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ARTICLE TYPE

Cholesterol appended bis-1,2,3-triazoles as simple supramolecular gelators for naked eye detection of Ag^{+}, Cu^{2+} and Hg^{2+} ions

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Cholesterol coupled bis 1,2,3-triazoles **1-3** have been synthesized and their gelation abilities are examined. Bis triazoles **1-3** form gel from $CHCl_3$- CH_3OH (2:1, v/v) mixture solvents. In contrast, compounds **4** and **5** which are devoid of triazoles, are unable to form gel under similar conditions and thus validate the essential role of triazoles in gelation. While the gel phase of **1** detects Cu^{2+} ions by showing phase transformation from gel to sol, gels derived from **2** and **3** undergo disintegration in presence of Ag^{+}, Cu^{2+} and Hg^{2+} ions. Such phase changes corroborate the visual sensing of the metal ions. Moreover, the fluorescence titration of **3** discriminates Cu^{2+}, Hg^{2+} and Ag^{+} ions by exhibiting differential quenching.

Introduction

Since the discovery, the copper-catalyzed azide-alkyne cycloaddition (CuAAC) reaction has been noted to be useful for different purposes, varying from traditional organic synthesis to advanced materials.[1,2] Different advantageous properties such as high chemical stability, strong dipole moment, heteroaromatic character and hydrogen bond donating and accepting abilities have enable the 1,2,3-triazole motif to interact with molecules and ions in productive manner.[3] The 1,2,3-triazole motif, surrogate of amide group, with greater dipole moment (5 D) provides the polarized C-H bond for interaction with anions and thus its use in devising anion-binding host is noteworthy.[4] Due to the presence of nitrogen atoms in the backbone, the triazole motif is also excellent in cation binding.[5] Thus integration of this functionality into several structural frameworks has been a topic of interest in sensing or detection of ionic analytes in supramolecular chemistry.[6]

In relation to this aspect, the synthesis of organogelators using 1,2,3-triazole functionality draws much attention in last few decades in gel chemistry.[7] Proper use of the 1,2,3-triazole scaffold in the design has led many supramolecular gelators that find use in detection of analytes through a change in state of the gels.[8] Sometimes, the use of amide in place of the triazole motif has been established ineffective in gelation.[9] Gels are viscoelastic material and have been known potential for application in materials, drug delivery and sensors etc.[10] The driving forces responsible for gel formation are specific or noncovalent interactions such as the dipole-dipole interaction, van der Waals forces and hydrogen bonding.[11] Perturbation of these weak forces by external stimuli disrupts the gels to the sols and offers promising opportunities for designing and constructing new functional materials.

In continuation of our work on sensing and detection of ionic analytes by different supramolecular architectures either in solution[12] or in gel phase,[13] we report here cholesterol appended 1,2,3- triazole-based compounds **1-3** (Fig. 1) that exhibit excellent gelation properties in organic solvent. The gel phases of the gelators act as potential media for detection of metal ions such as Cu^{2+}, Hg^{2+} and Ag^{+} ions. Compounds **4** and **5** (Fig. 1) without triazole motif was undertaken as reference that did not show gelation property under identical conditions and thus emphasized the key role of the 1,2,3-triazole unit in the designs.

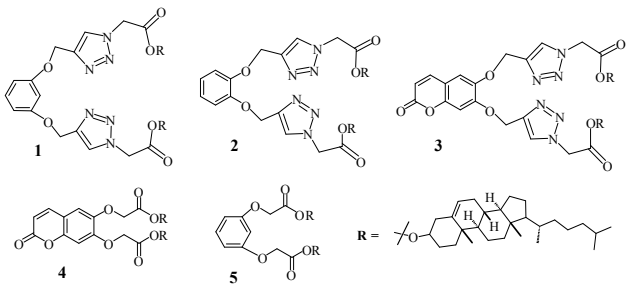

Figure 1. Structure of the compounds **1-5**.

The sensing and detection of Cu^{2+}, Hg^{2+} and Ag^{+} ions draw attention because of their biological relevance. Copper is linked with a variety of fundamental physiological processes in organisms. This metal ion causes environmental pollution and also serves as a catalytic cofactor for a variety of metalloenzymes.[14] Exposure to high levels of copper can cause gastrointestinal disturbance and liver or kidney damage.[15] Similarly, mercury and silver ions are also considered to be the toxic elements in the environment.[16] The exposure of mercury even at low concentration leads to various health problems,

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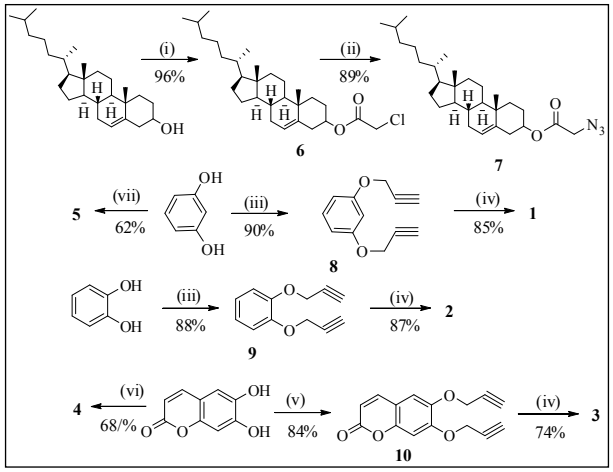
†Electronic Supplementary Information (ESI) available Figures showing the figures of FTIR, fluorescence and UV-vis titration curves, phase changes of gels, Job plots, binding constant curves, ^{1}H NMR changes and spectral data. See http://dx.doi.org/10.1039/b000000x/

especially neurological disorders. Owing to the broad employment in industries, such as electronics, photography, mirrors and pharmacy, a large amount of silver is released to the environment from industrial wastes and also to surface waters that causes high toxicity to aquatic organism.[17]

