartrate and 1.05×10^3 M^{-1} for D-tartrate anions. This indicated that **D-1** exhibited remarkable fluorescence enantioselectivity towards tartrate anions ($K_{ass(D)}/K_{ass(L)}$ = 0.27) (Table 1). The results of fluorescence spectra titrations indicated that enantiomers of the guest anion interacted with **L-1** and **D-1** in a similar fashion.

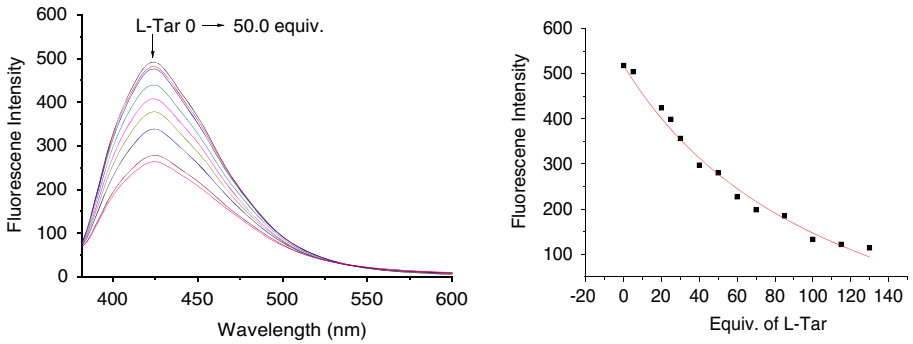


FIGURE 6 (a) Fluorescence spectra of sensor **D-1** (3.0×10^{-5} M) with L-tartrate anion in CH_3CN. Equivalents of anion: 0 → 50.0. λ_{ex} = 356 nm. (b) Changes in the fluorescence intensity of **D-1** at 423 nm upon addition of L-tartrate anion. The line shown is a non-linear fitted curve. The correlation coefficient (R) of the non-linear curve fitting is 0.9938

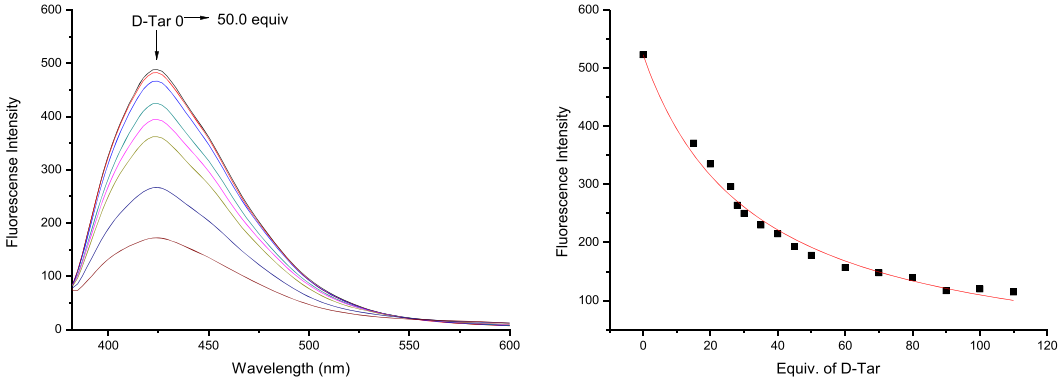


FIGURE 7 (a) Fluorescence spectra of sensor **D-1** (3.0×10^{-5} M) with D-tartrate anion in CH_3CN. Equivalents of anion: 0 → 50.0. λ_{ex} = 356 nm. (b) Changes in the fluorescence intensity of **D-1** at 423 nm upon addition of D-tartrate anion. The line shown is a non-linear fitted curve. The correlation coefficient (R) of the non-linear curve fitting is 0.9941

TABLE 1 The association constant (K) of sensor **L-1** and **D-1** (3.0×10^{-5} M) with L-tartrate anion and D-tartrate anion in acetonitrile at 25°C

Entry	Host	Guest[a]	K_{ass} [M^{-1}][b,c]	K(L)/K(D)	R
1	L-1	L-tartrate	1.15×10^3	4.83	0.9949
2	L-1	D-tartrate	2.39×10^2		0.9988
3	D-1	L-tartrate	2.86×10^2	0.27	0.9938
4	D-1	D-tartrate	1.05×10^3		0.9941

[a]Data were calculated from the results of the results of the fluorescent titrations in acetonitrile.

[b]All error values were obtained from nonlinear curve fitting.

[c]Tartrate anions were used as their tetrabutylammonium salts.

