ORIGINAL ARTICLE

Novel deep-cavity calix[4]arene derivatives with large *s*-triazine conjugate systems: synthesis and complexation for dyes

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Abstract Two novel deep-cavity calix[4] arenes 3 and 4 with large s-triazine π -conjugate systems were designed and synthesized in high yields by reacting calix[4]arene with mono phenyl-substituted cyanuric chloride or further substitution with aniline. The liquid-liquid extraction experiment showed that they possessed excellent extraction abilities towards one cationic and three anionic dyes (Orange I, methylene blue, neutral red, brilliant green). The highest extraction percentage of compound 4 was 88.8 % for brilliant green. The complexation UV-Vis spectra of compounds 3 and 4 with four dyes indicated the existences of complexation action between hosts and guests with 1:1 ratio of complexation in DMSO solution. The association constants suggested that the larger π -conjugate system of compound 4 possessed the stronger complexation abilities than that of compound 3. The association constant of compound 4 with BG was as high as $8.1 \times 10^6 \text{ M}^{-1}$.

Keywords Calix[4]arene \cdot Deep-cavity \cdot Triazine \cdot Complexation \cdot Dye

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Introduction

Calixarenes and their functionalized derivatives are macrocyclic molecules with interesting complexation abilities towards target ions or molecules [1, 2]. By introducing four large or long functional groups on calixarene skeleton, the so-called deep-cavity calixarene was prepared, which had a novel deep and wide cavity composed of four functional groups and calixarene skeleton. As a result, they usually exhibited unique complexation properties for guests based on these novel deep cavities. For examples, Sessler and co-workers [3] reported the synthesis and anion binding properties of a calix[6]phyrin with deep cavity. Gale and co-workers [4] described the fluoride-selective binding in a deep-cavity calix[4]pyrrole. Rissanen and co-workers [5] synthesized p-(1H-phenanthro[9,10-d]imidazol-2-yl)-substituted calix[4]arene with a deep cavity. Kuhnert used deep cavity tetraformyl calix[4]arenes in the synthesis of static and dynamic macrocyclic libraries [6]. Bryce prepared calix[6]arene derivatives selectively functionalized at alternate sites on the smaller rim with 2-phenylpyridine and 2-fluorenylpyridine substituents to provide deep cavities [7]. Lately, several deep-cavity calixarene with imidazolyl groups, water-soluble groups or fluorous groups were also studied [8–10]. However, literature survey indicated that, although all these various deep-cavity calixarenes showed excellent complexation abilities for inorganic ions or small organic molecules, none of them was studied on binding large guests, such as organic dyes.

On the other hand, in order to remove dyes from waste water, some researches focused on the supramolecular molecule-based hosts for binding dyestuff recently [11, 12]. Several calixarene-based derivatives and resins with good complxation abilities for dyes were reported by Yilmaz and co-workers [13, 14], Memon and co-workers

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[15, 16] and Diao and co-workers [17], respectively. But these literatures suggested that the cavity of calix[4]arene was small and not favorable for inclusion of dyes. On theory, deep-cavity calix[4]arene with novel deep and wide cavity might be favorable for binding dyes if the functional groups on calixarene skeleton could produce effective intermolecular action with dyes. However, no research was involved on this study up to now. In this paper, we wish to report the design and synthesis of novel deep-cavity calix[4]arene derivatives with large s-triazine conjugate systems, which could produce strong $\pi - \pi$ stacking action with dyes containing conjugated planar structures. The complexation experiments indicated these novel deepcavity calix[4]arene derivatives possess excellent complexation abilities for dyes based on the π - π stacking action, which was firstly studied for deep-cavity calixarene.

Experimental

Melting points were tested on WRS-3 micro melting point instrument. ¹H NMR spectra were recorded in CDCl₃ on a Bruker-ARX 400 instrument, using TMS as reference. ESI–MS spectra were obtained from DECAX-30000 LCQ Deca XP mass spectrometer. Elemental analyses were performed at Vario EL III elemental analyzer. The UV–Vis measurements were performed on Varian UV–Vis spectrometer. Dyes were purchased from Acros Organics, China. Their structures and UV spectra were showed in Fig. 1. All solvents were purified by standard procedures. Compounds 1 and 2 were prepared according to the literature [18].

