DOI: 10.1002/ejoc.201001169

Calix[4]arene with Lower-Rim β-Amino α,β-Unsaturated Ketones Containing Bis-Chelating Sites as a Highly Selective Fluorescence Turn-On Chemosensor for Two Copper(II) Ions

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Keywords: Fluorescence / Ionophores / Sensors / Supramolecular chemistry / Copper / UV/Vis spectroscopy

We report herein the synthesis of a fluorescence turn-on chemosensor, 25,27-bis{*N*-[1-(4-{[4-amino-4-(1-naphthyl)-2-oxo-3-butenyl]oxy}phenyl)aminocarbonyl]methoxy}-26,28-dihydroxycalix[4]arene (**3b**), which is highly selective toward Cu^{2+}. The fluorescence intensity of **3b** was enhanced upon adding $[Cu(ClO_4)_2]$, which reached a maximum with approximately 4 equiv. of Cu^{2+} but then started to decrease in intensity at higher Cu^{2+} concentrations. Job plot experiments revealed a 1:2 binding stoichiometry of **3b** with Cu^{2+}. Based on ^1H NMR titration results, we infer that there are two possible binding sites for Cu^{2+} in **3b**: one at the lower-rim phenolic-OH and amide groups, and the second at the β-amino α,β-unsaturated ketone groups. It is important to note that during the complexation of **3b** with $[Cu(ClO_4)_2]$, the Cu^{2+} ions were reduced to Cu^+ by both the phenolic OH and the amines of the β-amino α,β-unsaturated ketones. Furthermore, control compounds **6** and **9b** were synthesized to clarify the possible binding sites of Cu^{2+} in **3b**. By comparing the binding constants of **3b**, **6**, and **9b** with Cu^{2+}, we found that **3b** exhibited a positive allosteric behavior toward the coordination of two Cu^{2+} ions.

Introduction

Calix[4]arenes, which are obtained from the oligomerization of phenol and formaldehyde, offer a very useful molecular scaffold for the construction of multivalent binding sites.[1] Over the past few decades, much effort has been devoted to the development of appropriate calix[4]arene chemosensors for the selective and sensitive detection of heavy metal ions because of their essential or deleterious roles.[2,3] For instance, although Cu^{2+} is biologically important, its accumulation in the human body may induce hepatic cirrhosis or neurodegenerative diseases.[4] Accordingly, many fluorescent sensors for Cu^{2+} have been designed,[3,5] however, most of them undergo fluorescence quenching upon binding with Cu^{2+}.[3a–3c,5a–5d] Sensors that give fluorescence enhancement upon binding with metal ions are preferred for biological imaging over those that respond to metal ions with a fluorescence quenching. Nevertheless, sensors that "turn on" its fluorescence when complexed with Cu^{2+} are still rare;[3d,3e,5e,5f] thus, it is still a demanding task to develop new Cu^{2+} selective fluorescence turn-on sensors.

The design of most fluorescent chemosensors for metal ions are based on photophysical changes that involve, for example, photoinduced electron transfer (PET),[6] metal–ligand charge transfer (MLCT),[7] or excimer/exciplex formation.[8] Although excimer emission has been frequently observed in bis-fluorophore-substituted chemosensors that change conformation upon adding metal ions, exciplex formation, in contrast, has rarely been reported as a signaling mechanism in ion-sensing systems.[8a,8b]

We have been using a strategy to construct a variety of functionalized isoxazole units on calix[4]arene skeletons through 1,3-dipolar cycloaddition of alkynes and various aryl nitrile oxides.[9] Subsequent N–O bond cleavage of the isoxazole units by $[Mo(CO)_6]$-mediated ring opening reaction leads to the formation of enaminone derivatives efficiently.[10] Enaminones, also named β-amino α,β-unsaturated ketones, as one kind of 1,3-bifunctional compound, have been frequently used as metal ion chelating ligands.[11] For example, they have been used in the synthesis of metallomesogens by coordination with Ni^{2+} and Cu^{2+} in liquid crystal research.[12] Despite the useful properties of enaminone groups, to date, there have been few reports[13] on their use as metal ion binding ligands in calix[4]arene related ionophores. Our recent work showed that calix[4]arene with lower-rim distal bis-β-amino α,β-unsaturated ketones can function as a ditopic receptor for the simultaneous complexation of copper and acetate ions.[14] The redox properties of Cu^{2+}/Cu^+ with phenol seems to be a ubiquitous phenomenon, thus, the question arises: Can calix[4]arenes

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Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/ejoc.201001169.

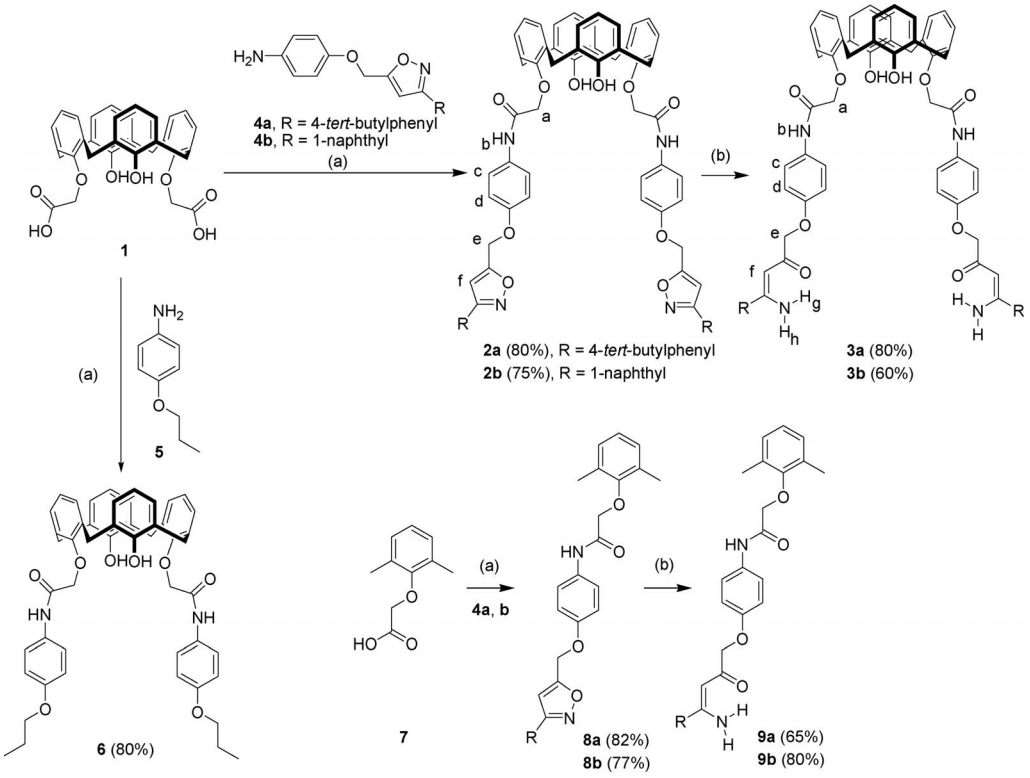
(which contain phenols) be used with fluorophores to generate useful Cu^{2+} sensors?

Herein, we report a copper(II)-induced fluorescence turn-on chemosensor, 25,27-bis{*N*-[1-(4-{[4-amino-4-(1-naphthyl)-2-oxo-3-butenyl]oxy}phenyl)aminocarbonyl]-methoxy}-26,28-dihydroxycalix[4]arene (**3b**), which contains amide-linked β-amino α,β-unsaturated ketones as the Cu^{2+} recognition sites and naphthalene pendants as the fluorophore units. On the lower rim of the conical calix[4]arene framework, host **3b** possesses two potential recognition sites for Cu^{2+} ions: one is near the β-amino α,β-unsaturated ketone groups and the second is situated near the cavity formed by the phenolic-OH and amide groups. The binding ability of **3b** and control compounds **6**, **9a**, and **9b** toward Cu^{2+} has been studied by UV/Vis, fluorescence, and ^1H NMR titrations.