3.3 | ^{1}H NMR studies

^{1}H NMR experiments were applied to investigate the stability of complexes of sensor **L-1** with enantiomers of tartrate anion because this is one of the most effective tools in studying host–guest supramolecular chemistry.[28] Figure 8 shows the spectra of **L-1** in DMSO-d_6 solution without (Figure 8b) and on addition of 1.0 equiv. D- or L-tartrate anion (Figure 8c,d). We found that on addition of D- or L-tartrate, the chiral C**H** proton of **L-1** was downshifted from 5.31 p.p.m. to 4.20 or 4.10 p.p.m. ($\Delta\delta$ = 1.11 or 1.21 p.p.m.), whereas the C**H** proton of tartrate appeared at 4.47 or 4.50 p.p.m. ($\Delta\delta$ = 0.80 or 0.83 p.p.m.) (Figure 8c,d). The interaction of sensor **L-1** with L-tartrate showed that the CH proton had a larger downfield shift than the chiral C**H** proton of the D-enantiomer. We also found that the −OH protons of tartrate at 3.30 p.p.m. had weakened and downshifted to 3.42 and 3.49 p.p.m. indicating that the −OH of tartrate interacted with the sensor (Figure 8b–d). Therefore, as the proposed modes show in Figure 9, the hydroxy group of tartrate may form hydrogen bonds with the oxygen atoms of **L-1**.

3.4 | DFT calculations recognition properties of L-1 and tartrate anion

The enantioselective recognition mechanism and binding energy between chiral **L-1** and tartrate anions can be obtained by calculation. In this study, All density functional theory (DFT)/ time-dependent DFT (DFT/time dependent density functional theory (TDDFT)) calculations based on the hybrid exchange correlation functional B3LYP[29] with 6-31G**basis set[30] were carried out using Gaussian 03 program.[31] For all calculations, the solvent effect of acetonitrile was considered using Cossi and Barone's conductor-like polarizable continuum model.[32] To investigate the electronic properties of singlet excited states, TDDFT was performed in the ground state geometries of **L-1** and **L-1** with D- or L-tartrate anion. Bond lengths were calculated and are shown in Figure 9. There was weak interaction between **L-1** and tartrate anion, with hydrogen bond sites between **L-1** and L-tartrate anion and bond lengths of 1.96 and 2.81 Å, respectively. However, the hydrogen bond lengths between **L-1** and D-tartrate anion were only 1.92 and 3.79 Å, with only one bond length < 3.50 Å; this indicated that the complex of **L-1** and L-tartrate anion was more stable. From the binding energy, it was possible to judge the interaction strength and enantiomer complex ability, which could provide enantioselective recognition. The results of the binding energy calculation for the interaction between **L-1** and tartrate anion enantiomers were ΔE = −12.27 and −8.44 KJ/mol, respectively. It was found that the negative binding energies between **L-1** and tartrate anion enantiomers were ~3.83 kJ/mol. In other words, stable complexes between **L-1** and tartrate enantiomers could be formed by molecular weak interactions. $|\Delta E_{L\text{-}1\text{-}L}| > |\Delta E_{L\text{-}1\text{-}D}|$ showed that the complex of **L-1** and L-tartrate anion was more stable than that of **L-1** and D-tartrate anion, which made the enantioselective recognition of salbutamol enantiomers feasible. Where $|\Delta E_{L\text{-}1\text{-}L}|$ and $|\Delta E_{L\text{-}1\text{-}D}|$ represented the binding energy between **L-1** and L-tartrate anion and **L-1** and D-tartrate anion, respectively.

