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Synthesis of porphyrin conjugates based on conformationally rigid and flexible resorcin[4]arene frameworks

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ABSTRACT

Porphyrin conjugates were synthesized based on conformationally rigid, bowl shaped cavitand, and flexible unfirm resorcin[4]arenes. The influence of the resorcin[4]arene fragment on the porphyrin fluorescence is investigated.

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1. Introduction

Well-defined architecture of an artificial receptor is an important aspect of molecular recognition and encapsulation. A large variety of macrocyclic oligomers, such as calixarenes,[1] resorcinarenes,[2] cyclodextrins,[3] and crown ethers[4] could afford attractive receptors possessing multipoint recognition ability toward non-covalently bound guest molecules. Cations, anions, and neutral guest molecules have been selectively sequestered by these macrocycles of widely varying design, size and shape. Porphyrins on the other hand, are a suitable class of compound for building artificial molecular devices because of their photoactive and electronic properties.[5] Combination of Calix and resorcin[4]arene fragments, which have unique three-dimensional shape and good complexation ability with porphyrins via covalent bond allows adjustment of the geometry of the complexing cavity, and thus provides wide prospects in the design of selective receptors and supersensitive sensors.[6] Though porphyrin–resorcin[4]arene conjugates are attractive receptors and possess multipoint recognition ability, they are not as widely studied as in the case of porphyrin–calixarene systems.

In this work we report efficient synthesis of porphyrin resorcin[4]arene conjugates in which the resorcin[4]arenes framework is either a conformationally rigid, bowl shaped cavitand or a flexible unlocked structure. The strategy we employed was to construct functionalized resorcinarene frameworks and to couple them with suitable porphyrins followed by porphyrin core metalation. The effect of the resorcin[4]arenes conjugates on fluorescence quenching of the porphyrin moiety by structurally different quinones is also reported.

2. Results and discussion

The balance between rigidity and flexibility is of particular importance for the binding and dynamic properties of host and guest. Rigid lock and key type cavitand receptors are expected to offer efficient recognition but will be too specific about size and shape of the substrates. When the process of exchange, regulation or cooperativity is the key parameter, a flexible receptor gains more significance. In this context, resorcin[4]arenes are a suitable platform for simple covalent modifications of the upper rim to afford both conformationally rigid, bowl shaped cavitand, and the more flexible unlocked counterpart.

Functionalized monobromo-methyl-resorcin[4]arenes **2b** and **3b** were synthesized in three steps (Scheme 1). Compound (**1**) was synthesized by acid catalyzed condensation of methyl-resorcinol and heptaldehyde. The conformationally locked bowl shape resorcin[4]arene **2a** was synthesized by reacting (**1**) with $BrClCH_2$, which introduced methylene bridges between four sets of proximate oxygens of resorcin[4]arenes.[7a] The synthesis of the unlocked compound **3a** was achieved by the reaction of octa-hydroxy (**1**) with methyl iodide.

The functionalization of resorcin[4]arene units was the next step. Monobromination of one of the benzylic hydrogens of both

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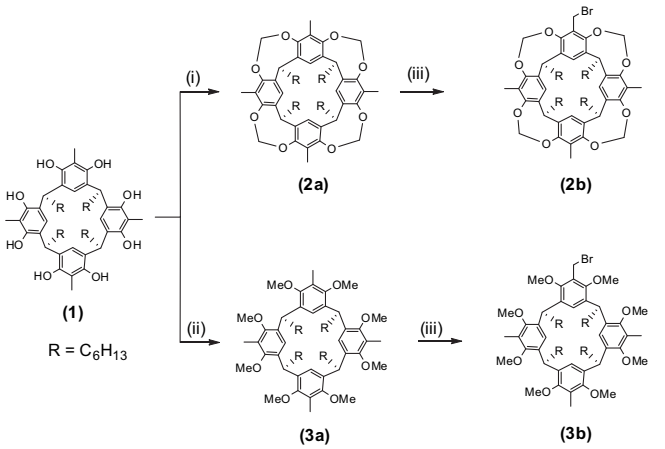
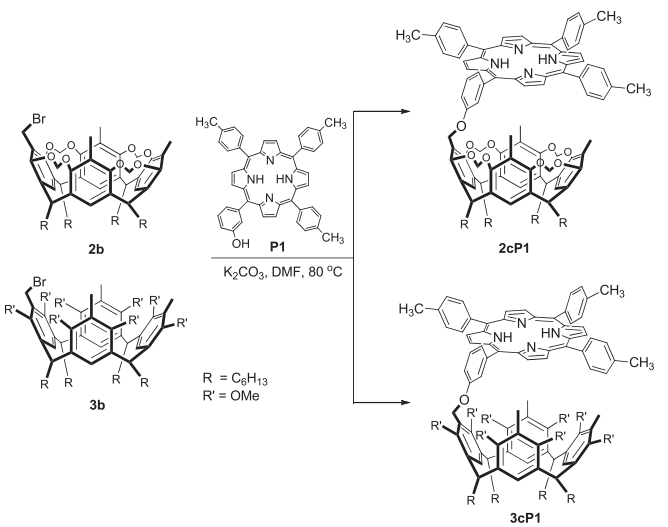