Results and Discussion

The syntheses of target molecules **3a** and **3b** and control compounds **6**, **9a**, and **9b** are depicted in Scheme 1. 25,27-Bis(carboxymethoxy)calix[4]arene (**1**) was prepared according to literature procedures.[15] Compounds **2a** and **2b** were synthesized in 75–80% yields by treatment of compound **1** with oxalyl chloride in anhydrous dichloromethane followed by coupling with phenylamines **4a** and **4b** (see the Supporting Information). Compounds **3a** and **3b** were then obtained through ring-opening reaction of the corresponding bis-isoxazoles **2a** and **2b** using $[Mo(CO)_6]$ as a reagent.[10d] Previously, the $[Mo(CO)_6]$-mediated ring-opening reactions were reported[10c] to have 70–85% yields in molecular systems without calix[4]arenes, however, in calix[4]arene systems the isolated yields were in the range of 40–65%, despite the fact that the reactions were usually run to completion.[10b] This result might be due to strong coordination of the β-amino ketone products with the pentacarbonylmolybdenum, thus, hampering its isolation. Gratifyingly, by extracting the reaction mixture successively with aqueous NH_4OH and ethylenediaminetetraacetic acid (EDTA), followed by column chromatography, we were able to improve the reaction yields to 60–80%. Control compounds **6**, **9a** and **9b** were also obtained using the same methodology. The control compound **6** was synthesized to test the metal ion binding ability of the calix[4]arene with two pendant *N*-arylamidomethyl groups (the upper component of compound **3b**). Compounds **9a** and **9b** were synthesized to verify the requirement for a calix[4]arene scaffold for the recognition of two Cu^{2+} ions. The structures of all products were confirmed by ^1H and ^{13}C NMR spectroscopy, mass spectrometry, and HRMS analyses (see Exp. Sect.).

Using UV/Vis spectroscopy and fluorescence spectrometry, the binding properties of **3b** toward 15 different perchlorate salts of metal ions (Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, Ba^{2+}, Cr^{3+}, Mn^{2+}, Ni^+, Cu^{2+}, Zn^{2+}, Hg^{2+}, Ag^+, Cd^{2+}, and



Scheme 1. Syntheses of target compounds **3a** and **3b**, control compounds **6**, **9a**, and **9b**. Reagents and conditions: (a) (i) oxalyl chloride, CH_2Cl_2, 40 °C, 3 h, (ii) 4-{3-[4-(*tert*-butyl)phenyl]isoxazol-5-ylmethoxy}phenylamine (**4a**), 4-{[3-(naphthalen-1-yl)isoxazol-5-yl]-methoxy}phenylamine (**4b**), or 4-propoxyaniline (**5**), Et_3N, CH_2Cl_2, room temp., 24 h; (b) $[Mo(CO)_6]$, CH_3CN/H_2O, reflux, 2 h.

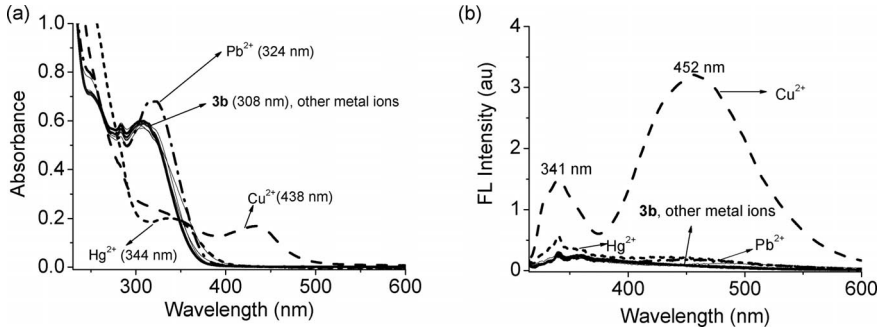


Figure 1. (a) UV/Vis and (b) fluorescence spectra of **3b** (20 μM) upon adding 5 equiv. of metal perchlorates (Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, Ba^{2+}, Cr^{3+}, Mn^{2+}, Ni^+, Cu^{2+}, Zn^{2+}, Hg^{2+}, Ag^+, Cd^{2+}, and Pb^{2+}) in acetonitrile. The excitation wavelength was 308 nm.

Pb^{2+}) were screened in CH_3CN, and the results are shown in Figure 1. In the absence of cations, calix[4]arene **3b** exhibited an absorption band with λ_{max} = 308 nm (Figure 1, a) and a very weak emission in the 300–600 nm region when excited at 308 nm (Figure 1, b). Among the 15 metal ions screened, only Cu^{2+} and Hg^{2+} led to some hypochromic and bathochromic shifts in the UV/Vis spectra of **3b**; furthermore, a small hyperchromic and bathochromic shift was observed in the presence of Pb^{2+}. In addition, only Cu^{2+} caused a dramatic enhancement of the fluorescence intensities of **3b** at 341 and 452 nm by 4- and 40-fold, respectively (Figure 1, b). These observations indicated that calix[4]arene **3b** has a high selectivity and sensitivity toward Cu^{2+}.[16]

To gain further insight into the binding of Cu^{2+} to **3b**, UV/Vis, fluorescence, and ^1H NMR titration experiments were carried out. Upon titration of **3b** with Cu^{2+}, the absorption maximum at 308 nm gradually decreased in intensity with concurrent formation of a new absorption band near 438 nm (Figure 2, a). Two isosbestic points at 263 and 345 nm were observed, indicating the formation of a well-defined metal complex. The fluorescence intensity of the naphthyl monomer emission (341 nm) was enhanced and a new broad emission band at 452 nm emerged, which may be attributed to the emission of an excimer[17] or an exciplex[8] of the β-amino β-naphthyl groups of **3b**. When more than 4 equiv. of Cu^{2+} was added, the emission band at 452 nm started to decrease (Figure 2, b), which might be

