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A switching sensor of C—H bond breakage/formation regulated by mediating copper (II)'s complexation

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ABSTRACT

Copper (II)-catalyzed selective C—H bond activation has been extensively investigated, but few examples are optically visible and reversible. We herein report a visible switching of copper (II)-catalyzed C—H bond formation/cleavage regulated by the association/disassociation between copper (II) and calix[3]dimethoxycarbazole (**2**). Upon binding to copper (II), the C—H bond of the bridging methylene of **2** is cleaved to produce a blue-color carbocationic intermediate **3**; once the copper ion is removed by its stronger ligand triethylenetetramine (**TETA**), **3** is then converted back to **2**, and its blue-color disappears correspondingly. The reversibility of the above optical behavior could be repeated up to 6 cycles by mediating the association/disassociation of **2-Cu**$^{2+}$ complexation. Thus, **2** could serve as a copper-selective switching sensor.

1. Introduction

Prior to the functionalization of hydrocarbons, C—H bond activation catalyzed by metals is usually a requisite step [1]. Copper (II)-catalyzed oxidative C—H bond activation is one of extensively investigated strategies in the field [2]. Copper catalyst is more than welcome in industry because it is an earth-abundant and inexpensive metal. Compared with Pd catalysis, however, Cu-catalyzed C—H bond activation is less efficient, partially due to its incompletely understood mechanism [3].

Trapping and characterization of the intermediates (or the transition state) of Cu(II)-oxidative C—H bond activation would be very helpful for deep understanding of the reaction mechanism. However, most of intermediates (or the transition states) are very reactive so that only those relatively stable ones could be isolated and characterized, *e.g.* iminium ions [4]. Although carbocation is also one of the commonly proposed intermediates for Cu(II)-oxidative C—H reactions, the trapping and characterization of a carbocation is still rare, possibly due to its highly reactive nature. If, however, the positive charge of a carbocation is substantially delocalized by the electronic donor groups such as dimethylamino and/or methoxy, carbocation might be able to be stabilized and captured [5]. As carbazolyl groups could also stabilize the carbocations [5d–5 g], we envisage that a carbocation intermediate of the derivatives of calix[3]carbazole (Precursor, Scheme 1), which our group recently developed [6], may be able to be stabilized and captured. If so, the derivatives of calix[3]carbazole may be utilized to exploit the reaction of Cu(II)-catalyzed oxidative C—H bond activation. What calix[3]carbazole needs is just a functional group to bind Cu^{2+} !

On the other hand, many natural enzymes could regulate the formation/breakage of C—H bonds in a reversible way, *e.g.*, NADH-ubiquinone oxidoreductase (complex I) [7]. Therefore, it would be a fascinating job for chemists to mimic the oxidoreductase and to construct a reversible process of C—H bond activation in an artificial system. As the electron-transfer (ET) step is often involved in the process of Cu(II)-oxidative C—H bond breakage, it is reasonable to postulate that the switch of ET process may lead to the reversible C—H bond activation (breakage/formation). The recent advances in supramolecular chemistry have made the reversible ET come true by regulating the ions association/dissociation in a host-guest system [8]. As such, the reversible C—H bond activation (breakage/formation) could possibly be regulated by mediating Cu(II) association/dissociation. Taken together, we then design calix[3]dimethoxycarbazole (**2**, Scheme 1) and we herein report

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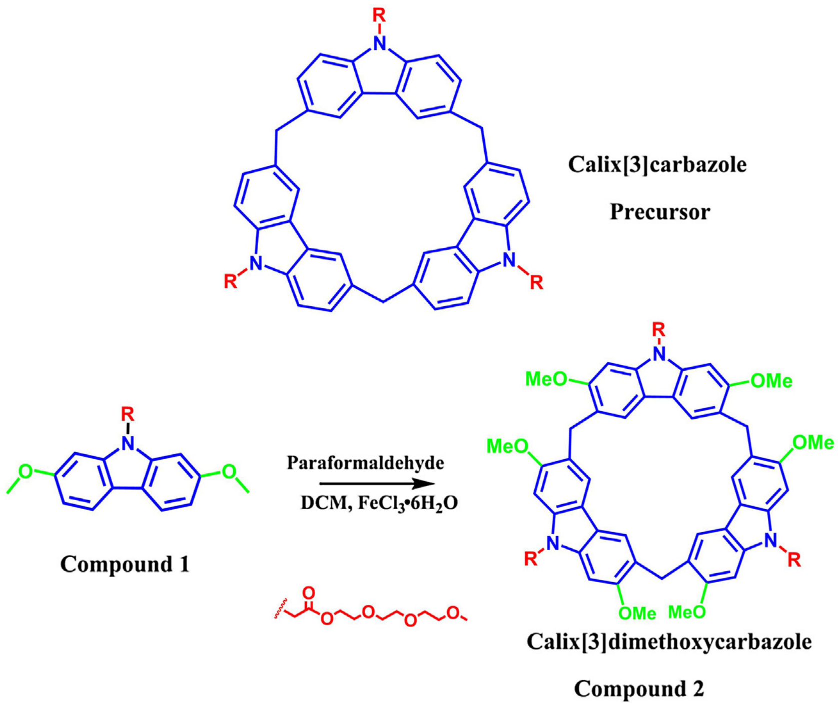