Scheme 1. Synthesis of monobromo resorcin[4]arene: (i) $BrCH_2Cl$, K_2CO_3, DMF, 80 °C (ii) MeI, K_2CO_3, DMF, 80 °C (iii) 1 equiv NBS, AIBN, benzene.

resorcin[4]arenes (**2a**–**3a**) upper rim was carried out for this purpose. A 1:1 M equiv of NBS and resorcin[4]arenes were reacted together and monobromination was achieved in more than 30% yield in both cases. The products were easily separated by simple column chromatography technique followed by vacuum drying, to give pure functionalized monobromo-methyl-resorcin[4]arenes (**2b**–**3b**) frameworks. The NMR and mass spectroscopic data confirmed the structure and purity of both systems.

The porphyrin used in this study was an appropriately functionalized *meso* tetraaryl porphyrin. Since the hydroxyl phenyl function can easily react with benzylic bromides, one aryl moiety of the porphyrin was a phenol. The three other aryl functions were toluyl groups to make the resulting system more soluble in organic solvents. The porphyrin was synthesized by mixed aldehyde condensation in propionic acid using 1 equiv of 3-hydroxybenzaldehyde with 3 equiv of *p*-tolualdehyde and 4 equiv of pyrrole followed by column purification (see Experimental section).

Prophyrin resorcin[4]arene conjugates **2bP1** and **3bP1** were synthesized by the reaction between hydroxy porphyrin unit **P1** and resorcin[4]arenes **2b** and **3b** (Scheme 2). The compounds were obtained in reasonably good yield (>75% yields). The resulting conjugates were easily purified by column chromatography due to the difference in polarity with the unreacted porphyrins or parent resorcin[4]arenes, and they were readily soluble in common organic solvents. Treatment the porphyrin conjugates with Zn(II) acetate yielded their metalated derivatives. The porphyrin conjugates as well as the Zn(II) derivatives were characterized by NMR, UV–vis, fluorescence, and mass spectroscopic methods.



Scheme 2. Synthesis of prophyrin resorcin[4]arene conjugates based on monobromo resorcin[4]arenes **2a** and **2b**.

The fluorescence quenching of porphyrin systems by benzoquinones is well known and it is well demonstrated that conjugation of porphyrin with a molecular trap like a calix[*n*]arene would enhance the fluorescence quenching considerably.[8] In the present report, four structurally different quinones—benzoquinone (BQ), 1,4-naphthoquinone (NQ), phenanthrenequinone (PAQ), and dichlorodicyanobenzoquinone (DDQ) were used to study the porphyrin fluorescence quenching. The decay of porphyrin fluorescence was followed by the addition of increasing amounts of different quinones to the solutions of parent porphyrin **P1**, **2cP1**, and **3cP1** conjugates in dichloromethane. The variation of fluorescence intensity is plotted against the concentration of quencher in all the cases.

Even though the analysis of the system is complicated by the possible competition between the quenching by free quinones and quenching by quinones complexed/trapped in resorcin[4]arene cavity, the presence of resorcin[4]arenes conjugated to porphyrins enhances the efficiency of fluorescence quenching. Fig. 1(a) shows fluorescence intensity as a function of the concentration of phenanthrenequinone [PAQ] for free porphyrin **P1**, and the conjugates **2cP1** and **3cP1**. After addition of 2.5×10^{-5} M of PAQ, the