Results and discussion

Synthesis

The syntheses of the compounds **1**, **2**, **3**, **4** and **5** were achieved according to the Scheme 1. Initially cholesterol was converted to the chloro ester **6** which on reaction with NaN_3 gave the azide compound **7**.[13d] On the other hand, the different phenolic substrates such as resorcinol, catechol and 6,7-dihydroxy coumarin were reacted with the propergyl bromide in presence of either Cs_2CO_3 or K_2CO_3 to generate alkyne functional group containing compounds **8**, **9** and **10**, respectively. Then copper (I)-catalysed click reaction was pursued on these alkynes using the azide compound **7**. In order to have the compound **4**, 6,7-dihydroxy coumarin was refluxed with chloro ester **6** in the presence of Cs_2CO_3 in dry CH_3CN. In the similar way, compound **5** was obtained from the reaction of resorcinol with the chloro ester **6** in the presence of K_2CO_3 in dry CH_3CN. All the compounds were fully characterized by usual spectroscopic methods.



Scheme 1. (i) Chloroacetyl chloride, pyridine, dry CH_2Cl_2, rt, 10h; (ii) CH_3CN, NaN_3, reflux, 5h; (iii) propergyl bromide, dry CH_3CN, K_2CO_3, reflux, 4h; (iv) **7**, dry DMF, $CuSO_4$, sodium ascorbate, 80^0C, 8-12 h; (v) propergyl bromide, dry CH_3CN, Cs_2CO_3, reflux, 3h; (vi) **6**, dry CH_3CN, Cs_2CO_3, reflux, 14h; (vii) **6**, dry CH_3CN, K_2CO_3, reflux, 8h.

Gelation study

Gelation studies were carried out by an inversion tube method, where the compound dissolved in a suitable solvent which forms a homogeneous solution was warmed and then cooled to form a gel which generally was reluctant to flow upon inversion. The gelation properties of the cholesterol derivatives **1- 5** were examined in a wide range of solvents or mixture of solvents (Table 1S). Due to presence of cholesterol unit having large hydrophobic surface, all the compounds were either insoluble or partially soluble in polar protic solvents like MeOH and H_2O. Whereas compounds **1-3** show partial gelation tendency in DMF, they exhibit well-organized molecular packing *via* self aggregation in mixture solvent of $CHCl_3$-CH_3OH (2:1, v/v). In contrast, compound **4**, devoid of triazole units, exhibited partial gelation from $CHCl_3$: CH_3OH (1:1, v/v) at a concentration that is three times higher than the mgc (minimum gelation concentration) of compound **3**. Compound **5** remained soluble under similar conditions. This indicated the key role of triazole motifs in **3** and **1** with respect to **4** and **5**, respectively during gelation.

Gels were prepared by dissolving required amount of gelators in $CHCl_3$:CH_3OH (2:1, v/v). Slight warming of the solutions of compounds **1**, **2** and **3** in $CHCl_3$:CH_3OH (2:1, v/v) followed by keeping at room temperature for 5 min led to the formation of gels.

Morphological study and thermal stability of gels

To gain visual insight into the aggregation mode and microscopic morphology of the gelators, scanning electron microscopy (SEM) was used. SEM images reveal the aggregated three dimensional networks with uneven surface (Fig. 2). While the gel state of **1** gives densely packed flakes with very small pores, the xerogel of **2** shows sponge like architecture with more porous surface. Gelator **3** having larger π-surface than **1** and **2** exhibits rock like morphology with large number of voids for solvent trapping in its gel state.

We believe that molecules **1-3** possibly follow a general packing shown in Fig. 3 for which a three dimensional network is set up in solution and solvents are trapped inside. To our opinion, the triazole which behaves like amide with greater dipole moment may be involved in intermolecular hydrogen bonding *via* trapped methanol (Fig. 3a) or directly without assistance of methanol (Fig. 3b) to form the self assembly in solution. The possibility of intermolecular hydrogen bonding of the triazole proton with the ester carbonyl oxygen to establish a network in the solution cannot be ruled out. In FTIR, small change in stretching frequencies of the ester carbonyls in the gel state with respect to amorphous state supports this proposition (Fig. 1S-3S). However, the large hydrophobic surface of cholesterol would stabilize the network.

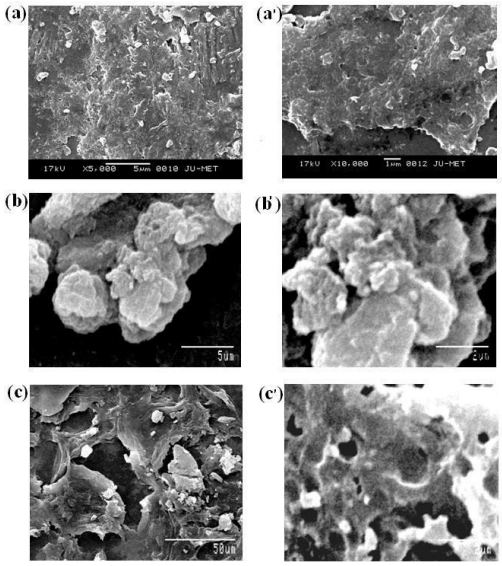


Figure 2. SEM images of $CHCl_3$:CH_3OH (2:1, v/v) gels of **1** (a and a′), **2** (b and b′) and **3** (c and c′) at different scale bar.

