

Metal ions recognition by 1,2,3-triazolium calix[4]arene esters synthesized via click chemistry

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Abstract Two triazole-modified calix[4]arene diesters were synthesized via Huisgen 1,3-dipolar cycloaddition between azides esters and alkynylcalixarenes. Their structures had been deduced from ^1H NMR, element analysis and ESI-MS. Two-phase extraction experiments indicated that triazole-modified calix[4]arene diethylester **3a** exhibited Cs^+ selectivity.

Keywords Triazole-modified calix[4]arene · Click chemistry · Extraction

Introduction

The application of click chemistry developed by Meldal [1] and Sharpless [2] involving the Cu(I)-catalyzed 1,3-dipolar cycloaddition of an azide and a terminal alkyne is rapidly growing, especially in the areas of biological, materials, and medicinal chemistry [3–5]. Besides the advantages of its high efficiency, regioselectivity, and compatibility with reaction conditions, the unique properties of the 1,4-disubstituted 1,2,3-triazole ring in terms of its ability to participate in hydrogen bond and dipole–dipole interactions has made click chemistry even more attractive in metal ions-binding. Recently, the role of 1,2,3-triazole in the formation of stable metal complexes has also been realized and accordingly some triazole-based receptors. For instance, Astruc and co-workers reported click assembly of 1,2,3-triazole-linked dendrimers for the recognition of

metals ions [6]. Xie and co-workers synthesized 2-pyridyl triazole substituted β -cyclodextrins via click chemistry as a Zn^{2+} fluorescent probes [7]. At the same time click reactions have already been used successfully to prepare water-soluble [8] and other triazole-modified calixarenes as ion sensors [9–15]. Recently, we synthesized a series of triazole-modified calix[4]crowns [16].

Calixarenes [17–19] are extensively utilized as the most versatile and useful building blocks for the design and construction of elaborated supramolecular systems. In order to preorganize the host it is usually desirable to prepare the calixarenes with well-defined structural features suitable for complexation. Also, the ion selectivity is dependent on cooperation of the conformation and substituents. It was reported that OCH_2COOR , $\text{OCOCH}_2\text{NR}_2$ etc. are favorable groups for the coordination of alkali metal ions [20–26]. By skillful combination of conformation and substituents via kinds of coupling technique, a series of excellent ionophores for Li^+ [21], Na^+ [18] and K^+ [20] and Cs^+ [22–26] ions have been synthesized. And also the studies of recognition behavior are very significant, especially on how to recognize cesium ion selectively. Therefore, we wanted to introduce the OCH_2COOR group to the calixarene cavity by the click chemistry and investigate its extraction ability towards alkali metal ions.

It is of interest to observe what happens when both triazole spacer and ester groups are incorporated into one calix[4]arene, due to the coordination of alkali metal ions is promoted by OCH_2COOR residues. In this paper we wish to report our investigation of triazole-modified calix[4]arene by 1,3-dipolar cycloaddition between azide esters and alkynylcalixarenes and as well as the cooperating complexation ability of the triazole and ester groups towards alkali metal ions. As expected, the complexation ability

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varies remarkably according to the triazole spacer and the different ester groups. Moreover, it was found that one of the diesters, triazole-modified calix[4]diethylesters **3a** exhibits cesium ion selectivity.

Experimental

Materials and methods

^1H NMR spectra were recorded on Varian Mercury VX400 at ambient temperature with TMS as the internal standard. ESI-MS were recorded on a Finnigan LCQ-Advantage instrument. UV-Vis spectra were obtained using a Scinco S-3100 UV-Vis recording spectrophotometer. All chemicals were A.R. grade and were purified by standard procedures.