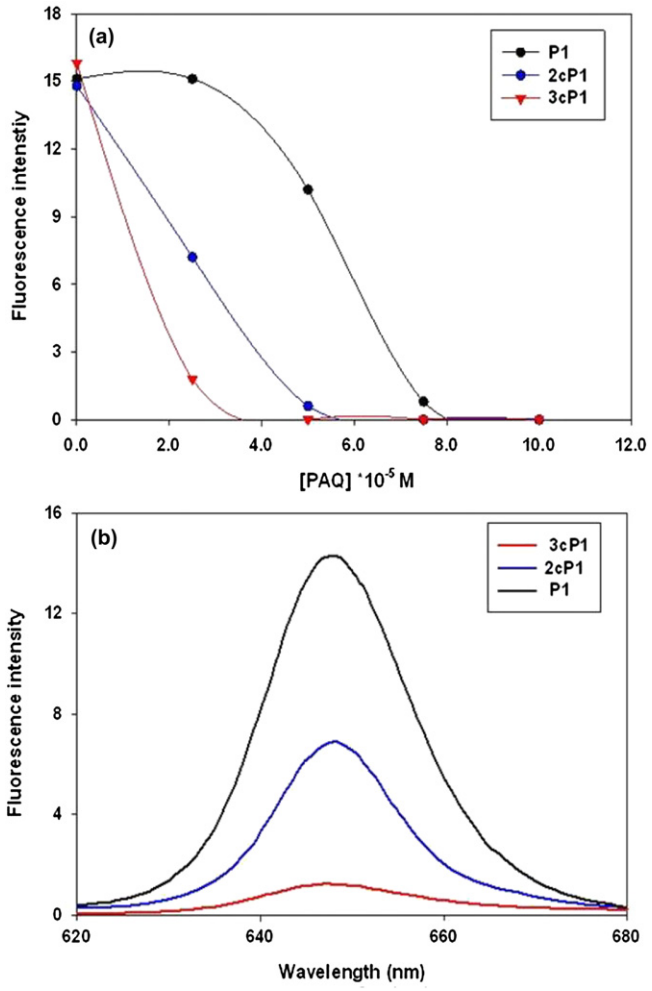


Fig. 1. (a) Fluorescence intensity as a function of the concentration of phenanthrenequinone [PAQ]; Porphyrin **P1** (▼); compound **2cP1** (●); compound **3cP1** (●): (b) Fluorescence emission bands at 648 nm measured after addition of 2.5×10^{-5} M of PAQ to Porphyrin **P1**, compound **2cP1** and compound **3cP1**.

fluorescence quenching efficiency was affected considerably by the structure and the presence of resorcin[4]arene fragments. The free porphyrin **P1** was not affected by the presence of PAQ, where as the porphyrin resorcin[4]arene conjugates **2cP1** and **3cP1** showed a decrease in the fluorescence intensities. Compared to the cavitand porphyrin resorcin[4]arene **2cP1**, the more flexible conjugate **3cP1** was more efficient in fluorescence quenching, suggesting its favorable flexible nature to adapt and to accommodate the aromatic guest molecules more easily. This effect is depicted in the fluorescence emission bands at 648 nm, after addition of 2.5×10^{-5} M of PAQ in Fig. 1(b).

The fluorescence decay profiles of NQ and BQ showed similar behavior as that of PAQ, where the quenching of the porphyrin fluorescence was enhanced due to the presence of resorcinarene fragments. The structurally unlocked resorcinarene **3cP1** exhibited more efficiency in fluorescence quenching (see Supplementary data). Furthermore, the presence of the phenyl group in the quinone structure enhanced efficiency of fluorescence quenching at lower concentration due to the improved accommodation of the guest molecule in the hydrophobic cavity.

As expected the structure of the quinone moiety has an important role in the enhanced quenching due to the presence of the resorcin[4]arene unit. When DDQ was used to quench the porphyrin fluorescence, the cavitand resorcin[4]arene unit in compound **2cP1** did not exhibit any favorable effect and showed similar quenching behavior free unconjugated porphyrin **P1** (Fig. 2). At the same time, the structurally flexible resorcinarene fragment in compound **3cP1** enhanced the porphyrin quenching notably. The presence of chloro and cyano groups in DDQ makes this quinone too large to be accommodated within the cavitand of the resorcin [4]arene framework in compound **2cP1**, and hence no improvement of the quenching was possible due to the trapped quinone. The unlocked structure of the resorcin[4]arene in **3cP1** conjugate, on the other hand, is sufficiently flexible to associate with these large sized substituents in DDQ to cause an enhanced effect. Thus, the quenching of porphyrin fluorescence using various quinones clearly demonstrates the different behavior of cavitand and flexible host molecular species toward molecular recognition. Interestingly, when excess zinc acetate was used to metalate the porphyrin conjugates, Zn(II) derivatives showed no effect of resorcinarene fragments in the florescence quenching for both compounds investigated. The presence of the excess metal prevents the accessibility to resorcinarene cavity (Fig. 3).

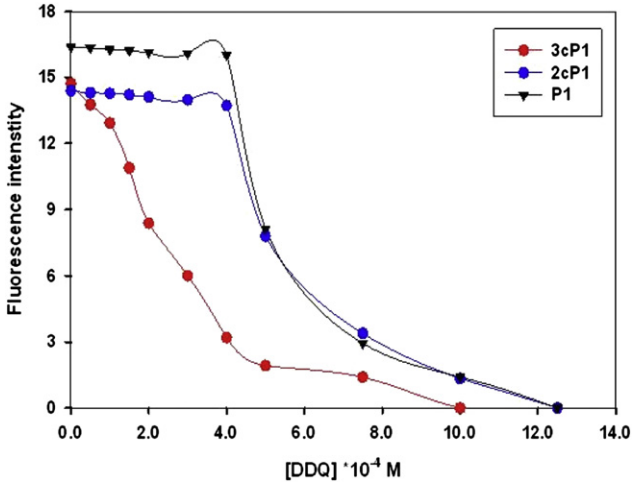


Fig. 2. Fluorescence intensity as a function of the concentration of dichlorodicyanobenzoquinone [DDQ]; Porphyrin **P1** (▼); compound **2cP1** (●); compound **3cP1** (●).