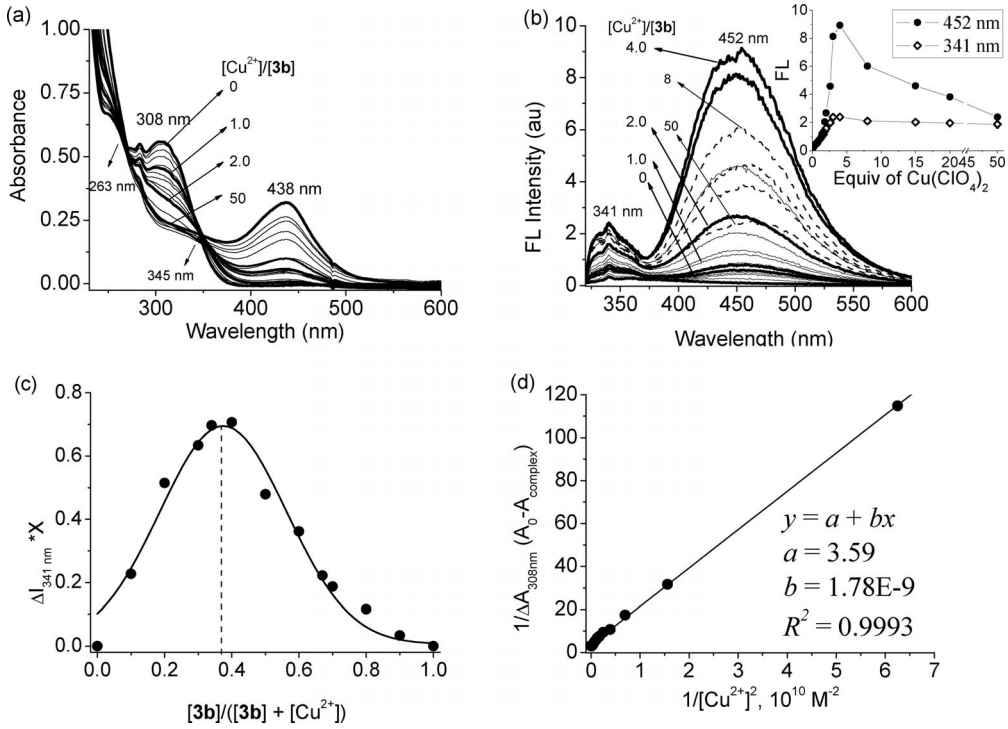


Figure 2. (a) UV/Vis and (b) fluorescence emission spectra of **3b** (20 μM) with various concentrations of $[Cu(ClO_4)_2]$ in CH_3CN. The excitation wavelength was 308 nm. The inset shows the variation of fluorescence intensity at 341 and 452 nm of **3b** by adding different amounts of $[Cu(ClO_4)_2]$. (c) The Job plot of the 1:2 complex of **3b** and Cu^{2+}, where the difference in fluorescence intensity at 341 nm (ΔI_{341} nm) was plotted against the mole fraction of **3b** at an invariant total concentration of 20 μM in CH_3CN. (d) Benesi–Hildebrand plot of **3b** (20 μM) with $[Cu(ClO_4)_2]$ in CH_3CN.[19]

due to an "inner filter effect"[18] of the absorption band at 438 nm. Alternatively, the increased metal complex concentration may contribute to the static quenching of the emission at 452 nm. Interestingly, a Job plot experiment, using the fluorescence spectra of **3b** and Cu^{2+} with a total concentration of 20 μM, revealed that the complexation between **3b** and Cu^{2+} adopted a 1:2 binding ratio (Figure 2, c). The association constant (K_a) of the 1:2 complex **3b**·$(Cu^{2+})_2$ was calculated to be 2.02×10^9 M^{-2} by a Banesi–Hildebrand plot.[19b]

In contrast to the 1:2 binding ratio of **3b** with Cu^{2+}, its binding ratios with Hg^{2+} and Pb^{2+} were both determined to be 1:1 by Job plot experiments (see Figures S-35 and S-36, see the Supporting Information). Moreover, using Benesi–Hildebrand plots, the association constants (K_a) of **3b** with Hg^{2+} and Pb^{2+} ions in CH_3CN were calculated to be 6.66×10^3 and 1.47×10^4 M^{-1}, respectively (see Table 1).[19]

Table 1. Fluorescence intensity changes $[(I - I_o)/I_o]$, binding ratio, and association constants (K_a) of **3b**, **6**, and **9b** (20 μM) toward Cu^{2+}, Hg^{2+}, and Pb^{2+}.

Host	Metal ion	$(I - I_o)/I_o$[a] λ_{341nm}	$\lambda_{452\ nm}$	Binding ratio (host/M^{II})	K_a
3b	Cu^{2+}	4.4	41.8	1:2	$2.02\ (\pm0.11) \times 10^9$ M^{-2}
3b	Hg^{2+}	0.9	1.6	1:1	$6.66\ (\pm4.01) \times 10^3$ M^{-1}
3b	Pb^{2+}	–0.2	1.3	1:1	$1.47\ (\pm0.17) \times 10^4$ M^{-1}
6	Cu^{2+}	–	–	1:1	$6.82\ (\pm2.81) \times 10^3$ M^{-1}
9b	Cu^{2+}	16.2	221[b]	1:1	$2.52\ (\pm0.30) \times 10^4$ M^{-1}

[a] Fluorescence intensity changes of **3b**, **6**, and **9b** after adding 5 equiv. of metal ions. [b] The emission maximum was at 446 nm.

To explain the observed 1:2 binding ratio of **3b** with Cu^{2+}, we looked for possible binding sites in the host. Undoubtedly, the β-amino α,β-unsaturated ketone groups of **3b** must constitute one of the possible binding sites for Cu^{2+}, whereas the lower rim cavity around the phenolic-OH and amide groups of **3b** might constitute the second. The UV/Vis and fluorescence spectra of **3b** with Cu^{2+} provided some clues to the possible binding sites. On the one hand, the absorption band at 308 nm, attributed to the absorption of β-amino α,β-unsaturated ketone conjugated naphthalene, gradually decreased in intensity during the addition of Cu^{2+}. On the other hand, the fluorescence of **3b** was enhanced by the addition of Cu^{2+}, which supports the notion that β-amino α,β-unsaturated ketones form a strong complex with Cu^{2+}. Such a chelation-enhanced fluorescence (CHEF) of **3b** was presumably mainly due to the conformational restriction of the two β-amino α,β-unsaturated ketone groups when chelated with Cu^{2+}, which inhibited intramolecular charge transfer. Furthermore, the excitation spectrum of **3b** in the presence of 5 equiv. of Cu^{2+} monitored at 452 nm was broadened and red-shifted ($\Delta\lambda$ = 4 nm) compared to that monitored at 341 nm for the monomer (Figure 3). The results implied that the two emission bands observed in Figure 2 (b) should be generated from different species, which might be a static excimer[17] or an exciplex[8b] when **3b** is complexed with Cu^{2+}.

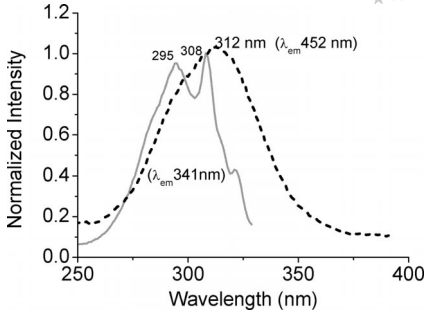


Figure 3. Excitation spectrum (normalized) of **3b** (20 μM) in the presence of 5 equiv. of $[Cu(ClO_4)_2]$ in CH_3CN monitored at 341 nm for the monomer (solid line) and at 452 nm for the excimer (dashed line).

As described above, the lower rim cavity around the phenolic-OH and amide groups of **3b** may constitute the second possible binding site for Cu^{2+}. The new absorption band of the complex at 438 nm is characteristic of an MLCT band between Cu^+ and the lower rim phenolic-OH.[12b,13] This means that Cu^{2+} was reduced to Cu^+ by the phenolic OH groups of calix[4]arene **3b**, and that the oxidized phenols help to trap the reduced Cu^+.[20] The auto-reduction of Cu^{2+} by phenol is well-documented,[21] and the reduction of Cu^{2+} by **3b** was verified by EPR experiments (Figure 4). The EPR signals of the paramagnetic Cu^{2+} in CH_3CN at 77 K were diminished by adding different amounts of **3b**. The results are consistent with our previous observations in other calix[4]arene systems containing pendant β-amino α,β-unsaturated ketones.[14] The addition of 0.5 equiv. of **3b** reduced the EPR intensity of Cu^{2+} to about 12%, which implied that both of the Cu^{2+} binding sites of **3b** have the potential to reduce Cu^{2+}. However, the two binding sites cannot effectively convert Cu^{2+} into Cu^+ at once, therefore, 12% of EPR signal remained. To clarify whether **3b** can bind Cu^+ directly, we also studied its binding ability toward $[Cu(CH_3CN)_4]PF_6$ by using UV/Vis spectroscopy; however, no change was observed (see Figure S-38 in the Supporting Information).