Synthesis of deep-cavity calix[4]arene 3

Under N₂ atmosphere, a mixture of *p*-tert-butylcalix[4]arene (0.5 mmol, 0.324 g), compound **1** (2 mmol, 0.482 g) and



Fig. 1 The structures of four dyes in complexation studies

K₂CO₃ (2 mmol, 0.276 g) was stirred in 30 mL of acetone at room temperature for 36 h. TLC detection indicated the disappearance of materials. Then the mixture was poured into 200 mL of ice water. After stirring for 30 min, white floccules appeared. Subsequently, the floccules were filtrated and precipitation was washed by 100 mL of ice water. Following by the dryness of precipitation, compound 3 was obtained as white powder in yield of 85 %. m.p. 321-322 °C. FT-IR (KBr), v (cm⁻¹): 3430 (N–H), 2963 (C(CH₃)₃), 1609, 1573, 1523, 1497 (mixed peaks of Ar and s-triazine), 1371 (C=N), 1298 (C-N), 1250 (Ar-O-C), 690 (C-Cl), 805 (C-N, s-triazine); ¹H NMR (400 MHz, CDCl₃) δ : 1.22 [s, 36H, $C(CH_3)_3$], 3.43 (d, J = 11.6 Hz, 4H, ArCH₂Ar), 3.74 (d, J = 11.6 Hz, 4H, ArCH₂Ar), 6.94–7.80 (m, 28H, ArH), 10.90 (s, 4H, ArNH); ESI–MS m/z (%): 1490.8 (MNa⁺, 100). Anal. calcd for C₈₀H₇₆O₄N₁₆Cl₄: C 65.48, H 5.21, N 15.28; found C 65.44, H 5.26, N 15.21.

Synthesis of deep-cavity calix[4]arene 4

Under N_2 atmosphere, a mixture of compound **3** (0.44 g, 0.3 mmol), aniline (0.3 mL, 3.3 mmol) and K₂CO₃ (2.2 mmol, 0.3 g) was refluxed in 30 mL of MeCN for 13 h. TLC detection indicated the disappearance of materials. After distilling off the solvent under reduced pressure, the residue was treated with 30 mL HCl (10 %) and extracted with 30 mL CHCl₃. The organic layer was separated, dried over anhydrous MgSO₄, and then filtered, concentrated. The residue was treated with methanol to give compound 4 as white powder in yield of 78 %. m.p. 335–336 °C. FT-IR (KBr), v (cm⁻¹): 3425 (N–H), 2962 (C(CH₃)₃), 1612, 1579, 1499 (mixed peaks of Ar and striazine), 1394 (C=N), 1298 (C-N), 1236 (Ar-O-C), 808 (C–N, s-triazine); ¹H NMR (400 MHz, CDCl₃) δ : 1.29 [s, 36H, C(CH₃)₃], 3.39 (d, J = 12.8 Hz, 4H, ArCH₂Ar), 4.03 $(d, J = 12.8 \text{ Hz}, 4\text{H}, \text{ArCH}_2\text{Ar}), 6.88-7.94 (m, 48\text{H}, \text{ArH}),$ 10.59 (s, 8H, ArNH); ESI–MS *m*/*z* (%): 1693.1 (M⁺, 100). Anal. calcd for C₁₀₄H₁₀₀O₄N₂₀: C 73.74, H 5.95, N 16.54; found C 73.68, H 5.98, N 16.49.

Extracting experiment of dyes

According to the reported method [19], 3 mL of chloro form solution containing calixarene derivatives $(1.0 \times 10^{-5} \text{ M})$ and 3 mL of aqueous solution containing corresponding dye $(1.0 \times 10^{-5} \text{ M})$ were placed in a flask. The mixture was shaken for 5 min and stored for 2 h at room temperature. The extraction ability was not affected by further shaking, indicating that the equilibrium had been attained within 2 h. The aqueous phase was separated and subjected to the analysis by UV absorption spectrometry at maximal absorbance. The extracting percentage (E%) was determined by the decrease of dye in the aqueous phase: $E\% = \{([dye]_{blank} - [dye]_{water})/[dye]_{blank}\} \times 100, where [dye]_{blank} denoted the dye concentrations in the aqueous phase after extraction with pure chloroform, and [dye]_{water} denoted the dye concentrations in the aqueous phase after extraction with chloroform solution containing deep-cavity calixarene as extractants. Average of twice-independent experiments was carried out and the difference between them were less than 1 %. Control experiments showed that the extraction percentages were less than 1 % in the absence of the hosts.$

UV-Vis spectra studies of complexation experiments

All UV–Vis experiments were performed in DMSO solution by adding aliquots stock solution of respective dyes. The stoichiometry of the complexes was determined by the Job method of continuous variations. The association constant was calculated by Benesi–Hilderbrand formula with nonlinear curve fitting procedure [20, 21].