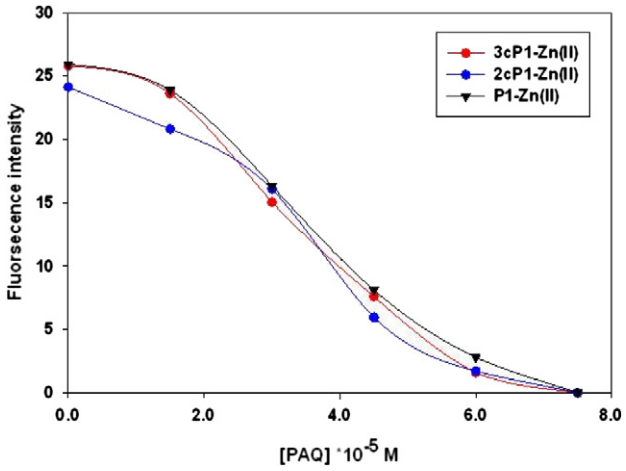


Fig. 3. Fluorescence intensity as a function of the concentration of phenanthrenequinone [PAQ]; porphyrin **P1**–**Zn**(**II**) (▼); compound **2cP1**–**Zn**(**II**) (●); compound **3cP1**–**Zn**(**II**) (●).

The ^{1}H NMR spectrum for compound **3cP1** in the absence of PAQ contains four signals from the nonequivalent methoxy groups, at 3.36, 3.38, 3.54, and 3.83 ppm. Upon addition of PAQ, the ^{1}H NMR spectrum shows new signals at 3.46 and 3.47 ppm corresponding to the methoxy groups. These signals result from noncovalent interactions when PAQ is accommodated inside the resorcinarene cavity (Fig. 4). This result is in agreement with the data from the fluorescence quenching studies. For smaller quinones, the in-out guest exchange is too fast for the NMR time scale to be observed.[7b]

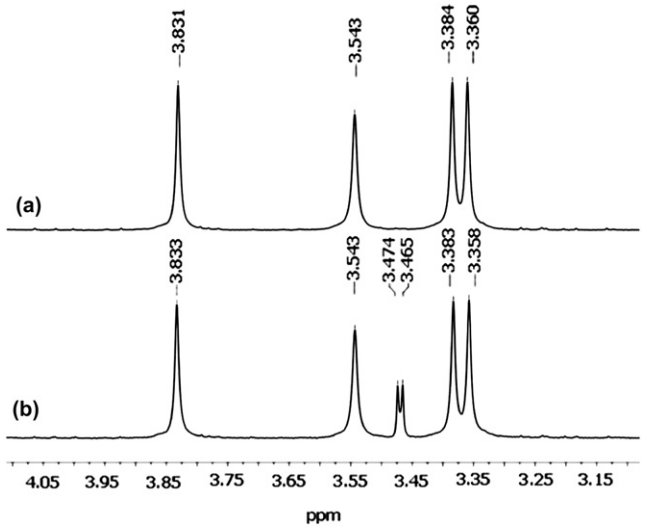


Fig. 4. ^{1}H NMR spectra of conjugate **3cP1** (600 MHz, $CDCl_3$): (a) before addition of PAQ and (b) after addition of PAQ.

3. Conclusion

In conclusion, conformationally locked and unlocked porphyrin resorcin[4]arene conjugates were synthesized. The structures of these compounds were confirmed by NMR and mass spectroscopic analyses. The data imply that at low concentration of quinone, the fluorescence quenching of the porphyrin is considerably enhanced by the attachment of resorcin[4]arene to the photoactive subunit, which is supported by ^{1}H NMR experiments. These types of conjugates present interesting opportunities for various applications

such as artificial enzyme mimics. Applications and further analyses of these systems are underway in our laboratories.

4. Experimental section

4.1. Material and method

UV–vis spectra were recorded on a Varian UV–vis cary-5 spectrophotometer. Fluorescence (emission) spectra were measured with Aminco Bowman Series 2 spectrophotometer. FAB mass analyses were performed using a high resolution GC MS DFS-Thermo instrument. ^{1}H NMR was done on Bruker Avance II 600 MHz and Burker DPX 400 spectrometers. Flash column chromatography was performed using 70–230 mesh ASTM Merck silica gel-60. DMF was dehydrated by vacuum distillation over Calcium hydride. Pyrrole was vacuum distilled before each usage. Azobisisobutylonitrile (AIBN) was crystallized form hot ethanol. *N*-Bromosuccinimide (NBS) was crystallized prior use form boiling water. All other reagents and solvents were of reagent grade purity and used without further purification.

4.2. Fluorescence decay study—procedure

Using dichloromethane, 20 mL of a 0.0025 mM solution of porphyrin (0.0050 mM solution in the case of Zn porphyrins) was prepared and taken in a vial. 10 mM solution of each quinones was prepared. Using a micropipette a small amount of Quinone is added to the porphyrin solution, shaken well and fluorescence at 648 nm was measured (excitation wave length is 418 nm). More quinone was added and fluorescence measured again. This was repeated again until the fluorescence intensity at 648 nm (602 nm in the case of Zn porphyrins) becomes zero. The result was then expressed as a function of the decay of fluorescence intensity against the concentration of quinone.