In order to determine the thermal stability of the gels, T_{gel} defined as the required temperature for the organogel to collapse was measured by the dropping ball method[18] and plotted against the gelator concentration (Fig. 4). The T_{gel} increased with increase in concentration of the gelators. Compound **3** was noticed to be

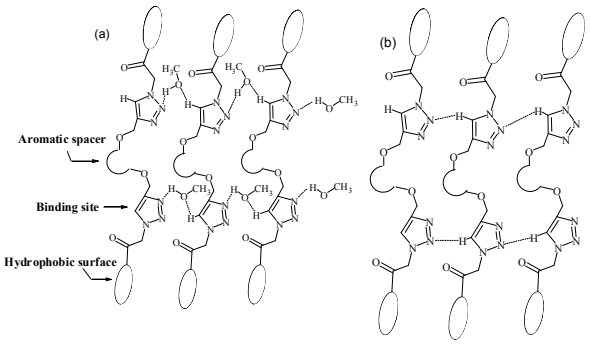


Figure 3. Suggested modes of interaction of the gelators **1**-**3** to form the networks in solution.

good gelator than **1** and **2** as it has lower minimum gelation concentration (mgc) value compared to others emphasizing the stacking interaction between π-surfaces of coumarin motifs. The gels were thermo reversible and gave distinct phase changes upon heating and cooling (Fig. 4S). At the T_gs, the gels were completely transformed into sols and readily became thick on cooling.

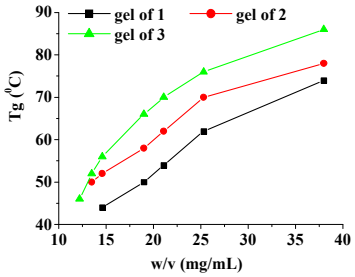


Figure 4. Variation of gel melting temperature (T_g) with increase in concentration of gelators.

Cation responsive behaviour of gels

The presence of triazole motifs in the structural backbones of the

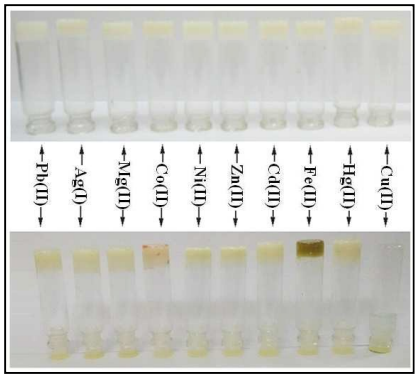


Figure 5. Photograph showing the changes in the $CHCl_3$:CH_3OH (2:1, v/v) gels of **1** (15 mg/ mL) when the gels were prepared with 5 equiv. amounts of different metal ions [c = 0.2 M in $CHCl_3$:CH_3OH (2:1, v/v) as perchlorate salt]. Similar observation was obtained when the gels were kept in contact with 0.5 mL of different metal solution (c = 0.2 M) in $CHCl_3$:CH_3OH (2:1, v/v).

gelators attracted us to explore the gels in cation sensing. Compound **1** which exhibited gel in $CHCl_3$:CH_3OH (2:1, v/v) turned into solution in presence of Cu^{2+} ions. Initially, the gel started to disintegrate in presence of Cu^{2+} ions and was completely ruptured to the sol state within 30 mins. Under similar conditions, the gel state of **1** remained unaffected in presence of other tested metal ions such as Pb^{2+}, Ag^{+}, Mg^{2+}, Co^{2+}, Ni^{2+}, Zn^{2+}, Cd^{2+}, Fe^{2+} and Hg^{2+} ions. Figure 5 demonstrates this feature. These findings suggested the selective interaction of the gelator **1** to Cu^{2+} ions over the other metal ions tested. To our opinion, the strong interaction of Cu^{2+} ion with the triazoles in the pseudo cavity of **1** disrupts the gel.

However, Cu^{2+} ion-induced broken gel of **1** was recovered instantly upon addition of 1-dodecanethiol (Fig. 6) and thereby interpreted the chemical reversibility of the process.

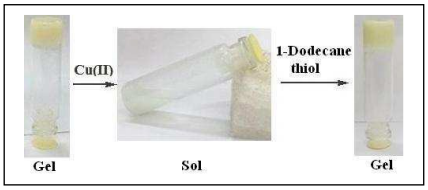


Figure 6. Chemical responsiveness of the gel of **1** [15 mg/ mL in $CHCl_3$: MeOH (2:1, v/v)] on successive addition of 5 equiv. amounts of Cu^{2+} (c = 0.2 M) and 1-dodecanethiol (c = 0.2 M, 10 equiv).