Results and discussion

Syntheses, structures and conformations

The synthetic route was shown in Scheme 1. Although several calix[4]arene derivatives with triazine units were studied previously [22, 23], no large π -conjugate triazinesubstituted calix[4]arene derivatives was reported. In order to bind dyes effectively with $\pi - \pi$ stacking action, we designed compound 4 with two phenyl groups on the triazine units as target deep-cavity calix[4] arene with large π conjugate system. Due to cyanuric chloride containing three chloric groups, there are several synthetic routes to prepare compound 4. We had tried to introduce triazine units into calix[4]arene by reacting *p-tert*-butylcalix[4]arene with cyanuric chloride directly, but many side reactions occurred and no compound with definite structure was separated. The reason might be attributed to the difficulty of selective substitution of three chloric groups in cyanuric chloride. Also, we tried to react *p-tert*-butylcalix[4]arene with triazine derivative 2 with two phenyl groups to prepare compound 4. However, compound 4 with four large functional groups could not be obtained as main product under all kinds of reaction condition, and the separation of compound 4 was difficult due to the low reactive abilities of the functional groups and several other substituted calix[4]arene derivatives were formed. Interestingly, it was found compound 3 could be conveniently prepared in 85 % yield by reacting *p-tert*-butylcalix[4]arene with mono phenyl-substituted cyanuric chloride 1 at room temperature. Subsequently, by refluxing compound 3 with excess aniline under K₂CO₃/MeCN system,



Scheme 1 The synthetic routes of title compounds

target deep-cavity calix[4]arene **4** was easily obtained in 78 % yield with simple procedure of precipitation. To the best of our knowledge, compounds **3** and **4** were the first examples of deep-cavity calix[4]arene derivatives with large *s*-triazine conjugate systems.

All new compounds were characterized by elemental analyses, IR spectra, ESI–MS spectra and ¹H NMR spectra. The ESI–MS spectra of compounds **3** and **4** showed clearly molecular ion peak at 1490.8 (MNa⁺) and 1693.1 (M⁺), respectively. In the ¹H NMR spectra, compounds **3** and **4** showed singlet for the *tert*-butyl groups, one pair of doublets (1:1) for the methylene bridges of the calix[4]arene skeleton (the ¹H NMR spectrum of compound **4** was shown in Fig. 2). All the spectral data were in accordance with the calix[4]arene units adopt the cone conformation as shown in Scheme 1.

Complexation studies for dyes

Calix[4]arene derivatives **3** and **4** possess novel cavity with large π -conjugate systems, which could produce strong π - π stacking action with corresponding guests. Thus, four common dyes with large π -conjugate system [Orange I (OI), methylene blue (MB), neutral red (NR), brilliant green (BG)] were chosen as representation for the complexation studies of compounds **3** and **4**. The complexation abilities of compounds **3** and **4** towards four dyes were preliminarily studied by two phase extraction experiment (H₂O/CHCl₃). The results were summarized in Fig. 3. It could be seen that compounds **3** and **4** exhibited excellent extraction percentage for four tested dyes. The extraction



Fig. 3 Percentage extraction (%) of compounds 3 and 4 towards four dyes

Fig. 4 The UV spectra of compound 4 $(1 \times 10^{-5} \text{ M})$, MB $(1 \times 10^{-5} \text{ M})$, and 4 $(1 \times 10^{-5} \text{ M})$ in the presence of MB $(1 \times 10^{-5} \text{ M})$

percentage of compound 4 for brilliant green was as high as 88.8 %. For all dyes, the extraction percentages of compound 4 were higher than that of compound 3. Comparing with the structures of compounds 3 and 4, these results might indicate that the larger π -conjugate system of compound 4 produced more excellent complexation abilities for dyes as expected.