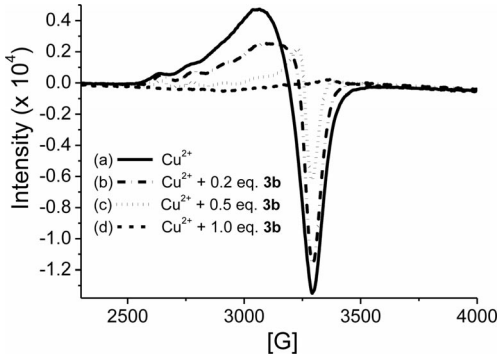


Figure 4. EPR spectra of $[Cu(ClO_4)_2]$ (5 mM) after adding different amounts (a) 0, (b) 0.2, (c) 0.5, and (d) 1.0 equiv. of **3b** at 77 K, recorded at X-band with microwave power of 20 mW and microwave frequency of 9.5 GHz.

To further confirm the proposed double binding sites for Cu^{2+} in **3b**, we carried out ^1H NMR titration experiments

with *tert*-butylphenyl-substituted calix[4]arene **3a** by adding [Cu(ClO_4)$_2$]. We used **3a** (R = *tert*-butylphenyl) instead of **3b** (R = 1-naphthyl) to investigate the effect of added [Cu(ClO_4)$_2$] on the ^{1}H NMR chemical shift changes because the former has a simpler proton splitting pattern than the latter. Detailed assignment of the ^{1}H NMR signals of **3a** was based on HMQC, HMBC, and 2D H,H-COSY experiments (Figures S-19 to S-22 in the Supporting Information). The ^{1}H NMR spectra of ligand **3a** in CD_3CN in the presence of different amounts of Cu^{2+} are depicted in Figure 5 (for proton labeling of **3a**, see Scheme 1). The methylene protons (H_e) near the α,β-unsaturated ketones were downfield shifted from δ = 5.26 ppm to δ = 5.64 ppm ($\Delta\delta$ = +0.38 ppm) in the presence of 2 equiv. of Cu^{2+}. Such a downfield shift of H_e is expected when metal ions form a complex with the carbonyl groups of the α,β-unsaturated ketones. In addition, the signals of the amino protons (H_g and H_h) disappeared and this was accompanied by the appearance of a new 1:1:1 triplet signal at δ = 6.82 (J = 53 Hz); the unique triplet pattern was probably due to the splitting of a metal-bound amino group by the nitrogen nucleus (I = 1).[14,22] Furthermore, the signals in the aromatic region (δ = 7.5 to 8.8 ppm) became more complicated and was accompanied by the appearance of some new signals. Signals of the phenolic-OH and amide-H_b were first broadened and then disappeared during the addition of 0–3.0 equiv. of Cu^{2+} ions (Figure 5, a–e). Based on these observations, we believe that the lower rim phenol hydroxyl groups and the amide groups might assist each other in the coordination of Cu^+.

The infrared spectra of **3b** and **3b**·(Cu^+)$_2$ provided further structural information on the complex (see Figure S-39 in the Supporting Information). For compound **3b**, the 1604 cm^{-1} band is characteristic of the conjugated C=O group of an enaminone, in which intramolecular hydrogen bonding substantially lowers the C=O stretching frequency.[12b,23] Compound **3b** also shows a typical C=O band of an amide group at 1684 cm^{-1}. The infrared spectrum of the complex **3b**·(Cu^+)$_2$ showed a significant shift of the amide C=O frequency from 1684 to 1664 cm^{-1}, which might be due to the binding of Cu^+ with the nitrogen of the amide group.[24] A literature survey also supported the idea that Cu^{2+}/Cu^+ ions preferentially coordinate with the nitrogen atoms of amide groups.[19b,25] Furthermore, the IR signals of enaminones (C=O at 1604 cm^{-1} and C=C at 1531 cm^{-1}) were found to be broadened and slightly shifted to higher frequency when **3b** complexed with Cu^+. The formation of complex **3b**·(Cu^+)$_2$ was also confirmed by the FAB mass spectrum (see Figure S-40 in the Supporting Information), which showed a peak at m/z 633.

Based on the information obtained from UV/Vis, fluorescence, IR, ^{1}H NMR, and EPR spectroscopic studies upon adding Cu^{2+} to **3b**, we propose a possible binding mode for the 1:2 complex of **3b** with two Cu^+ as shown in Scheme 2.

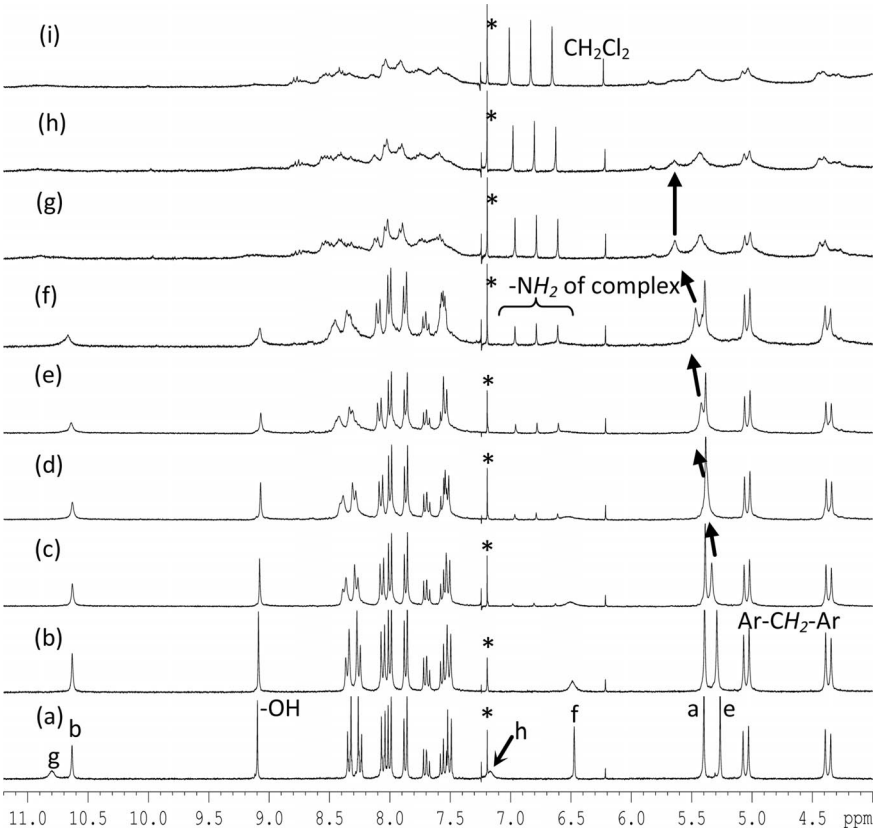
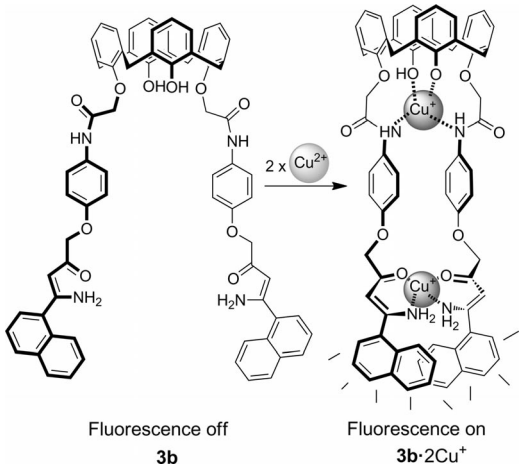


Figure 5. ^{1}H NMR spectra of **3a** (5 mM) in CD_3CN in the presence of different amounts of Cu[(ClO_4)$_2$]: (a) 0, (b) 0.2, (c) 0.4, (d) 0.6, (e) 0.8, (f) 1.0, (g) 1.5, (h) 2.0 and (i) 3.0 equiv. Where * denotes external standard $CHCl_3$. The intensity of spectra f–i was doubled for observing the weak new signals. For proton labeling of **3a**, see Scheme 1.