A similar study was carried out with the gelator **2** which showed interaction with Ag^{+}, Cu^{2+} and Hg^{2+} ions in the gel state (Fig. 7). The gel state of **2** showed quick response towards Ag^{+} ions and was converted to the sol within 20 mins. In comparison, Hg^{2+} and Cu^{2+} ions-induced gel breaking took almost 1h. Inspite of having similar structural feature of **2** with respect to the isomeric structure **1** the additional preference for Hg^{2+} and Ag^{+} is possibly linked with the self-assemble pattern of the gelators as well as dimension of the pseudo cavity of **2**.

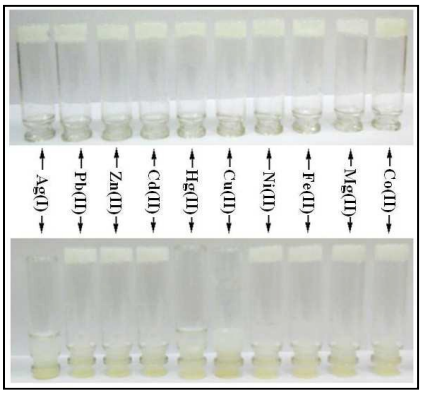


Figure 7. Photograph showing the changes in the $CHCl_3$:CH_3OH (2:1, v/v) gels of **2** (15 mg/ mL) after keeping contact with 0.5 mL of different metal ions [c = 0.2 M in $CHCl_3$:CH_3OH (2:1, v/v) as perchlorate salt] for 2h. Similar observation was obtained when the gels were prepared with 5 equiv. amounts of different metal ions (c = 0.2 M) in $CHCl_3$:CH_3OH (2:1, v/v).

Like **1**, metal ions-induced broken gels of **2** were quickly recovered with the addition of 1-dodecanethiol for Cu^{2+}, Hg^{2+} ions. Under identical conditions, Ag^{+} ion- induced broken gel was not recovered upon addition of 1-dodecanethiol (Fig. 5S). But addition of tetrabutylammonium chloride (TBACl) retrieved

gelation (Fig. 6S). These experimental findings are thus useful in distinguishing Ag^+ ion form Cu^{2+} and Hg^{2+} ions.

Cation interaction in solution

In order to realize, the metal-binding characteristics of the triazole-based compound **2** in the solution phase using fluorescence, we tuned the design **2** introducing coumarin as a fluorescent probe to get a new structure **3**. The design was undertaken in such a way that the binding site was alike to that of **2**. In the study, compound **3** also formed gel in $CHCl_3$:CH_3OH (2:1, v/v). The light yellowish gel phase of **3** behaved to the cations in the similar way as noticed for compound **2** (Fig. 7S). Here also the gel was transformed into the solution in the presence of Ag^+, Hg^{2+} and Cu^{2+} ions. While in presence of Ag^+ ion the gel was readily converted to sol within 15 mins, almost 30 mins were taken for Hg^{2+} and Cu^{2+} ions to collapse the gels (Fig. 8S). Like the case with gelator **2**, Hg^{2+} and Cu^{2+} ions-induced broken gels of **3** were converted to the gel states in the presence of 1-dodecanethiol. On the other hand, TBACl on scavenging Ag^+ ions induced further gelation of the sol state (Fig. 8S).

Careful investigation on the Figs. 5, 7 and 7S reveals that the gel states of **1**, **2** and **3** are completely converted to their sol states (within time span of 0.25h-1h) in presence of 5 equiv. amounts of the selective metal salts. On using 1 equiv. amount of the metal salts, the gels were slowly disrupted and completely converted to the sol states on keeping for a longer time (1.5h – 5h) and thereby indicated that the sensitivity of the gels are dependent on the amount of the metal salts used (Fig. 9S).

We further investigated the interaction of **3** with the said metal ions in CH_3CN: $CHCl_3$ (4:1, v/v) (Fig. 10S). Among the different metal ions Ag^+, Cu^{2+} and Hg^{2+} brought about significant quenching in emission (Fig. 8a). Cu^{2+} ions quenched the emission to the greater extent than Ag^+ and Hg^{2+} ions as evident from the Stern-Volmer plot (Fig. 8b). The quenching of emission is here attributed to the activation of photoinduced electron transfer (PET) process occurring in between the excited state of coumarin and the binding site. The metal ions interacted with **3** in 1:1 stoichiometric fashion as evident from the Job plots (Fig. 11S-12S).[19]

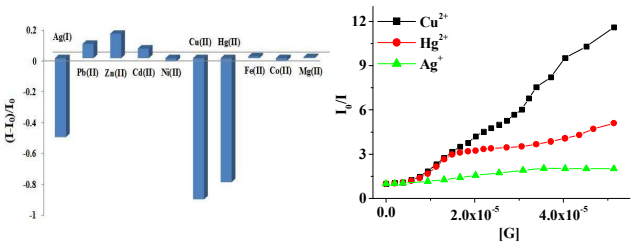


Figure 8. (a) Change in fluorescence ratio (λ_{ex} = 330 nm) of **3** (c = 2.0 x 10^{-5} M) at 420 nm upon addition of 5 equiv. amounts of metal ions (c = 8.0 x 10^{-4} M) in CH_3CN: $CHCl_3$ (4:1, v/v); (b) Stern – Volmer plot for **3** (c = 2.0 x 10^{-5} M) with metal ions (c = 8.0 x 10^{-4} M) at 420 nm in CH_3CN: $CHCl_3$ (4:1, v/v).