4.3. Synthesis

*4.3.1. meso-5-(3-Hydroxyphenyl)-10,15,20-(4-toluyl)porphyrin (**P1**).* The porphyrin was synthesized by mixed aldehyde condensation in propionic acid using 1.0 equiv of 3-hydroxybenzaldehyde, 3.0 equiv of 4-tolualdehyde, and 4.0 equiv of pyrrole. Thus to 0.5 L of hot propionic acid, 3-hydroxybenzaldehyde (4.88 g, 40 mmol) and 4-tolualdehyde (14.20 mL, 120 mmol) were added and stirred for 10 min. As the mixture was about to boil, pyrrole (11.08 mL, 160 mmol) was added with vigorous mixing. The reaction was refluxed for 45 min, allowed to cool to room temperature, and kept in the refrigerator at 8–10 °C overnight. The precipitate formed was then collected by filtration and washed with hot water until all propionic acid was removed. The crude reaction products were loaded onto a flash silica gel column by dissolving in minimum quantity of dichloromethane and eluted with a solvent gradient from 100% CH_2Cl_2 to 98% CH_2Cl_2/2% CH_3OH (v/v). Compound **P1** is the second band of the column following the tetratoluylporphyrin. This fraction was collected and did second column purification with 99% CH_2Cl_2/1% CH_3OH (v/v) to remove traces of impurities. Compound **P1** was obtained as purple solid (1.57 g, 6% yield). UV–vis in CH_2Cl_2: λ_{max} nm ($\varepsilon\times10^{-5}$ M^{-1} cm^{-1}): 417 (2.25), 514 (0.086), 548 (0.038), 589 (0.024), and 645 (0.027); ^{1}H NMR (400 MHz, $CDCl_3$) δ: −2.80 (s, 2H), 2.70 (s, 9H), 7.20 (m, 1H), 7.54 (m, 7H), 7.63 (t, 1H, J=2.4 Hz), 7.76 (m, 1H), 8.09 (d, 6H, J=8.0 Hz), 8.85 (s, 8H); HRMS (EI): m/z $[M]^+$, found 672.2883. $C_{47}H_{36}N_4O$ requires 627.2889.

*4.3.2. meso-5-(3-Hydroxyphenyl)-10,15,20-(4-toluyl) porphyrinato zinc(II) (**ZnP1**).* Compound **P1** (100 mg) was dissolved in chloroform (25 mL) and zinc acetate (100 mg) in methanol (15 mL) was added. The mixture was refluxed until the UV–vis spectrum showed no peak at 650 nm (650 nm peak is exclusively for free-base porphyrin). The solvent was then evaporated off and the crude product was purified by column chromatography (silica gel, 98% CH_2Cl_2/2% CH_3OH (v/v)). Compound **P1** was obtained as brownish red (98 mg, 90% yield). UV–vis in CH_2Cl_2: λ_{max} nm ($\varepsilon\times10^{-5}$ M^{-1} cm^{-1}): 418 (3.03), 546 (0.118) and 587 (0.009).

*4.3.3. Octol-resorcin[4]arene (**1**)[7a,9].* Methyl-resorcinol (10 g, 0.081 mol) was dissolved in ethanol (62.7 mL, 775 mL/mol) and 37% aqueous HCl (15.1 mL, 185 mL/mol). The solution was cooled in ice bath and heptaldehyde (11.3 mL, 0.081 mol) was added slowly over a period of 30 min. The reaction mixture was allowed to warm to room temperature and refluxed for 12 h. The yellow colored precipitate was filtered and washed several times with distilled water until it turns neutral to pH paper. Yield 10.7 g (**88**%). Mp: >220 °C (decomposed); ^{1}H NMR (400 MHz, DMSO-d_6) δ: 0.84 (t, 12H, J=6.25 Hz), 1.23 (m, 32H), 1.93 (s, 12H), 2.21 (s, 8H), 4.18 (t, 4H J=7.75 Hz)), 7.21 (s, 4H), 8.69 (br s, 8H); ^{13}C NMR (100 MHz, DMSO-d_6) δ: 10.7, 14.2, 22.9, 28.9, 29.8, 32.1, 35.4, 38.4, 73.0, 113.6, 122.0, 124.6, 154.0.

*4.3.4. Bridged resorcin[4]arene (**2a**)[7a,10].* Compound **1** (5 g, 5.5 mmol) was dissolved in DMF (55 mL) in a sure-sealed tube. Potassium carbonate (12 g, 88 mmol) was added and stirred for 0.5 h. Then bromochloromethane (7.7 mL, 88 mmol) was added at room temperature. The reaction mixture was sealed and immersed in preheated oil bath 80 °C for 24 h. The reaction mixture was poured into cold ice water and the white solid was collected by section filtration. Yield 4.9 g (**94**%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 0.92 (t, 12H, J=6.80 Hz), 1.37 (m, 32H), 2.00 (s, 12H), 2.22 (q, 8H), 4.28 (d, 4H, J=7.2 Hz), 4.78 (t, 4H, J=8.0 Hz), 5.91 (d, 4H, J=6.8 Hz), 7.00 (s, 4H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 10.3, 14.1, 22.7, 27.9, 29.2, 30.1, 31.8, 37.0, 98.5, 117.6, 123.6, 138.0153.2.