In the lower part of the complex **3b**·$(Cu^+)_2$, two β-amino α,β-unsaturated ketone moieties collaborate to coordinate to Cu^+ with a tetrahedral geometry.[26] Concurrently, the phenolic hydroxyl group on the lower rim of calix[4]arene **3b** also chelates with a Cu^+ ion, and the amide groups nearby should assist in this coordination.



Scheme 2. Possible binding mode of **3b** with two Cu^+ ions.[27]

Control compounds **6**, **9a**, and **9b** were also synthesized to provide further evidence for the proposed binding modes. The recognition of Cu^{2+} by calix[4]arene **6**, which possessed only the pendant *N*-arylamidomethyl groups (the upper component of compound **3b**) without the β-amino α,β-unsaturated ketones, was investigated by UV/Vis spectroscopy, ^{1}H NMR, ESI-MS, and EPR analyses. The UV/Vis spectrum of calix[4]arene **6** with Cu^{2+} in CH_3CN was similar to that observed in **3b**, where a new broad absorption band at 438 nm appeared (see Figure S-41 in the Supporting Information). The association constants (K_a) of **6** with Cu^{2+} was calculated to be 6.82×10^3 M^{-1} from a Benesi–Hildebrand plot.[19a] The EPR signal of Cu^{2+} disappeared after adding 1 equiv. of calix[4]arene **6** (Figure S-42), which supported the proposal that the autoreduction of Cu^{2+} to Cu^+ occurred in the presence of **6**. In addition, ^{1}H NMR signals of the hydroxyl protons of **6** disappeared after adding 1 equiv. of Cu^{2+}, implying the participation of phenol hydroxyl groups in the complexation (see Figure S-43 in the Supporting Information). It is worth noting that all the proton signals, except the hydroxyl protons, were little shifted, which implied that the binding interaction of **6** with Cu^+ was weak. Furthermore, the ESI mass spectrum (see Figure S-44 in the Supporting Information) showed two peaks at *m*/*z* 869.4 and 871.4, which corresponded to the calculated mass of **6**·$^{63}Cu^+$and **6**·$^{65}Cu^+$, respectively. These results support the proposal that the lower rim of **6** alone can recognize Cu^{2+} and create a UV/Vis band at 438 nm, which is similar to the spectra observed in the complexation of **3b** with Cu^{2+} (see above).

In a similar way, the binding ability of control compound **9b** toward Cu^{2+} was also investigated. Compound **9b**, which resembles the structure of **3b** but without a calix[4]arene scaffold, also showed selective binding toward Cu^{2+} (see Figure S-45 in the Supporting Information) and its absorption spectra showed a hypochromic effect and a small bathochromic shift with isosbestic points at 243 and 349 nm (Figure 6, a). It should be noted that there is a major difference between the absorption spectra of **9b** and **3b** when these compounds were titrated with Cu^{2+}; the former did not show an MLCT band around 438 nm (cf. Figure 2, a). Despite this difference in absorption spectra, the emission phenomena of both compounds were quite similar: both the monomer emission (λ_{em} = 341 nm) and the longer emission bands (λ_{em} = 446 nm) of **9b** were gradually enhanced upon adding Cu^{2+} (Figure 6, b). The new, broad emission band at 446 nm is unlikely to arise from the emission from a naphthyl excimer because the possibility of forming an intermolecular complex at such a low concentration (20 μM) is slim.[28] Thus, the new emission band may be attributed to exciplex formation between Cu^+ and the β-amino β-naphthyl α,β-unsaturated ketone of **9b**. Exciplex formation between Ag^+ and several aromatic moieties has been reported,[8a,27] however, to the best of our knowledge, there has been no report of such an exciplex formation between a β-amino β-naphthyl α,β-unsaturated ketone and Cu^{2+}. To fully understand the mechanism of exciplex formation, additional photophysical measurements, such as time-resolved fluorescence or laser flash photolysis experiments, would be needed in the future. We also found that Cu^{2+} was reduced by **9b**, as evidenced by the silent EPR signal of Cu^{2+} by added **9b** (see Figure S-42c in the Supporting Information). In our previous work,[14] we found that the β-amino α,β-unsaturated ketone could participate in the reduction of Cu^{2+} in a lower-rim propyl ether protected calixarene. Here,

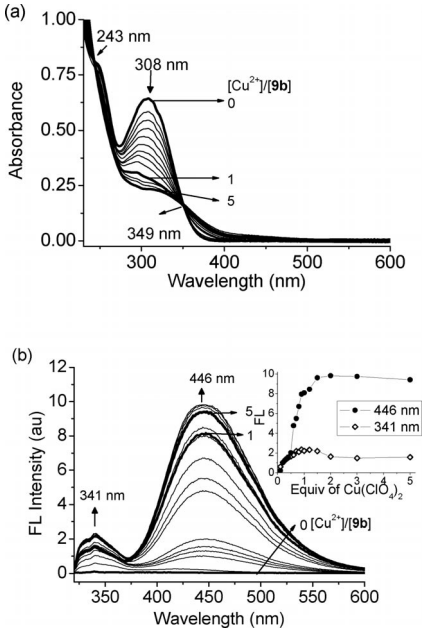


Figure 6. (a) UV/Vis and (b) fluorescence emission spectra of **9b** (20 μM) with various amounts of $[Cu(ClO_4)_2]$ in CH_3CN. Excitation wavelength was 308 nm. The inset shows the variation of fluorescence intensity of **9b** at 341 and 446 nm with different amounts of $[Cu(ClO_4)_2]$.

the autoreduction of Cu^{2+} to Cu^{+} by a β-amino α,β-unsaturated ketone was again proven to be efficient in the control compound **9b**, therefore, the need for a calixarene scaffold can be excluded for the autoreduction of Cu^{2+} to Cu^{+}. From the titration experiment, the association constant[19a] of **9b** with Cu^{2+} was calculated to be 2.52×10^4 M^{-1}, and the binding ratio determined by the Job plot was 1:1 (see Figure S-47 in the Supporting Information). The binding of Cu^{+} with **9a** was also supported by ^{1}H NMR titration experiments (see Figure S-48 in the Supporting Information). By comparing the binding constants of **3b**, **6**, and **9b** with Cu^{2+} (see Table 1), we found that **3b** exhibited positive allosteric[29] behavior toward the coordination of two Cu^{2+} ions. In other words, when one of the two binding sites of **3b** chelates the first Cu^{2+}, the conformation of the second binding site changes and helps the complexation of the second Cu^{2+} ion.

Conclusions

We have reported the syntheses of a novel fluorescence turn-on chemosensor **3b**, which showed high selectivity and sensitivity toward Cu^{2+} among 15 different metal ions screened. Calix[4]arene **3b** was found to coordinate with two equivalents of $[Cu(ClO_4)_2]$ through two binding sites: (1) the lower-rim phenolic-OH and amide groups, and (2) the pendant β-amino α,β-unsaturated ketones. It should be noted that the autoreduction of Cu^{2+} to Cu^{+} was observed during complexation of **3b**. The association constant (K_a) of the 1:2 complex **3b**·$(Cu^{+})_2$ was calculated to be 2.02×10^9 M^{-2} by the Benesi–Hildebrand plot. Finally, an exciplex emission from the complexation of **9b** with Cu^{2+} is unprecedented, and the system deserves further study with time-resolved fluorescence lifetime measurements to understand the dynamics of such novel exciplex formation.

Experimental Section

General: ^{1}H NMR spectra were measured with either a 300 or 500 MHz spectrometer. Natural abundance ^{13}C NMR spectra were measured using pulse Fourier transform techniques, with a 300 or 500 MHz NMR spectrometer operating at 75.4 and 125.7 MHz, respectively. Broad-band decoupling, DEPT, H,H-COSY, H,C-COSY, HMQC, and HMBC were carried out to simplify spectra and aid peak identification. All reported yields are quoted as an average of three runs and are based on recovered starting materials.