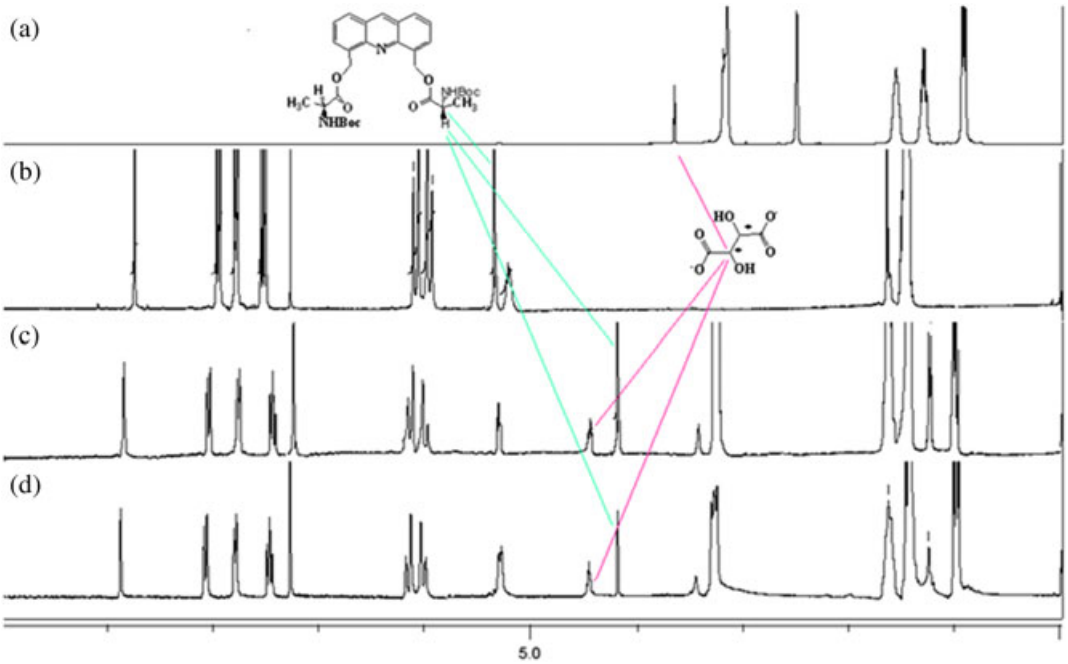


FIGURE 8 ^{1}H NMR spectra (400 MHz, DMSO-d_6 25°C) of **L-1** and tartrate anion complexes at ([**L-1**] = [guest] = 4.0 nM in DMSO-d_6 at 400 MHz. (a) Racemic tartrate anion, (b) sensor **L-1**, (c) sensor **L-1**+ D-tartrate anion, (d) sensor **L-1** + L-tartrate anion

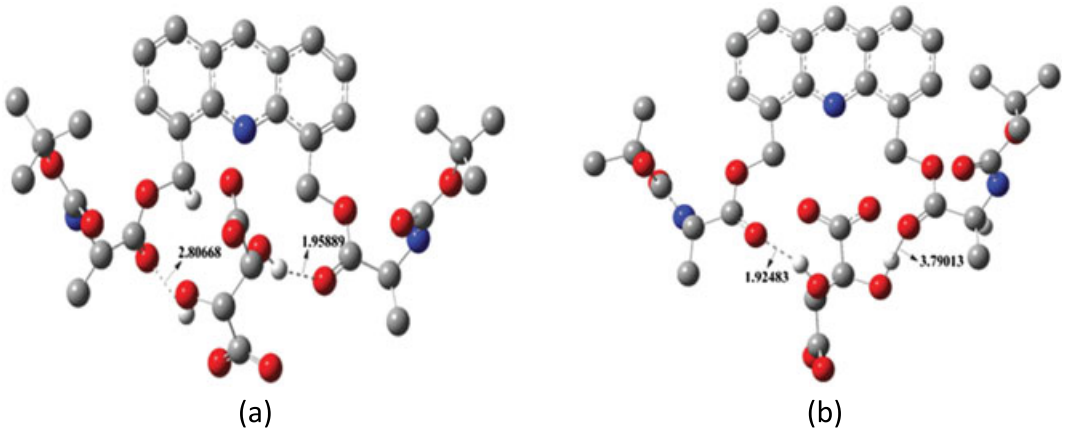


FIGURE 9 (a) Optimized geometry of the complex: **L-1** and L-tartrate anion. (b) Optimized geometry of the complex: **L-1** and D-tartrate anion

The above results illustrated that the nature of the sensor, multiple hydrogen-bonding interactions and complementary stereogenic center interactions may be responsible for the enantioselective recognition of tartrate.

4 | CONCLUSION

We have demonstrated that upon the introduction of *N*-Boc-protected alanine to the acridine, acridine-based chiral fluorescence sensors **L-1** and **D-1** act as excellent enantioselective fluorescent sensors for tartrate anions.

ACKNOWLEDGEMENTS

We thank the National Natural Science Foundation of China (Grant No. U1404207) and the Program for He'nan Innovative Research Team in University (15IRTSTHN005) for financial support.