In UV-vis, small change in absorbance of **3** with ratiometric behaviour was observed during titration with the metal ions such as Cu^{2+}, Ag^+ and Hg^{2+}. In case of other metal ions, the change in absorbance of **3** was negligible (Fig. 13S).

Due to absence of fluorophore in **1** and **2**, we performed only the UV-vis titrations to understand their solution phase interactions with the metal ions (Fig. 14S-15S). Both **1** and **2** (c = 2.0 x 10^{-5} M) in CH_3CN: $CHCl_3$ (4:1, v/v) exhibited absorption peak at ~274 nm. In presence of Cu^{2+} ions the intensity of this peak was increased considerably in both cases. In case of titrations with Ag^+ and Hg^{2+} ions, the change in absorbance of **2** was minor. Other metal ions showed negligible change in the

Table 1: Binding constant values for **1 - 3** (c = 2.0 x 10^{-5} M) with the metal ions (c = 8.0 x 10^{-4} M) in CH_3CN: $CHCl_3$ (4:1, v/v).

Metal ligand complex	Binding constant values (M^{-1})	
	From fluorescence titration	From UV-vis titration
1 - Cu^{2+}	-	(1.14 ± 0.11) x 10^5
2 - Hg^{2+}	-	(2.89 ± 0.61) x 10^4
2 - Ag^+	-	(8.42 ± 0.78) x 10^4
2 - Cu^{2+}	-	(1.84 ± 0.17) x 10^4
3 - Hg^{2+}	(2.33 ± 0.75) x 10^4	(2.69 ± 0.31) x 10^4
3 - Ag^+	(2.59 ± 0.72) x 10^4	(3.42 ± 0.86) x 10^4
3 - Cu^{2+}	(5.00 ± 1.10) x 10^4	(1.11 ± 0.13) x 10^5

absorption spectra of both **1** and **2**. The non linear fitting of the emission and UV-vis titration data wherever applicable (Fig. 16S-21S) gave the binding constant values (Table 1).[20] As can be seen from Table 1, compounds **1** and **3** show marginally higher binding with Cu^{2+} ion than Ag^+ and Hg^{2+} ions.

^{1}H NMR study

It is important to be mentioned that compounds **1**, **2** and **3** showed small change in chemical shift values in the presence of the metal ions such as Ag^+, Cu^{2+} and Hg^{2+}. For **1**, the triazole ring proton of type 'a' underwent downfield chemical shift to the small extent. The protons of types 'c' and 'd' became broad in the presence of Cu^{2+} ions (Fig. 9). In case of **2**, the change in chemical shift value of the triazole ring protons in the presence of metal ions was too small. This was also true with the compound **3** (Fig. 22S-23S). This indicated that the triazoles in **1**, **2** and **3** interacted with the said metal ions very weakly. In this context, the mode of interaction of the triazoles with the metal ions is assumed to be in accordance with the observation of Noor *et al*.[5i] Such weak interaction is noted to be enough functional in breaking the gels.

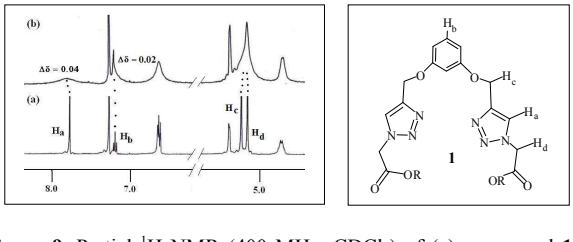


Figure 9. Partial ^{1}H NMR (400 MHz, $CDCl_3$) of (a) compound **1** (c = 6.29 x 10^{-3} M) and (b) **1** with Cu^{2+} (1:1).

Conclusion

In conclusion, cholesterol appended 1,2,3-triazoles-based compounds **1-3** have been designed and synthesized. Triazole

arms are disposed around different aromatic spacers. The compounds **1-3** form nice gels in $CHCl_3/CH_3OH$ (4/1, v/v). The hydrogen bonding role of the triazole units and the hydrophobic interaction between the cholesterol units allow the gelators to form gel in $CHCl_3/CH_3OH$ (4/1, v/v). Model compounds **4** and **5**, devoid of triazoles did not produce gels and thereby suggested the important role of triazoles in the designs. The gels show excellent cation responsive behavior. It is to note that inspite of similar gelation properties of the triazole-based compounds; the metal ion-responsive character of the gels varies with the disposition of the triazole motifs around the aromatic spacer. While the gel of **1** is rapidly transformed into sol state in the presence of Cu^{2+} ion, gels of **2** and **3** with identical binding sites exhibit the gel to sol transformation in the presence of Cu^{2+}, Hg^{2+} and Ag^{+} ions. Interestingly, while Cu^{2+} and Hg^{2+} ions-induced broken gels of both **2** and **3** were changed into their gel states immediately upon addition of 1-dodecanethiol, under similar conditions Ag^{+} ion-induced broken gel remained unaffected. Addition of TBACl to the Ag^{+} ion containing sols of **2** and **3** brought about gelation and thus enabled us to distinguish this ion effectively from Cu^{2+} and Hg^{2+} ions. Furthermore, compound **3** with coumarin fluorophore distinguishes Cu^{2+}, Hg^{2+} and Ag^{+} ions in solution fluorometrically by showing PET-based differential quenching of emission. Further study along this direction is underway in our laboratory.