General Procedure for the Synthesis of 2a and 2b: To a well-stirred solution of **1** (100 mg, 0.19 mmol) and 2–3 drops of *N*,*N*-dimethylformamide (DMF) in anhydrous CH_2Cl_2 (10 mL), was added oxalyl chloride (0.18 mL, 2.05 mmol) under nitrogen at room temperature. The reaction mixture was heated at reflux temperature for 3 h. Solvent and excess oxalyl chloride were removed under reduced pressure and the residue was further dried in vacuo. The residue was dissolved in anhydrous CH_2Cl_2 (10 mL) followed by addition of a solution of amines **4a**–**b** (**4a**: 123 mg, 0.38 mmol; **4b**: 120 mg, 0.38 mmol) and triethylamine (8–10 drops) in anhydrous CH_2Cl_2 (10 mL). The reaction mixture was heated to 40 °C for 24 h. After evaporation of solvent, the crude product was purified by column chromatography to afford **2a**–**b**.

25,27-Bis(*N*-{1-[4-({3-[4-(*tert*-butyl)phenyl]-5-isoxazolyl}methoxy)-phenyl]aminocarbonyl}methoxy)-26,28-dihydroxycalix[4]arene (2a): Yield 80% (175 mg); white solid; m.p. >270 °C (decomp.); R_f = 0.35 (*n*-hexane/ethyl acetate, 1:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.32 (s, 18 H, *t*Bu), 3.58 (d, J = 13.5 Hz, 4 H, ArCH_2Ar), 4.22 (d, J = 13.5 Hz, 4 H, ArCH_2Ar), 4.62 (s, 4 H, H_a), 5.16 (s, 4 H, H_e), 6.70 (s, 2 H, H_f), 6.76–6.82 (m, 6 H, Ar-H), 6.90 (t, J = 7.5 Hz, 2 H, Ar-H), 7.03 (d, J = 7.5 Hz, 4 H, Ar-H), 7.15 (d, J = 7.4 Hz, 4 H, Ar-H), 7.34 (d, J = 9.0 Hz, 4 H, Ar-H), 7.45 (d, J = 8.4 Hz, 4 H, *t*Bu-Ph), 7.78 (d, J = 8.4 Hz, 4 H, *t*Bu-Ph), 8.36 (s, 2 H, OH), 10.19 (s, 2 H, H_b) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 31.2 (CH_3), 31.8 (CH_2), 34.8 (Cq), 61.9 (CH_2), 74.8 (CH_2), 101.4 (CH), 115.1 (CH), 120.4 (CH), 121.1 (CH), 125.8 (CH), 125.9 (Cq), 126.6 (CH), 127.1 (CH), 127.5 (Cq), 129.2 (CH), 129.9 (CH), 131.6 (Cq), 132.6 (Cq), 150.3 (Cq), 151.7 (Cq), 153.3 (Cq), 154.4 (Cq), 162.4 (Cq), 164.7 (Cq), 168.4 (Cq) ppm. MS (FAB): m/z = 1149 [M + H$^+$]. HRMS: calcd. for $C_{72}H_{69}N_4O_{10}$ 1149.5013; found 1149.5032.

25,27-Bis{*N*-[1-(4-{[3-(1-naphthyl)-5-isoxazolyl]methoxy}phenyl)-aminocarbonyl]methoxy}-26,28-dihydroxycalix[4]arene (2b): Yield 75% (162 mg); yellowish-brown solid; m.p. 150–151 °C; R_f = 0.41 (*n*-hexane/ethyl acetate, 1:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.59 (d, J = 13.5 Hz, 4 H, ArCH_2Ar), 4.23 (d, J = 13.5 Hz, 4 H, ArCH_2Ar), 4.64 (s, 4 H, H_a), 5.22 (s, 4 H, H_e), 6.71 (s, 2 H, H_f), 6.77–6.94 (m, 8 H, Ar-H), 7.05 (d, J = 7.5 Hz, 4 H, Ar-H), 7.16 (d, J = 7.5 Hz, 4 H, Ar-H), 7.38 (d, J = 9.1 Hz, 4 H, Ar-H), 7.49–7.57 (m, 6 H, naphthyl-H), 7.74 (dd, J = 7.2, 1.2 Hz, 2 H, naphthyl-H), 7.87–7.95 (m, 4 H, naphthyl-H), 8.35 (s, 2 H, OH), 8.41–8.45 (m, 2 H, naphthyl-H), 10.20 (s, 2 H, H_b) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 31.8 (CH_2), 61.9 (CH_2), 74.8 (CH_2), 104.8 (CH), 115.2 (CH), 120.5 (CH), 121.1 (CH), 125.2 (CH), 125.7 (CH), 126.3 (CH), 126.5 (Cq), 127.1 (CH), 127.1 (CH), 127.5 (Cq), 128.0 (CH), 128.4 (CH), 129.2 (CH), 129.9 (CH), 130.3 (CH), 130.9 (Cq), 131.7 (Cq), 132.6 (Cq), 133.8 (Cq), 150.3 (Cq), 151.7 (Cq), 154.5 (Cq), 162.7 (Cq), 164.7 (Cq), 167.9 (Cq) ppm. MS (FAB): m/z = 1137 [M + H$^+$]. HRMS: calcd. for $C_{72}H_{56}N_4O_{10}$ 1136.3999; found 1136.3983.

General Procedure for the Synthesis of 3a and 3b: To a well-stirred solution of compound **2a**–**b** (**2a**: 60.0 mg, 0.05 mmol; **2b**: 100 mg, 0.09 mmol) and $[Mo(CO)_6]$ (4 equiv.) in CH_3CN, was added 2–3 drops of water, then the reaction mixture was heated to reflux temperature for 2 h. Subsequently, solvent was removed and the residue was dissolved in CH_2Cl_2 (10 mL). The solution was treated with aq. NH_4OH (10 mL) and the organic layer was washed with water (100 mL) and aq. 1 M EDTA (50 mL), dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography to afford pure **3a**–**b** in 60–80% yields.

25,27-Bis(*N*-{1-[4-({4-amino-4-[4-(*tert*-butyl)phenyl]-2-oxo-3-butenyl}oxy)phenyl]aminocarbonyl}methoxy)-26,28-dihydroxycalix[4]arene (3a): Yield 80% (48.0 mg, 0.04 mmol); pale-yellow solid; m.p. 196–198 °C; R_f = 0.44 (*n*-hexane/ethyl acetate, 1:3). ^{1}H NMR (300 MHz, CD_3CN): δ = 1.28 (s, 18 H, *t*Bu), 3.59 (d, J = 13.5 Hz, 4 H, ArCH_2Ar), 4.28 (d, J = 13.5 Hz, 4 H, ArCH_2Ar), 4.50 (s, 4 H, H_a), 4.63 (s, 4 H, H_e), 5.73 (s, 2 H, H_f), 6.51 (s, 2 H, H_h), 6.71–6.83 (m, 6 H, H_d and H_o), 6.92 (t, J = 7.5 Hz, 2 H, H_k), 7.09 (d, J = 7.5 Hz, 4 H, H_l), 7.22 (d, J = 7.5 Hz, 4 H, H_p), 7.32 (d, J = 8.8 Hz, 4 H, H_c), 7.47 (d, J = 8.3 Hz, 4 H, H_j), 7.58 (d, J = 8.3 Hz, 4 H, H_i), 8.33 (s, 2 H, OH), 9.89 (s, 2 H, H_b), 10.07 (br. s, 2 H, H_g) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 32.0 (CH_3), 32.7 (CH_2), 36.1 (Cq), 73.5 (CH_2), 76.1 (CH_2), 91.1 (CH), 116.3 (CH), 122.2 (CH), 122.6 (CH), 127.5 (CH), 128.0 (CH), 128.3 (CH), 129.3 (Cq), 130.8 (CH), 131.2 (CH), 133.0 (Cq), 135.0 (Cq), 135.3 (Cq), 152.5 (Cq), 153.3 (Cq), 156.1 (Cq), 156.5 (Cq), 164.5 (Cq), 166.6

(Cq), 195.2 (Cq) ppm. MS (FAB): *m*/*z* = 1153 [M + H$^+$]. HRMS: calcd. for $C_{72}H_{73}N_4O_{10}$ 1153.5327; found 1153.5350.