*4.3.5. Monobromo bridged resorcin[4]arene (**2b**).* Compound **2a** (2 g, 2.15 mmol) and AIBN (100 mg, 0.6 mmol) dissolved in degassed benzene (40 mL). *N*-Bromosuccinimide (0.387 mg, 2.15 mmol) was then added and the reaction mixture refluxed overnight. After cooling the mixture was filtered and the filtrate was evaporated to dryness. The solid residue is dissolved in minimum amount of petroleum ether–ethyl acetate (1:1 v/v) mixture and then adsorbed on silica gel and dried. It was then mounted on the top of a silica gel column and eluted with petroleum ether ethyl acetate (93:7 v/v). The intended compound was the second last fraction from the column. The solvent was evaporated off and the white solid was dried on a vacuum decicator to obtain constant weight. Yield 0.8 g (37%); ^{1}H NMR (600 MHz, $CDCl_3$) δ: 0.90 (m, 12H,), 1.30 (m, 32H), 1.90 (s, 9H), 2.19 (m, 8H), 4.37 (d, 2H, J=7.2 Hz), 4.42 (d, 2H, J=7.2 Hz), 4.60 (s, 2H), 4.73 (t, 2H, J=7.8 Hz), 4.77 (t, 2H, J=7.8 Hz), 5.87 (d, 2H, J=6.6 Hz), 5.95 (d, 2H, J=7.2 Hz), 6.97 (s, 3H), 7.15 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 10.2, 10.6, 14.1,14.1, 22.0, 22.7, 24.4, 27.9, 27.9, 29.5, 29.5, 29.7, 30.1, 30.2, 31.9, 31.9, 33.9, 36.9, 37.0, 98.3, 99.1, 117.2, 117.3, 118.4, 121.9, 123.9, 124.0, 123.9, 137.0, 137.8, 138.2, 138.4, 153.3, 153.3, 153.5, 153.6.

*4.3.6. Octamethoxy resorcin[4]arene (**3a**).* Compound **1** (5 g, 5.6 mol) was dissolved in acetone (50 mL) in a sure-sealed tube. Potassium carbonate (12.1 g, 88 mmol) was added and stirred for 0.5 h. Then methyl iodide (5.5 mL, 88 mmol) was added at room temperature. After addition, the reaction mixture was sealed and immersed in preheated oil bath 80 °C for 24 h. The tube was cooled in ice water and the solid was filtered off. The compound was crystallized in acetone/methanol mixture. White crystals were obtained. Yield 4.4 g (**80**%). Mp=109 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 0.86 (t, 12H, J=6.8 Hz), 1.30 (m, 32H), 1.86 (m, 8H), 2.17 (s, 12H), 3.52 (s, 24H), 4.46 (t, 4H, J=7.2 Hz), 6.55 (s, 4H); ^{13}C NMR (150 MHz, $CDCl_3$)

δ: 10.2, 14.1, 22.8, 28.6, 29.6, 31.9, 35.6, 37.5, 59.9, 98.5, 123.4, 124.2, 133.1155.5.

*4.3.7. Monobromo octamethoxy resorcin[4]arene (**3b**).* Compound **3a** (2 g, 2.01 mmol) and AIBN (100 mg, 0.6 mmol) dissolved in degassed benzene (40 mL). *N*-Bromosuccinimide (0.362 mg, 2.01 mmol) was then added and the reaction mixture refluxed overnight. After cooling the mixture was filtered and the filtrate was evaporated to dryness. The solid residue in dissolved in minimum amount of petroleum ether–ethyl acetate (1:1 v/v) mixture and then adsorbed on silica gel and dried. It was then mounted on the top of a silica gel column and eluted with petroleum ether ethyl acetate (95:5 v/v). The intended compound was the second last fraction from the column. The solvent was evaporated off and the white crystalline solid was dried on a vacuum decicator to obtain constant weight. Yield 0.65 g (30%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 0.88 (t, 12H, *J*=4.8 Hz), 1.29 (m, 32H), 1.87 (m, 8H), 2.12 (s, 6H), 2.22 (s, 3H), 3.44 (s, 6H), 3.45 (s, 6H), 3.58 (s, 6H), 3.87 (s, 6H), 4.49 (q, 4H, *J*=5.2 Hz), 4.70 (s, 2H), 6.42 (s, 1H), 6.65 (s, 1H), 6.73 (s, 2H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 10.4, 10.5, 14.2, 22.8, 23.0, 24.8, 26.4, 27.1, 28.7, 32.1, 36.0, 36.0, 37.6, 37.6, 60.1, 60.1, 60.2, 61.7, 123.7, 123.9, 124.2, 124.4, 125.5, 128.7, 132.1, 132.9, 133.8, 135.1, 155.7, 155.9, 156.1, 156.3.