In order to investigate further the binding behaviors of compounds **3** and **4** for dyes, the complexation behaviors were studied by UV–Vis spectra titration. The respective UV–Vis spectra of compounds **3**, **4**, four dyes, and the absorption spectra of compounds **3** or **4** in the presence of four dyes with various concentrations (0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 2.0×10^{-5} M) were studied. Figures 4 and 5 showed the representative UV–Vis spectra of complexation of compound **4** with Methylene blue. The other UV–Vis spectra were summarized in support information. It could

be seen that little shift of the maximal absorption wavelength were observed before and after mixing compound **4** with methylene blue, but the maximal absorbance increased obviously with the increase of concentration. Moreover, based on the absorbance at maximal absorption wavelength, the association constants and correlation coefficients were calculated by Benesi–Hildebrand equation, which was usually used to study the complexation behaviors of host–guest [20, 21]. The calculated formula was as follows:

$$\frac{1}{\Delta A} = \frac{1}{K_{s}\Delta\varepsilon[H][G]^{n}} + \frac{1}{\Delta\varepsilon[H]}$$

 \sim

where H is host; G is guest; n is the ratio of complexation; [H] and [G] are the concentration of host and guest,

100

90

80 70

60 % 50 ш

40

30 20

10

0



Fig. 5 UV spectra of compound 4 $(1 \times 10^{-5} \text{ M})$ in the presence of MB in DMSO solution. The concentrations of dye were from the bottom 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, $(\times 10^{-5} \text{ M})$

Table 1 Association constants (K_s) and correlation coefficients (R^2) for the complexation behaviors of compounds **3** and **4** with four dyes

Dyes	3			4		
	n	R^2	Ks	n	R^2	Ks
OI	1	0.9977	3.4×10^{4}	1	0.9921	1.8×10^{6}
MB	1	0.9834	7.1×10^{4}	1	0.9942	4.7×10^{6}
NR	1	0.9908	6.2×10^{4}	1	0.9897	3.8×10^{6}
BG	1	0.9935	2.9×10^4	1	0.9962	8.1×10^{6}

respectively; K_s is association constant; $\Delta \varepsilon$ is molar absorption coefficient; ΔA is the change of absorbance at maximal absorption wavelength.

The calculated results were summarized in Table 1. It could be seen that the correlation coefficients (R^2) were close to 1 when the values of the ratio of complexation (n) were 1. These results indicated the formation of 1:1 host–guest complexes for compounds **3** and **4** with dyes.

Fig. 6 The ESI-MS spectrum of compound 4 with MB (mol ratio = 1:4)

Furthermore, both compounds **3** and **4** exhibited high association constants. The association constant of **4** with BG was as high as 8.1×10^6 M⁻¹. These data suggested the strong complexation action between hosts and guests. The association constants of compound **4** were far higher than that of compound **3**, indicating compound **4** possessed stronger complexation abilities for dyes than compound **3**, which were in accord with the results of extraction experiments. These results were also attributed to that the larger π -conjugate systems of compound **4** resulting in stronger π - π stacking action between host and guest.

Also, the complexation DMSO solution of compound **4** with MB (mol ratio = 1:4) was studied by ESI-MS spectrum. The result was exhibited in Fig. 6. It could be seen that although the far excess of MB was added, only the 1:1 complexation peak at 1977.7 was observed. This result was in accordance with the result of 1:1 complexation of UV-Vis spectra. Combining all these complexation experimental results, it could be concluded that compounds **3** and **4** possess excellent complexation abilities for dyes and 1:1 complexes were formed in DMSO solution. Compound **4** exhibited stronger complexation action than compound **3**, which indicated the larger π -conjugate systems of compound **4** resulting in stronger complexation abilities based on π - π stacking action.

Conclusions

Two novel deep-cavity calix[4]arene with large *s*-triazine π -conjugate systems were designed and synthesized in high yields. The liquid–liquid extraction experiments showed that they possessed excellent extraction abilities towards dyes. The highest extraction percentage of compound **4** for Brilliant green was 88.8 %. The complexation UV–Vis spectra of compounds **3** and **4** with four dyes indicated 1:1 complexes between host and guest in DMSO solution. The association constant of compound **4** with BG was as high as $8.1 \times 10^6 \text{ M}^{-1}$. Compound **4** exhibited stronger



complexation action that compound **3**, which was attributed to the stronger π - π stacking action of larger π -conjugate systems of compound **4** for dyes.

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