REFERENCES

[1] L. Pu, *Acc. Chem. Res.* **2012**, *45*, 150.
[2] X. Yang, X. Liu, K. Shen, Y. Fu, M. Zhang, C. Zhu, Y. Cheng, *Org. Biomol. Chem.* **2011**, *9*, 6011.
[3] Y. P. Dai, X. Y. Liu, P. Wang, J. X. Fu, K. Yao, K. X. Xu, *RSC Adv.* **2016**, *6*, 99933.
[4] K. X. Xu, Y. X. Wang, S. Y. Jiao, J. Zhao, C. J. Wang, *Can. J. Chem.* **2010**, *88*, 367.
[5] U. S. Sorensen, T. J. Bleisch, A. E. Kingston, R. A. Wright, B. G. Johnson, D. D. Schoepp, P. L. Ornstein, *Bioorg. Med. Chem.* **2003**, *11*, 197.
[6] A. L. Koner, J. Schatz, W. M. Nau, U. Pischel, *J. Org. Chem.* **2007**, *72*, 3889.
[7] K. A. Schug, W. Lindner, *Chem. Rev.* **2005**, *105*, 67.
[8] K. Ghosh, T. Sarkar, *Tetrahedron Lett.* **2013**, *54*, 4568.
[9] K. Ghosh, A. Majumdar, *Tetrahedron Lett.* **2016**, *57*, 3629.
[10] K. Ghosh, T. Sarkar, *Tetrahedron Lett.* **2014**, *55*, 1342.
[11] R. K. Jain, A. D. Hamilton, *Org. Lett.* **2000**, *2*, 1721.
[12] Y. P. Dai, K. X. Xu, Q. Li, C. Y. Wang, X. Y. Liu, P. Wang, *Spectrochim. Acta A* **2016**, *57*, 1.
[13] N. Singh, G. W. Lee, D. O. Jang, *Tetrahedron* **2008**, *64*, 1482.
[14] K. X. Xu, X. M. Xie, H. J. Kong, P. Li, J. L. Zhang, X. B. Pang, *Sensors Actuator B Chem.* **2014**, *201*, 131.
[15] Q. Li, K. X. Xu, P. Song, Y. P. Dai, L. Yang, X. B. Pang, *Dyes Pigment* **2014**, *109*, 169.
[16] R. A. Bissell, A. P. de Silva, H. Q. N. Gunaratne, P. L. M. Lynch, G. E. M. Maguire, K. R. A. S. Sandanayake, *Chem. Soc. Rev.* **1992**, *21*, 187.
[17] R. A. Bissell, A. P. de Silva, H. Q. N. Gunaratne, P. L. M. Lynch, G. E. M. Maguire, C. P. McCoy, K. R. A. S. Sandanayake, *Topic Curr. Chem.* **1993**, *168*, 223.
[18] A. W. Czarnik, *Acc. Chem. Res.* **1994**, *27*, 302.
[19] E. J. Cho, J. W. Moon, S. W. Ko, J. Y. Lee, S. K. Kim, J. Yoon, K. C. Nam, *J. Am. Chem. Soc.* **2003**, *125*, 12376.
[20] K. X. Xu, S. Y. Jiao, W. Y. Yao, H. J. Kong, J. L. Zhang, C. J. Wang, *Sensors Actuator B Chem.* **2013**, *177*, 384.
[21] J. Chiron, J. P. Galy, *Synlett* **2003**, 2349.
[22] P. Alaei, S. Rouhani, K. Gharanjig, J. Ghasemi, *Spectrochim. Acta A* **2012**, *90*, 85.
[23] A. D. Becke, *J. Chem. Phys.* **1993**, *98*, 1372.
[24] T. Gunnlaugsson, A. P. Davis, M. Glynn, *Chem. Commun.* **2001**, 2556.
[25] T. Gunnlaugsson, A. P. Davis, J. E. O'Brien, M. Glynn, *Org. Lett.* **2002**, *4*, 2449.
[26] B. Valeur, J. Pouget, J. Bourson, M. Kaschke, N. P. Ernsting, *J. Phys. Chem.* **1992**, *96*, 6545.
[27] D. N. Nicolaides, D. R. Gautam, K. E. Litinas, T. Papamehael, *J. Chem. Soc. Perkin Trans.* **2002**, *1*, 1455.
[28] L. Fielding, *Tetrahedron* **2000**, *56*, 6151.
[29] A. D. Becke, *J. Chem. Phys.* **1993**, *98*, 5648.
[30] M. M. Francl, W. J. Pietro, W. J. Hehre, J. S. Binkley, M. S. Gordon, D. J. De Frees, J. A. Pople, *J. Chem. Phys.* **1982**, *77*, 3654.
[31] R. M. Yucel, Y. He, A. M. Zaslavsky, *Stat. Med.* **2011**, *30*, 3447.
[32] V. Barone, M. Cossi, *J. Phys. Chem. A* **1998**, *102*, 1995.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

How to cite this article: Wang C, Wang P, Liu X, Fu J, Xue K, Xu K. Novel enantioselective fluorescent sensors for tartrate anion based on acridinezswsxa. *Luminescence*. 2017. https://doi.org/10.1002/bio.3327