25,27-Bis{*N*-[1-(4-{[4-amino-4-(1-naphthyl)-2-oxo-3-butenyl]oxy}-phenyl)aminocarbonyl]methoxy}-26,28-dihydroxycalix[4]arene (3b): Yield 60% (60.0 mg, 0.05 mmol); pale-yellow solid; m.p. 170–172 °C; R_f = 0.23 (*n*-hexane/ethyl acetate, 1:2). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.55 (d, *J* = 13.4 Hz, 4 H, ArCH_2Ar), 4.20 (d, *J* = 13.4 Hz, 4 H, ArCH_2Ar), 4.54 (s, 4 H, H_a), 4.56 (s, 4 H, H_e), 5.60 (br. s, 2 H, H_h), 5.74 (s, 2 H, H_f), 6.67–6.87 (m, 8 H, Ar-H), 6.99 (d, *J* = 7.5 Hz, 4 H, Ar-H), 7.14 (d, *J* = 7.5 Hz, 4 H, Ar-H), 7.28 (d, *J* = 8.9 Hz, 4 H, Ar-H), 7.39–7.53 (m, 8 H, naphthyl-H), 7.79–7.85 (m, 4 H, naphthyl-H), 8.08–8.12 (m, 2 H, naphthyl-H), 8.31 (s, 2 H, OH), 10.09 (s, 2 H, H_b), 10.23 (br. s, 2 H, H_g) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ_c = 31.7 (CH_2), 72.1 (CH_2), 74.7 (CH_2), 94.0 (CH), 114.8 (CH), 120.6 (CH), 120.9 (CH), 125.0 (CH), 125.1 (CH), 125.7 (CH), 126.3 (CH), 126.9 (CH), 127.0 (CH), 127.5 (CH), 128.3 (CH), 129.1 (CH), 129.8 (CH), 129.9 (Cq), 130.0 (CH), 130.8 (Cq), 132.6 (Cq), 133.5 (Cq), 135.1 (Cq), 150.4 (Cq), 151.7 (Cq), 155.0 (Cq), 163.3 (Cq), 164.6 (Cq), 194.7 (Cq) ppm. MS (FAB): *m*/*z* = 1141 [M + H$^+$]. HRMS: calcd. for $C_{72}H_{60}N_4O_{10}$ 1140.4309; found 1140.4326.

General Procedure for the Synthesis of 25,27-Bis[*N*-(1-propoxy-phenyl)aminocarbonyl]methoxy-26,28-dihydroxycalix[4]arene (6): The synthetic procedure was adapted from that used for compounds **2a**–**b**. Compounds **1** (100 mg, 0.19 mmol) and **5** (58.0 mg, 0.38 mmol) were used. Yield 80% (123 mg, 0.15 mmol); white solid; m.p. 286–287 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.05 (t, *J* = 7.5 Hz, 6 H, CH_3), 1.78–1.85 (m, 4 H, $CH_3CH_2CH_2$), 3.58 (d, *J* = 13.5 Hz, 4 H, Ar-CH_2-Ar), 3.91 (t, *J* = 6.6 Hz, 4 H, $CH_3CH_2CH_2$), 4.24 (d, *J* = 13.5 Hz, 4 H, Ar-CH_2-Ar), 4.63 (s, 4 H, COCH_2), 6.74–6.82 (m, 6 H, Ar-H), 6.88–6.93 (m, 2 H, Ar-H), 7.03 (d, *J* = 7.5 Hz, 4 H, Ar-H), 7.16 (d, *J* = 7.5 Hz, 4 H, Ar-H), 7.29–7.32 (m, 4 H, Ar-H), 8.29 (s, 2 H, OH), 10.10 (s, 2 H, -N*H*CO) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 10.5 (CH_3), 22.6 (CH_2), 31.7 (CH_2), 69.8 (CH_2), 74.8 (CH_2), 114.6 (CH), 120.7 (CH), 120.9 (CH), 126.9 (CH), 127.5 (Cq), 129.1 (CH), 129.8 (CH), 130.3 (Cq), 132.6 (Cq), 150.5 (Cq), 151.8 (Cq), 156.0 (Cq), 164.7 (Cq) ppm. MS (FAB): *m*/*z* = 807 [M + H$^+$]. HRMS: calcd. for $C_{50}H_{51}N_2O_8$ 807.3647; found 807.3628.

X-ray Crystal Data for Compound 6: $C_{53}H_{48}N_{3.50}O_8$; *M* = 861.95; monoclinic; *a* = 9.9577(5) Å, *b* = 16.1397(8) Å, *c* = 28.3971(14) Å, α = 90°, β = 92.523(1)°, γ = 90°; *V* = 4559.4(4) Å^3; space group $P2_1/n$; *Z* = 4; calculated density 1.256 Mg m^{-3}; crystal dimensions (mm^3): 0.45 × 0.28 × 0.25; *T* = 150(2) K; λ (Mo-K_α) = 0.71073 Å; μ = 0.085 mm^{-1}; 29335 reflections collected, 10455 independent (R_{int} = 0.0450), 607 parameter refined on F^2; R_1 = 0.0717; *wR*2[F^2] = 0.1696 (all data); GOF on F^2 1.096; $\Delta\rho_{max}$ = 0.508 e Å^{-3}.

CCDC-680702 (for **6**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

General Procedure for the Synthesis of Compounds 8a and 8b: To a well-stirred solution of **7** (100 mg, 0.55 mmol) and 2–3 drops of dimethylformamide (DMF) in anhydrous CH_2Cl_2 (10 mL), was added oxalyl chloride (0.24 mL, 2.77 mmol) under nitrogen at room temperature. The reaction mixture was heated to reflux temperature for 3 h. Solvent and excess oxalyl chloride were removed under reduced pressure and the residue was further dried in vacuo. The residue was dissolved in anhydrous CH_2Cl_2 (10 mL) followed by addition of a solution of amines **4a**–**b** (**4a**: 177 mg, 0.55 mmol; **4b**: 174 mg, 0.55 mmol) and triethylamine (8–10 drops) in anhydrous CH_2Cl_2 (10 mL). The reaction was heated to 40 °C for 24 h, then, after evaporation of solvent, the crude product was purified by column chromatography to afford **8a**–**b**.

***N*-(4-{[3-(4-*tert*-Butylphenyl)isoxazol-5-yl]methoxy}phenyl)-2-(2,6-dimethylphenoxy)acetamide (8a):** Yield 82% (218 mg); grayish white solid; m.p. 142–144 °C; R_f = 0.5 (*n*-hexane/ethyl acetate, 2:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.34 (s, 9 H, *t*Bu), 2.28 (s, 6 H, Ar-CH_3), 4.38 (s, 2 H, H_a), 5.16 (s, 2 H, H_c), 6.62 (s, 1 H, H_d), 6.97–7.05 (m, 5 H, Ar-H), 7.46 (d, *J* = 8.3 Hz, 2 H, Ar-H), 7.60 (d, *J* = 8.9 Hz, 2 H, Ar-H), 7.73 (d, *J* = 8.3 Hz, 2 H, Ar-H), 8.64 (s, 1 H, H_b) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 16.2 (CH_3), 31.1 (CH_3), 34.7 (Cq), 61.6 (CH_2), 70.3 (CH_2), 101.3 (CH), 115.2 (CH), 121.6 (CH), 124.8 (CH), 125.8 (CH), 126.5 (CH), 129.1 (CH), 130.2 (Cq), 131.2 (Cq), 153.3 (Cq), 154.0 (Cq), 154.7 (Cq), 162.3 (Cq), 166.4 (Cq), 168.0 (Cq) ppm. MS (FAB): *m*/*z* = 485 [M + H$^+$]. HRMS: calcd. for $C_{30}H_{32}N_2O_4$ 484.2362; found 484.2367.