Experimental section

Materials

Cholesterol, resorcinol and catechol were purchased from Spectrochem. 6,7-Dihydroxycoumarin was obtained from Sigma-Aldrich. Chloroacetyl chloride, sodium azide, cesium carbonate were purchased from Spectrochem. Metal perchlorates used in the study were purchased from Sigma-Aldrich and were carefully handled. All solvents used in the synthesis were purified, dried and distilled as required. Solvents used in NMR experiments were obtained from Aldrich. Thin layer chromatography was performed on Merck precoated silica gel 60-F_{254} plates. ^1H and ^{13}C NMR spectra were recorded using Bruker 400 MHz instrument using TMS as internal standard. High resolution mass data were acquired by the electron spray ionization (ESI) technique on XEVO GS-2 QTOf Waters mass spectrometer. FTIR measurements of all the compounds and dried gels (xerogels) were carried out using a Perkin-Elmer L120-00A spectrometer (ν_{max} in cm^{-1}) using KBr cell and KBr pellets, respectively. Scanning electron microscopy (SEM) images were obtained on Hitaci-S-4800 instrument. Fluorescence and UV-Vis studies were performed using Horiba Fluoromax 4C spectrofluorimeter and Shimadzu UV-2450 spectrophotometer, respectively.

Synthetic procedure

Chloro-acetic acid 17-(1,5-dimethyl-hexyl)-10,13-dimethyl-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl ester (6)[13d]

To a stirred solution of cholesterol (0.5 g, 1.29 mmol) in 20 mL dry CH_2Cl_2 was added chloroacetyl chloride (0.16 mL, 1.93 mmol) and pyridine (0.05 mL, 0.65 mmol) under nitrogen atmosphere. The mixture was allowed to stir for 10 h at room temperature. After completion of reaction, the solvent was evaporated and the crude was extracted with $CHCl_3$ (3 × 30 mL). The organic layer was washed several times with water, separated and dried over Na_2SO_4. Evaporation of the solvent gave white solid compound which on recrystallization from petroleum ether afforded pure product **6** (0.58 g, yield 96%), mp 148 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 5.37 (m, 1H), 4.72 (m, 1H), 4.03 (s, 2H), 2.36 (m, 2H), 2.02–0.85 (m, 38H), 0.67 (s, 3H); FTIR (KBr, cm^{-1}): 2939, 2907, 2821, 1753, 1620, 1195.

Azido-acetic acid 17-(1,5-dimethyl-hexyl)-10,13-dimethyl-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl ester (7)[13d]

To a stirred solution of compound **6** (0.5 g, 1.08 mmol) in CH_3CN (20 mL), NaN_3 was added (0.11 g, 1.6 mmol) and the reaction mixture was refluxed for 5 h. The progress of reaction was monitored by TLC. After completion of reaction, solvent was evaporated off and water was added. The reaction mixture was extracted with $CHCl_3$. Evaporation of the solvent gave the crude azide **7** (0.45 g, yield 89%, mp 116 °C), which after recrystallization from diethyl ether was directly used in the next step. FTIR (KBr, cm^{-1}): 2107, 1747, 1213.

1, 3-Bis-prop-2-ynyloxy-benzene (8)

A mixture of resorcinol (1 g, 9.09 mmol) and K_2CO_3 (5.01 g, 33.36 mmol) in dry CH_3CN (30 mL) was refluxed for 1h and then propergyl bromide (4.37 g, 36.36 mmol) was added to it. The reaction mixture was further refluxed for 4h. After completion of reaction, organic solvent was evaporated off under reduced pressure and water was added to it. Then reaction mixture was extracted with $CHCl_3$, washed with water and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave the crude product which was purified by column chromatography using 8% ethyl acetate in petroleum ether as eluent to afford the pure compound **8** (1.52 g, yield 90%). ^1H NMR (400 MHz, $CDCl_3$): δ 7.23-7.19 (m, 1H), 6.36-6.61 (m, 3H), 4.67(s, 4H), 2.52 (t, 2H, J = 2.4 Hz); FTIR (KBr, cm^{-1}): 3291, 2122, 1594, 1490, 1455.

1, 2-Bis-prop-2-ynyloxy-benzene (9)

Compound **9** was prepared according to the same procedure as followed for the synthesis of **8**. In this case, 1g of catechol was transformed into the compound **9** in 88% yield (1.49 g). ^1H NMR (400 MHz, $CDCl_3$): δ 7.09 – 7.04 (m, 2H), 7.00 – 6.96 (m, 2H), 4.75 (d, 4H, J = 2.40 Hz), 2.50 (t, 2H, J = 4 Hz); FTIR (KBr, cm^{-1}): 3289, 2121, 1594, 1501, 1457.

6,7-Bis-prop-2-ynyloxy-chromen-2-one (10)

6,7-Dihydroxycoumarin (0.1 g, 0.56 mmol) was dissolved in dry CH_3CN (30 mL) containing 2% dry DMF and to this solution Cs_2CO_3 (0.55 g, 1.68 mmol) was added under stirring. The reaction mixture was refluxed for 1h and then propergyl bromide (0.27 g, 2.25mmol) was added to it. The reaction mixture was allowed to reflux for another 8h. After completion of the reaction, the organic solvent was evaporated off and the crude mass was extracted with $CHCl_3$. Evaporation of the solvent in vacuo gave the crude product which was purified by column chromatography using 25% ethyl acetate in petroleum ether to to have the desired

product **10** (0.11 g, yield 84%, mp 144 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64 (d, 1H, *J* = 8 Hz), 7.09 (s, 1H), 7.06 (s, 1H), 6.32 (d, 1H, *J* = 8 Hz), 4.83 (d, 2H, *J* = 4 Hz), 4.79 (d, 2H, *J* = 4 Hz) 2.59- 2.55 (m, 2H); FTIR (KBr, cm^{-1}): 3265, 2116, 1704, 1696, 1613, 1561.