Scheme 1. Calix[3]carbazole and calix[3]dimethoxycarbazole.

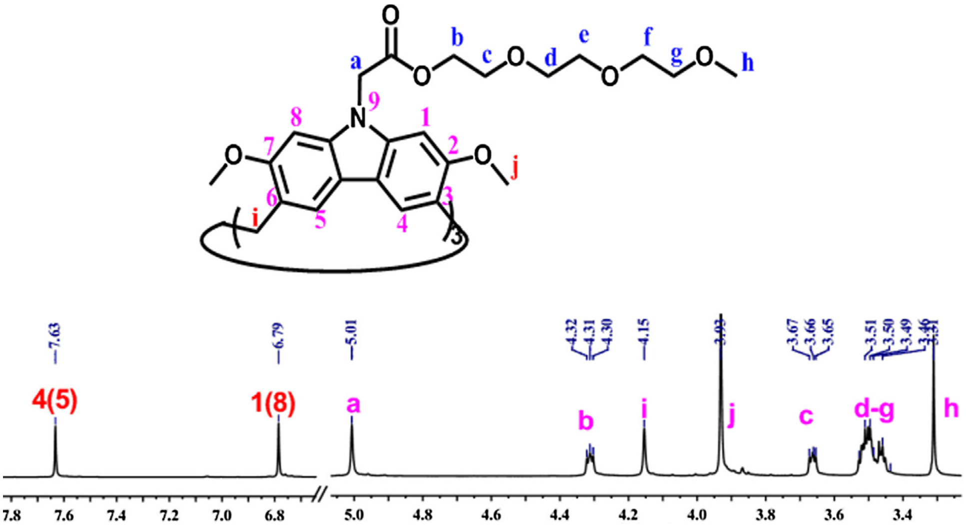

Fig. 1. Partial ^{1}HNMR spectrum of **2** (600 MHz, CD_2Cl_2,25 °C).

the unique sensing behavior of its reversible C—H bond formation/breakage.

2. Experimental

2.1. General techniques

Triethylenetetramine (TETA), copper (II) trifluoromethanesulfonate $Cu(OTf)_2$ and various deuterated solvents were purchased from Sigma-Aldrich (China). 4-Methoxy-2-nitroaniline was obtained from Energy Chemical (China).The purities of all the chemicals are higher than 98%. The acetonitrile (MeCN) for spectral measurement was purchased from Sigma-Aldrich (China) and its purity was higher than 99.9%. Thin layer chromatography (TLC) analysis of reaction mixtures was performed on Dynamic adsorbents silica chromatography F-254 TLC plates. Column chromatography was done using silica gel 200–300 mesh as stationary phase. UV–vis absorption spectra were recorded at 298 K on Beijing purkinje TU-1810 spectrophotometer. NMR spectra was recorded at 298 K on Bruker Avance-III 600 spectrometer, unless otherwise noted. Chemical shifts were reported in units (ppm) and all coupling constants (J values) were reported in Hertz (Hz) using TMS as the internal standard. High resolution mass spectra (electrospray ionization: ESI) were carried out at 298 K on a Bruker micrOTOF-Q instrument.

For all the measurements, the solutions of both **1** and **2** were freshly prepared before use. For UV–vis titration, the stock solutions of various guests were prepared by dissolving them in MeCN (2×10^{-2} M). The final concentrations of both **1** and **2** for UV–vis measurements were generally 20 μM, unless otherwise noted. For NMR measurements, the stock solutions of various guests were prepared by dissolving them in MeCN-d_3 (5.0×10^{-2} M). The con-