*4.3.8. Porphyrin resorcin[4]arene conjugate (**2cP1**). meso*-5-(3-Hydroxyphenyl)-10,15,20-(4-toluyl)porphyrin (**P1**) (100 mg, 0.149 mmol) and K_2CO_3 (100 mg, 0.73 mmol) were dissolved in dry DMF (5 mL) in a sealed tube and stirred for 15 min. Monobrominated cavitand resorcin[4]arene, **2b**,(150.3 mg, 0.149 mmol) was added to this mixture, the tube sealed and stirred in an oil bath at 80d °C for one day. The DMF was evaporated off and the solid residue was washed with water and dried. The crude produce is adsorbed on silica and mounted on a silica column and eluted with chloroform. The first band is collected, solvent removed and dried in a vacuum decicator to get constant weight. Compound **2cP1** was obtained as brownish red solid (183 mg, 77% yield). UV–vis in CH_2Cl_2: λ_{max} nm ($\varepsilon\times10^{-5}$ M^{-1} cm^{-1}): 417 (3.64), 514 (0.134), 549 (0.057), 590 (0.032) and 644 (0.032). FAB mass: $[M-1]^+$ 1599.1; ^{1}H NMR (400 MHz, $CDCl_3$) δ: −2.79 (s, 2H), 0.89 (t, 12H, *J*=6.8 Hz), 1.34 (m, 32H), 1.87 (s, 6H), 1.92 (s, 3H), 2.21 (m, 8H), 2.71 (s, 9H), 4.32 (d, 2H, *J*=7.2 Hz), 4.42 (d, 2H, *J*=7.2 Hz), 4.73 (t, 2H, *J*=8.0 Hz), 4.81 (t, 2H, *J*=8.0 Hz), 5.21 (s, 2H), 5.76 (d, 2H, *J*=6.8 Hz), 5.97 (d, 2H, *J*=6.8 Hz), 6.93 (s, 1H), 6.97 (s, 2H), 7.24 (s, 1H), 7.33 (m, 1H), 7.56 (m, 6H), 7.68 (t, 1H, *J*=8.0 Hz), 7.77 (t, 1H, *J*=2.0 Hz), 7.91 (d, 1H, *J*=7.6 Hz), 8.09 (d, 6H, *J*=6.8 Hz), 8.86 (s, 8H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 10.4, 10.5, 14.1, 14.1, 14.1, 21.5, 22.7, 22.7, 27.9, 28.9, 29.0, 29.2, 29.4, 29.5, 29.6, 29.7, 29.7, 30.1, 30.3, 31.8, 31.9, 31.9, 33.8, 37.0, 37.1, 72.1, 98.6, 100.0, 100.3, 110.4, 114.1, 117.1, 122.0, 123.3, 124.1, 124.5, 127.6, 127.7, 127.8, 128.4, 132.9, 132.9, 134.5, 136.3, 137.6, 137.9, 137.9, 138.3, 138.5, 138.6, 139.3, 139.6, 142.7, 153.2, 153.4, 153.7, 153.9, 160.3.

*4.3.9. Porphyrin resorcin[4]arene conjugate (**2cP1**–**Zn**(**II**)).* Compound **2cP1** (30 mg) was dissolved in chloroform (10 mL) and zinc acetate (30 mg) in methanol (5 mL) was added. The mixture was refluxed until the UV–vis spectrum showed no peak at 650 nm. The solvent was then evaporated off and the crude product was purified by column chromatography (silica gel, CH_2Cl_2. Compound **2cP1**–**Zn**(**II**) was obtained as brownish red solid (27 mg, 90% yield). UV–vis in CH_2Cl_2: λ_{max} nm ($\varepsilon\times10^{-5}$ M^{-1} cm^{-1}): 418 (4.64), 546 (0.179) and 586 (0.039); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 0.92 (t, 12H, *J*=6.8 Hz), 1.36 (m, 32H), 1.91 (s, 6H), 1.96 (s, 3H), 2.26 (m, 8H), 2.75 (s, 9H), 4.35 (d, 2H, *J*=7.2 Hz), 4.43 (d, 2H, *J*=7.2 Hz), 4.74 (t, 2H, *J*=8.0 Hz), 4.82 (t, 2H, *J*=8.0 Hz), 5.22 (s, 2H), 5.79 (d, 2H, *J*=6.8 Hz), 5.98 (d, 2H, *J*=7.2 Hz), 6.96 (s, 1H), 6.99 (s, 2H), 7.26 (s, 1H), 7.34 (m, 1H), 7.59 (m, 6H), 7.71 (t, 1H, *J*=8.0 Hz), 7.82 (s, 1H), 7.95 (d, 1H, *J*=7.6 Hz), 8.13 (m, 6H), 9.01 (s, 8H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 10.2, 10.9, 14.3, 14.4, 21.8, 22.9, 22.9, 28.1, 28.2, 29.2, 29.4, 29.6, 29.7, 29.8, 29.9, 29.9, 29.9, 30.3, 30.4, 31.8, 32.0, 32.1, 32.2, 34.1, 37.2, 61.6, 98.4, 99.9, 113.9, 114.3, 117.3, 117.6, 120.2, 124.3, 127.5, 131.8, 132.2, 132.3, 134.6, 137.4, 137.4, 137.5, 137.9, 138.2, 138 9, 140.0, 150.1, 150.5, 150.6, 150.6, 153.5, 153.7, 154.3, 156.9.