General procedure for the synthesis of compound **1**

A solution of *p*-*tert*-butylcalix[4]arene (4 g, 6.2 mmol) and BrCH_2CCH (1.7 mL, 15.5 mmol) in acetone (150 mL) and K_2CO_3 (1.8 g, 13.0 mmol) were heated to reflux for 17 h. The cooled reaction mixture was filtered and washed with chloroform. The filtrate were removed under vacuum and the residue was further purified by crystallization by slow diffusion of methanol into a chloroform solution. The product was collected by filtration, washed with methanol (3×10 mL) and dried under vacuum.

General procedure for the synthesis of compounds **3a**

1 (290 mg, 0.40 mmol), $\text{CuSO}_4 \times 5\text{H}_2\text{O}$ (100 mg, 0.402 mmol) and sodium ascorbate (200 mg, 1.010 mmol) were added to a solution of **2** (114 mg, 0.88 mmol) in DMF (15.0 mL). The mixture was heated at 90 °C for 10 h, and then diluted with ethyl acetate (20 mL) and washed with water (3×10 mL). The organic phase was dried over MgSO_4 , filtered and the solvent removed under reduced pressure. The residue was recrystallized from $\text{CH}_2\text{Cl}_2/\text{MeOH}$ to afford **3a** as a white solid in 86% yield.

Compound **3a**: ^1H NMR (400 MHz, CDCl_3) δ : 1.17 (s, 18H, Bu^t), 1.22 (s, 18H, Bu^t), 1.25–1.28 (m, 6H, CH_3), 3.29 (d, 2H, $J = 12.8$ Hz, ArCH_2Ar), 3.42 (d, 2H, $J = 13.2$ Hz, ArCH_2Ar), 4.35 (d, 2H, $J = 13.2$ Hz, ArCH_2Ar), 4.46 (d, 2H, $J = 12.8$ Hz, ArCH_2Ar), 4.17–4.26 (m, 4H, CH_2CH_3), 4.91 (d, 2H, $J = 17.6$ Hz, OCH_2), 4.99 (d, 2H, $J = 10$ Hz, NCH_2), 5.32 (d, 2H, $J = 17.6$ Hz, OCH_2), 6.19 (d, 2H, $J = 10$ Hz, NCH_2), 6.87 (d, 4H, $J = 7.6$ Hz, ArH), 7.06 (d, 4H, $J = 7.6$ Hz, ArH), 7.36 (s, 2H, CH), 8.00 (s, 2H, ArOH). ESI(+)-MS(m/z , %): 981.2 (M^+ , 100). Anal. calc. for $\text{C}_{58}\text{H}_{74}\text{N}_6\text{O}_8$: C, 70.85%; H, 7.59%; N, 8.55%; found: C, 70.89%; H, 7.53%; N, 8.60%.

General procedure for the synthesis of compounds **3b**

The compound **3a** was stirred in methanol and toluene (50 mL V/V = 1:1) for 10 h under reflux. After the solvent was removed under reduced pressure, a portion of water was added for precipitation. The solid material was filtered, washed with water, and dried. Finally, purified by recrystallization from the chloroform–methanol.