Compound 1

To a stirred solution of compound **8** (0.1 g, 0.53 mmol) and compound **7** (0.62 g, 1.32 mmol) in dry DMF (20 mL), sodium ascorbate (0.02 g, 0.12 mmol) in dry DMF (2 mL) was added and stirred for 5 minutes at room temperature. Then solid $CuSO_4.5H_2O$ (0.01 g, .04 mmol) was added to it and the reaction mixture was allowed to heat at 80 ^oC for 9h. After completion of the reaction, the reaction mixture was extracted with 2% CH_3OH in $CHCl_3$ and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave white solid compound. Recrystallization using methanol followed by washing with diethyl ether afforded pure product **1** in 85% yields (0.51 g, mp 188 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.76 (s, 2H), 7.18 (t, 1H, *J* = 8 Hz), 6.63 – 6.59 (m, 3H), 5.38 (d, 2H, *J* = 4 Hz), 5.22 (s, 4H), 5.14 (s, 4H), 4.72-4.68 (m, 2H), 2.33 (m, 4H), 2.02 – 0.68 (m, 82H, cholesteryl protons); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.5, 159.3, 144.5, 138.9, 130.0, 124.1, 123.3, 107.6, 102.1, 76.5, 61.9, 56.6, 56.1, 51.1, 49.9, 42.3, 39.6, 39.5, 37.8, 36.8, 36.5, 36.1, 35.7, 31.88, 31.80, 28.2, 28.0, 27.6, 24.2, 23.8, 22.8, 22.5, 21.0, 19.2, 18.7, 11.8; FTIR (KBr, cm^{-1}): 3450, 2948, 2867, 2851, 1751, 1733, 1593; HRMS (TOF MS ES+): calcd 1147.7915 $(M + Na)^+$, found 1147.7404 $(M + Na)^+$.

Compound 2

Compound **2** was achieved according to the same procedure as followed for the synthesis of **1**. Click reaction between compounds **9** (0.1 g, 0.53 mmol) and **7** (0.62 g, 1.32 mmol) yielded the crude mass which on purification using 2% CH_3OH in $CHCl_3$ furnished the desired compound **2** in appreciable yield (0.52 g, yield 87%, mp 208 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.79 (s, 2H), 7.06 – 7.04 (m, 2H), 6.95 – 6.93 (m, 2H), 5.38 (br s, 2H), 5.27 (s, 4H), 5.19 (s, 4H), 4.69-4.67 (m, 2H), 2.33-2.31 (m, 4H), 2.03 – 0.67 (m, 82H, cholesteryl protons); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.8, 148.4, 144.4, 138.9, 124.7, 123.2, 122.2, 115.3, 76.4, 63.3, 56.6, 56.1, 50.9, 49.9, 42.3, 39.7, 39.5, 37.8, 36.8, 36.5, 36.1, 35.8, 31.8, 31.7, 28.2, 28.0, 27.6, 24.2, 23.9, 22.8, 22.5, 21.0, 19.2, 18.7, 11.8; FTIR (KBr, cm^{-1}): 3421, 2946, 2868, 1748, 1591; HRMS (TOF MS ES+): calcd 1147.7915 $(M + Na)^+$, found 1147.7524 $(M + Na)^+$.

Compound 3

To a mixture of compound **10** (0.1 g, 0.39 mmol) and **7** (0.45 g, 0.97 mmol) in dry DMF (20 mL), was added sodium ascorbate (0.02 g, 0.12 mmol) in DMF (2 mL) under stirring condition at room temperature followed by the addition of $CuSO_4.5H_2O$ (0.01 g, .04 mmol). The reaction mixture was then allowed to heat at 80 ^oC for 12h. After completion of reaction, solvent was evaporated off. The crude mass was extracted with 2% CH_3OH in $CHCl_3$ (3 x 30 mL). The organic layer was washed with water and dried over Na_2SO_4. Evaporation of the solvent under reduce pressure gave crude mixture which was chromatographed on a silica gel column using 1% CH_3OH in $CHCl_3$ as eluent to get the desired product **3** in 74% yield (0.35 g, mp 262 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84 (s, 1H), 7.79 (s, 1H), 7.60 (d, 1H, *J* = 8 Hz), 7.11 (s, 1H), 7.00 (s, 1H), 6.28 (d, 1H, *J* = 8 Hz), 5.37 (br s, 2H), 5.29 (d, 4H, *J* = 8 Hz), 5.16 (d, 4H, *J* = 8 Hz), 4.68 (m, 2H), 2.31 (m, 4H), 2.02 – 0.62 (m, 82H, cholesteryl protons); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.6, 161.1, 152.2, 150.4, 144.9, 143.9, 143.2, 143.1, 138.9, 124.9, 124.8, 123.3, 114.0, 113.3, 112.2, 102.3, 64.1, 63.0, 56.6, 56.1, 51.0, 49.9, 42.3, 39.6, 39.5, 37.8, 36.8, 36.5, 36.1, 35.8, 31.87, 31.80, 29.6, 28.2, 28.0, 27.6, 24.2, 23.8, 22.8, 22.5, 21.0, 19.2, 18.7, 11.8; FTIR (KBr, cm^{-1}): 3409, 2932, 2868, 2851, 1745, 1727, 1615, 1465; HRMS (TOF MS ES+): calcd 1193.7916 $(M+1)^+$, found 1193.7938 $(M+1)^+$.