2-(2,6-Dimethylphenoxy)-*N*-(4-{[3-(naphthalen-1-yl)isoxazol-5-yl]methoxy}phenyl)acetamide (8b): Yield 77% (203 mg); pale-yellow solid; m.p. 129–130 °C; R_f = 0.65 (*n*-hexane/ethyl acetate, 1:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.26 (s, 6 H, Ar-CH_3), 4.36 (s, 2 H, H_a), 5.17 (s, 2 H, H_c), 6.63 (s, 1 H, H_d), 6.96–7.03 (m, 5 H, Ar-H), 7.45–7.53 (m, 3 H, naphthyl-H),7.59 (d, *J* = 8.9 Hz, 2 H, Ar-H), 7.66 (d, *J* = 6.6 Hz, 1 H, naphthyl-H), 7.85–7.91 (m, 2 H, naphthyl-H), 8.34–8.39 (m, 1 H, naphthyl-H), 8.64 (s, 1 H, H_b) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 16.2 (CH_3), 61.5 (CH_2), 70.3 (CH_2), 104.7 (CH), 115.2 (CH), 121.5 (CH), 124.8 (CH), 125.0 (CH), 125.4 (CH), 126.1 (CH), 126.3 (Cq), 127.0 (CH), 127.7 (CH), 128.3 (CH), 129.1 (CH), 130.2 (CH), 130.7 (Cq), 131.2 (Cq), 133.6 (Cq), 154.0 (Cq), 154.6 (Cq), 162.5 (Cq), 166.4 (Cq), 167.5 (Cq) ppm. MS (EI): *m*/*z* = 478 [M]$^+$. HRMS: calcd. for $C_{30}H_{26}N_2O_4$ 478.1894; found 478.1884.

General Procedure for the Synthesis of 9a and 9b: To a well-stirred solution of compound **8a**–**b** (**8a**: 100 mg, 0.21 mmol; **8b**: 200 mg, 0.42 mmol) and [$Mo(CO)_6$] (1.3 equiv.) in CH_3CN (10 mL), was added 2–3 drops of water, then the reaction mixture was heated to reflux temperature for 2 h. The solvent was removed and the residue was dissolved in CH_2Cl_2 (10 mL). The solution was treated with aq NH_4OH (10 mL) and the organic layer was washed with water (100 mL) and aq. 1 M EDTA (50 mL), dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography to afford pure **9a**–**b** in 65–80% yields.

***N*-{4-[4-Amino-4-(4-*tert*-butylphenyl)-2-oxobut-3-enyloxy]phenyl}-2-(2,6-dimethylphenoxy)acetamide (9a):** Yield 65% (65.0 mg, 0.13 mmol); pale-yellow solid; m.p. 70–72 °C; R_f = 0.43 (*n*-hexane/ethyl acetate, 1:1). ^{1}H NMR (300 MHz, CD_3CN): δ = 1.33 (s, 9 H, *t*Bu), 2.29 (s, 6 H, Ar-CH_3), 4.38 (s, 2 H, H_a), 4.57 (s, 2 H, H_c), 5.63 (br. s, 1 H, H_f), 5.81 (s, 1 H, H_d), 6.93–7.06 (m, 6 H, Ar-H), 7.43–7.57 (m, 6 H, Ar-H), 8.58 (s, 1 H, H_b), 10.15 (br. s, 1 H, H_e) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 16.3 (CH_3), 31.1 (CH_3), 34.8 (Cq), 70.38 (CH_2), 72.1 (CH_2), 90.25 (CH), 115.1 (CH), 121.6 (CH), 124.9 (CH), 125.9 (CH), 126.0 (CH), 129.2 (CH), 130.3 (Cq), 130.5 (Cq), 133.6 (Cq), 154.1 (Cq), 154.5 (Cq), 155.4 (Cq), 163.2 (Cq), 166.4 (Cq) ppm. MS (FAB): *m*/*z* = 487 [M + H$^+$]. HRMS: calcd. for $C_{30}H_{34}N_2O_4$ 486.2519; found 486.2520.

***N*-{4-[4-Amino-4-(naphthalen-1-yl)-2-oxobut-3-enyloxy]phenyl}-2-(2,6-dimethylphenoxy)acetamide (9b):** Yield 80% (160 mg, 0.33 mmol); pale-yellow solid; m.p. 79–81 °C; R_f = 0.2 (*n*-hexane/ethyl acetate, 2:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.31 (s, 6 H, Ar-CH_3), 4.35 (s, 2 H, H_a), 4.60 (s, 2 H, H_c), 5.74 (s, 1 H, H_d), 5.84 (br. s, 1 H, H_f), 6.93 (d, *J* = 8.8 Hz, 2 H, Ar-H), 6.99–7.09 (m, 2 H, Ar-H), 7.46–7.57 (m, 6 H, Ar-H and naphthyl-H), 7.86–7.92 (m, 2 H, naphthyl-H), 8.09–8.12 (m, 1 H, naphthyl-H), 8.61 (s, 1 H,

H_b), 10.25 (br. s, 1 H, H_e) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 16.2 (CH_3), 70.3 (CH_2), 71.8 (CH_2), 93.8 (CH), 115.0 (CH), 121.5 (CH), 124.8 (CH), 124.9 (CH), 124.9 (CH), 125.6 (CH), 126.4 (CH), 126.9 (CH), 128.4 (CH), 129.1 (CH), 129.9 (Cq), 130.1 (CH), 130.3 (Cq), 130.5 (Cq), 133.5 (Cq), 135.0 (Cq), 154.0 (Cq), 155.3 (Cq), 163.5 (Cq), 166.4 (Cq), 194.1 (Cq) ppm. MS (FAB): *m*/*z* = 481 [M + H^+]. HRMS: calcd. for $C_{30}H_{28}N_2O_4$ 480.2049; found 480.2056.

General Procedures for the UV/Vis and Fluorescence Spectroscopic Experiments: UV/Vis spectra were recorded with an HP-8453 spectrophotometer equipped with a diode array detector; the resolution was set at 1 nm. Fluorescence spectra were recorded with an Aminoco Bowman Series 2 type spectrofluorimeter. For all measurements of fluorescence spectra, excitation was at 308 nm with the excitation and emission slit width at 4.0 nm. UV/Vis and fluorescence titration experiments were performed with 20 μM solutions of **3b** and **9b** in CH_3CN and varying concentrations of metal perchlorate in CH_3CN. During the measurements, the temperature of the quartz sample cell and chamber was kept at 25 °C.

General Procedures for the ^1H NMR Titration Experiments: ^1H NMR titration spectra were recorded at 300 MHz with tetramethylsilane (TMS) in a coaxial capillary tube as an external standard. Experiments were performed with 5 mM solutions of **3b**, **6**, and **9b** in CH_3CN and varying concentrations of $[Cu(ClO_4)_2]$ in CH_3CN at 25 °C.

Supporting Information (see footnote on the first page of this article): Additional experimental procedures, 1D and 2D NMR spectra, UV/Vis and Fluorescence titration spectra, and X-ray crystallographic information.

Acknowledgments

We thank the National Science Council (NSC) and the Ministry of Education, Taiwan, Republic of China (MOE ATU program) for financial support

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Received: August 19, 2010
Published Online: February 2, 2011