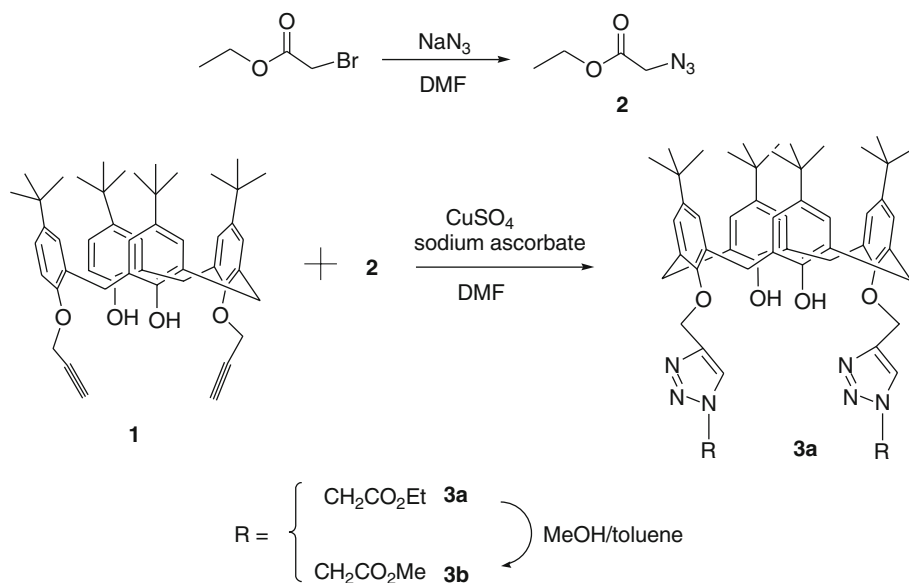
Compound **3b**: ^1H NMR (400 MHz, CDCl_3) δ : 0.91 (s, 18H, Bu^t), 1.34 (s, 18H, Bu^t), 2.87 (s, 6H, OCH_3), 3.27 (d, 4H, $J = 12.4$ Hz, ArCH_2Ar), 4.37 (d, 4H, $J = 12.4$ Hz, ArCH_2Ar), 4.87 (s, 4H, NCH_2), 5.10 (s, 4H, OCH_2), 6.71 (s, 4H, ArH), 7.03 (s, 4H, ArH), 8.01 (s, 2H, ArOH), 8.02 (s, 2H, CH). ESI(+)-MS(m/z , %): 954.5 (M^+ , 100). Anal. calc. for $\text{C}_{56}\text{H}_{70}\text{N}_6\text{O}_8$: C, 70.42%; H, 7.39%; N, 8.80%; found: C, 70.23%; H, 7.25%; N, 8.90%.

Solvent extraction experiments

Picrate extraction experiments were performed by following Ho's procedure [27]. One milliliter 5×10^{-4} M solution of calixarene in CHCl_3 was vigorously shaken with 2 mL of a 5×10^{-5} M aqueous picrate solution in water and the concentration of picrate ion remaining in the aqueous phase was then determined by UV spectra from the resulting absorbance at 380 nm. Blank experiments showed that no picrate extraction occurred in the absence of calixarene.

Results and discussion

The synthetic route is depicted in Scheme 1. As a first step azide esters **2** was synthesized by reacting bromoethylacetate with NaN_3 in DMF at 90 °C in high yield and without purification [28]. Then The reaction of alkynylcalixarenes **1** [29] with **2** has been carried out in DMF at 90 °C with copper(II) sulfate, and sodium ascorbate to afford triazole-modified calix[4]arene diesters **3a** in good yield up to 86% after recrystallization from $\text{CH}_2\text{Cl}_2/\text{MeOH}$. The diethylesters **3a** was transformed into corresponding the dimethylesters (**3b**) by ester exchange reaction in near quantitative yield in refluxing MeOH and toluene (V/V = 1:1). The structures of these compounds **3a**, **3b** were characterized by ESI-MS spectra, elemental analyses and ^1H NMR spectra. The ESI-MS spectra of **3a** and **3b** show the expected molecular ion peaks, which indicate that the ester is linked to the calix[4]arene moiety by the triazole groups. In ^1H NMR spectra a pair of two doublets (d) of ArCH_2Ar protons for compound **3a**, two doublets for ArCH_2Ar protons for compound **3b** and two singlets for the *tert*-butyl groups for compounds **3a**, **3b**