Compound 4

To a stirred solution of 6,7-dihydroxycoumarin (0.2g, 1.12 mmol) in dry CH_3CN containing 2% dry DMF was added Cs_2CO_3 (1.09g, 3.36 mmol) at room temperature. The reaction mixture was refluxed for 1h and then compound **6** (1.57 g, 3.36 mmol) was added to it. Then it was allowed to reflux for 14 h. After completion of reaction, the organic solvent was evaporated under reduced pressure and water was added to the crude mass. Then reaction mixture was extracted with 2% CH_3OH in $CHCl_3$. Evaporation of the solvent gave the crude product which was purified by column chromatography using $CHCl_3$ as eluent to afford the pure compound **4** in 68 % yield (0.78 g), mp 148 ^0C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.58 (d, 1H, *J* = 8 Hz), 6.99 (s, 1H), 6.74 (s, 1H), 6.30 (d, 1H, *J* = 8 Hz), 5.37-5.34 (m, 2H), 4.74(s, 2H), 4.71 (s, 2H), 3.56-3.51 (m, 2H), 2.36 (m, 4H), 2.02 – 0.67 (m, 82H, cholesteryl protons); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.1, 160.9, 151.8, 150.5, 144.7, 142.9, 140.7, 139.1, 123.2, 121.7, 114.3, 114.0, 112.5, 102.1, 75.3, 71.8, 67.6, 66.1, 56.7, 56.6, 56.1, 50.1, 49.9, 42.3, 39.79, 39.70, 39.5, 37.9, 37.2, 36.8, 36.55, 36.50, 36.1, 35.7, 31.9, 31.8, 31.6, 30.9, 29.6, 28.2, 28.0, 27.6, 24.2, 23.8, 22.8, 22.6, 22.5, 21.08, 21.02, 19.3, 19.2, 18.7, 11.8; FTIR (KBr, cm^{-1}):3387, 2933, 1761, 1731, 1614, 1450, 1383; HRMS (TOF MS ES+): calcd 1031.7262 $(M + 1)^+$, found 1031.7262 $(M + 1)^+$.

Compound 5

Compound **5** was prepared according to the same method as followed for the synthesis of **4**. In this case, resorcinol (0.2 g, 1.81 mmol) gave the desired gummy product **5** in 62% yield (1.13 g). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.12 (t, 1H, *J* = 8 Hz), 6.54-6.43 (m, 3H), 5.37 (s, 2H), 4.73 (m, 2H), 4.56 (s, 4H), 2.35 (d, 4H, *J* = 8 Hz), 2.02 – 0.67 (m, 82H, cholesteryl protons); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.5, 159.0, 139.2, 130.1, 123.0, 107.8, 102.5, 75.3, 65.5, 56.6, 56.1, 49.9, 42.3, 39.7, 39.5, 37.9, 37.2, 36.8, 36.5, 36.1, 35.8, 31.9, 31.8, 28.2, 28.0, 27.6, 24.2, 23.8, 22.8, 22.5, 21.0, 19.3, 18.7, 11.8; FTIR (KBr, cm^{-1}): 3369, 2935, 2867, 1758, 1742, 1604; HRMS (TOF MS ES+): calcd 1001.7000 $(M + K)^+$, found 1001.6927 $(M + K)^+$.

Gelation test

The respective amounts of **1-5** were dissolved in desired organic solvents (1 mL) forming a homogeneous solution, slightly warmed and then allowed to cool slowly to room temperature to form a gel. All the gels were tested by an inversion of vial method.

Determination of gel-sol transition temperature (T_g)

The gel-to-sol transition temperature (T_g) was measured by the dropping ball method. The Tg was defined as the temperature at which the gel melted and started to flow. In this test, a small glass ball was carefully placed on the top of the gel to be tested, which was present in a test tube. The tube was slowly heated in a thermostated oil bath until the ball fell to the bottom of the test tube. The temperature at which the ball reaches the bottom of the test tube is taken as T_g of that system.

General procedure for fluorescence and UV-vis titrations

Stock solutions of the compounds were prepared in CH_3CN: $CHCl_3$ (4:1, v/v) in the concentration of 2.0 x 10^{-5} M. Stock solutions of metal salts were also prepared in the same solvent in the concentration of 8.0 x 10^{-4} M. Solution of each compound (2 mL) was taken in the cuvette and to this solution different metal solutions were individually added in different amounts. Upon addition of metal ion, the change in emission of the compound was recorded. The same stock solutions were used to perform the UV-vis titration experiment in the same way.

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GRAPHICAL ABSTRACT

Cholesterol appended bis-1,2,3-triazoles as simple supramolecular gelators for naked eye detection of Ag^{+}, Cu^{2+} and Hg^{2+} ions

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Cholesterol coupled bis 1,2,3-triazoles have been designed and synthesized. Their gelation abilities and cation responsive behaviors are documented.