*4.3.10. Porphyrin resorcin[4]arene conjugate (**3cP1**). meso*-5-(3-Hydroxyphenyl)-10,15,20-(4-toluyl)porphyrin (**P1**) (100 mg, 0.149 mmol) and K_2CO_3 (100 mg, 0.73 mmol) were dissolved in dry DMF (5 mL) in a sealed tube and stirred for 15 min. Monobrominated cavitand resorcin[4]arene. (Resorcarene(cavit)–Br) (160 mg, 0.149 mmol) was added to this mixture, the tube sealed and stirred in an oil bath at 80 °C for one day. The DMF was evaporated off and the solid residue was washed with water and dried. The crude produce is adsorbed on silica and mounted on a silica column and eluted with chloroform. The first band is collected, solvent removed and dried in a vacuum decicator to get constant weight. Compound **3cP1** was obtained as brownish red solid (203 mg, 82% yield). UV–vis in CH_2Cl_2: λ_{max} nm ($\varepsilon\times10^{-5}$ M^{-1} cm^{-1}): 417 (5.22), 514 (0.199), 550 (0.099), 589 (0.059) and 645 (0.053). FAB mass: $[M-1]^+$ 1662.8; ^{1}H NMR (400 MHz, $CDCl_3$) δ: −2.76 (s, 2H), 0.84 (m, 12H), 1.27 (m, 32H), 1.86 (m, 8H), 2.09 (s, 6H), 2.17 (s, 3H), 2.72 (s, 9H), 3.39 (s, 6H), 3.42 (s, 6H), 3.58 (s, 6H), 3.87 (s, 6H), 4.46 (t, 2H, *J*=7.2 Hz), 4.52 (t, 2H, *J*=7.2 Hz), 5.27 (s, 2H), 6.38 (s, 1H), 6.65 (s, 1H), 6.74 (s, 2H), 7.45 (m, 1H), 7.57 (d, 6H, *J*=7.6 Hz), 7.69 (t, 1H, *J*=8.0 Hz), 7.89 (m, 2H), 8.12 (d, 6H, *J*=7.6 Hz), 8.91 (m, 8H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 9.1, 9.3, 13.0, 20.5, 21.8, 27.5, 30.9, 34.7, 34.7, 36.4, 36.4, 58.8, 58.9, 58.9, 60.7, 61.8, 113.0, 118.5, 122.1, 126.4, 126.9, 133.5, 136.3, 138.3, 142.7, 154.2, 154.8, 154.9, 155.6, 156.4.

*4.3.11. Porphyrin Resorcin[4]arene conjugate (**3cP1**–**Zn**(**II**)).* Compound **3cP1** (30 mg) was dissolved in chloroform (10 mL) and zinc acetate (30 mg) in methanol (5 mL) was added. The mixture was refluxed until the UV–vis spectrum showed no peak at 650 nm. The solvent was then evaporated off and the crude product was purified by column chromatography (silica gel, CH_2Cl_2. Compound **3cP1**–**Zn** (**II**) was obtained as brownish red solid (28 mg, 92% yield). UV–vis in CH_2Cl_2: λ_{max} nm ($\varepsilon\times10^{-5}$ M^{-1} cm^{-1}): 419 (3.22), 550 (0.137) and 595 (0.034); ^{1}H NMR (400 MHz, $CDCl_3$), 0.82 (m, 12H), 1.26 (m, 32H), 1.86 (m, 8H), 2.07 (s, 6H), 2.16 (s, 3H), 2.73 (s, 9H), 3.38 (s, 6H), 3.40 (s, 6H), 3.58 (s, 6H), 3.87 (s, 6H), 4.46 (t, 2H, *J*=7.2 Hz), 4.50 (t, 2H, *J*=7.2 Hz), 5.27 (s, 2H), 6.36 (s, 1H), 6.61 (m, 1H), 6.75 (s, 2H), 7.45 (m, 1H), 7.57 (d, 6H, *J*=7.2 Hz), 7.69 (t, 1H, *J*=8.0 Hz), 7.89 (m, 2H), 8.12 (d, 6H, *J*=7.6 Hz), 9.01 (m, 8H); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 10.2, 10.3, 14.1, 21.5, 22.8, 22.8, 28.5, 28.6, 28.9, 29.2, 29.6, 29.6, 29.7, 29.7, 35.7, 35.7, 37.4, 37.5, 59.9, 59.9, 60.0, 62.8, 113.9, 114.1, 115.9, 120.6, 121.2, 121.3, 121.8, 123.1, 123.4, 123.5, 123.6, 124.1, 127.3, 127.4, 127.5, 128.8, 131.8, 131.9, 131.9, 132.0, 133.3, 134.4, 137.1, 139.3, 139.9, 144.3, 150.0, 150.3, 150.3, 150.4, 155.2, 155.8, 155.9, 156.6, 157.3.

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Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2011.02.024. These data include MOL files and InChIKeys of the most important compounds described in this article.

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