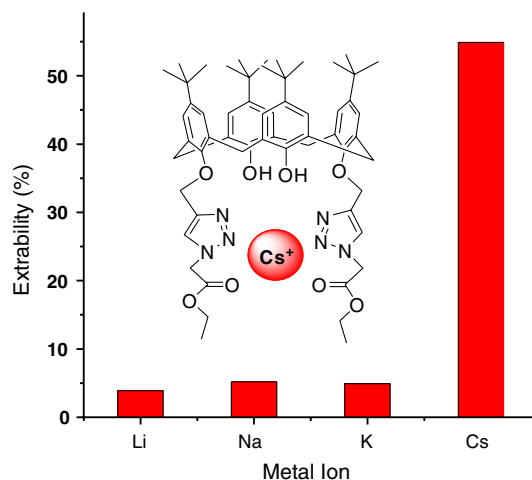
Scheme 1 Synthesis of triazole-modified calix[4]arene esters

suggest that triazole-modified calix[4]arene ester **3a** and **3b** keep the cone conformation [30–32].

Examination of the CPK molecular models reveals that triazole-modified calix[4]arene ester are well preorganized to extract cation. The ions binding properties of **3a** and **3b** were investigated by extracting the picrate salts from the aqueous to the organic phase [27]. In order to compare the influence of the triazole groups on the extraction, the *p*-*tert*-butylcalix[4]arene 1,3-diethylacetate **4** was used as a reference compound [20]. The result of extraction studies was listed in Table 1. Arnaud-Neu reported that the reference compound **4** failed to show any significant extraction potential. We have investigated the picrate extraction experiment, compound **4** have a very poor extractants of alkaline metal picrates and the percentage extraction is up to 1%. However, it can be seen from Table 1 in comparison with **4**, triazole-modified calix[4]diester **3a** showed higher extraction selectivity towards Cs^+ and the extraction ratio Cs^+/Na^+ of compound **3a** is up to 10.52 which indicated that the triazole groups inflected the extraction ability and selectivity. It is well-known that 1,2,3-triazole groups containing the nitrogen atom are preferable for complexing the more polarizable transition metal cations such as the Pb^{2+} , Cu^{2+} , Cd^{2+} , Zn^{2+} and so on [9–15]. And also, it was reported that OCH_2COOR , $\text{OCOCH}_2\text{NR}_2$ etc. are favorable groups for the coordination of alkali metal ions. We have also performed the ^1H NMR experiments in CDCl_3 in the presence of the picrates and found that the chemical shift of proton on the triazole group have no change. Therefore, the high extraction selectivity towards alkali metal cations for the triazole-modified calix[4]arene **3a** and **3b** could be because the flexible triazole groups facilitate the complexation between the ester groups and the soft alkali metal

Table 1 Percentage extraction of alkali metal ions

Host	Li^+	Na^+	K^+	Cs^+	Cs^+/Na^+
3a	3.9	5.2	4.9	54.7	10.52
3b	1.9	8.7	37.4	16.4	1.89
4	<1	<1	<1	<1	



ions by enhancing the flexibility of the cavity formed by the two ester group. At the same time, it revealed that the cavity formed by the two moderately rigid ester group is so larger that the ester groups are preferable for the complexing the much softer and larger alkaline metal ion such as the Cs^+ . Meanwhile, the triazole-modified calix[4]diester **3a** and triazole-modified calix[4]dimethylester **3b** display different selectivity towards alkali metal ions. According to the literature the extraction selectivity towards alkali metal cations is relative to the cavity

dimensions [20]. These dimensions may allow the inclusion of the smaller or the larger cation by a flexing movement of the pendant ligating groups or a change in the tilt angle of the aromatic rings. Therefore, for the triazole-modified calix[4]diethylester **3a** the endmost ethyl groups of the ester groups had the much stronger influence on the cavity dimensions formed by the two ester groups than the endmost methyl groups. The ethylester groups may form the larger cavity to fit the largest Cs^+ and the methylester groups may form the small cavity to fit the K^+ which emphasized the importance of the size-fit effect.

In conclusion, two triazole-modified calix[4]arene diesters were synthesized via click chemistry. Two-phase extraction experiments indicated that triazole-modified calix[4]arene diethylester **3a** exhibited high Cs^+ selectivity through the cooperating complexation of the triazole and ester groups.

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