A Dual-Thermo-Responsive Gemini-Type Supra-Amphiphilic Macromolecular [3]Pseudorotaxane Based on Pillar[10]arene/Paraquat Cooperative Complexation

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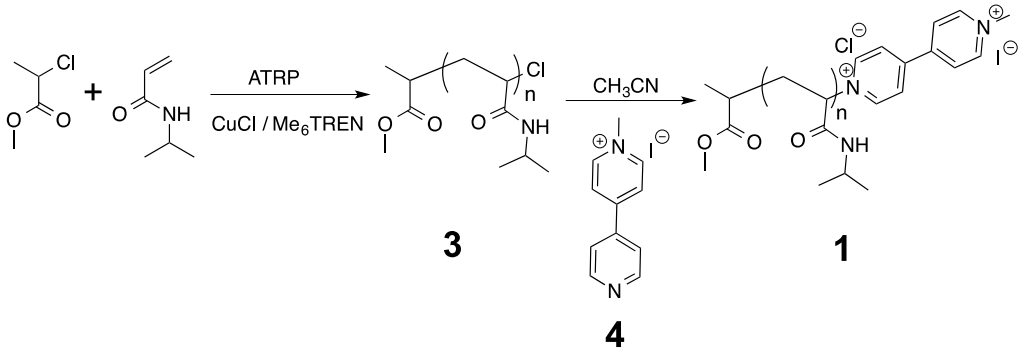
Supporting Information

1. Materials and methods

All reagents were commercially available and used as supplied without further purification. Compounds **WP10**[S1] and **2**[S2] were prepared according to published procedures. NMR spectra were recorded with a Bruker Avance DMX 600 spectrophotometer or a Bruker Avance DMX 400 spectrophotometer using the deuterated solvent as the lock and the residual solvent or TMS as the internal reference. Low-resolution electrospray ionization mass spectra were recorded with a Bruker Esquire 3000 Plus spectrometer. Molecular weights and molecular weight distributions were determined by gel permeation chromatography (GPC) with a Waters 1515 pump and Waters 1515 differential refractive index detector (set at 30 ºC). It used a series of three linear Styragel columns (HT2, HT4, and HT5) at an oven temperature of 45 ºC. The eluent was THF at a flow rate of 1.0 mL/min. A series of low polydispersity polystyrene standards was employed for the GPC calibration. Transmission electron microscopy (TEM) investigations were carried out on a HITACHI HT-7700 instrument. Dynamic light scattering (DLS) measurements were carried out using a 200-mW polarized laser source Nd: YAG (λ = 532 nm). The polarized scattered light was collected at 90° in a self-beating mode with a Hamamatsu R942/02 photomultiplier. The signals were sent to a Malvern 4700 submicrometer particle analyzer system. UV-vis spectroscopy was performed on a Shimadzu UV-2550 instrument at room temperature. The fluorescence experiments were carried out on a Shimadzu RF-5301 spectrofluorophotometer.

*2. Synthesis of Polymer **1***

Scheme S1. Synthesis of polymer **1**



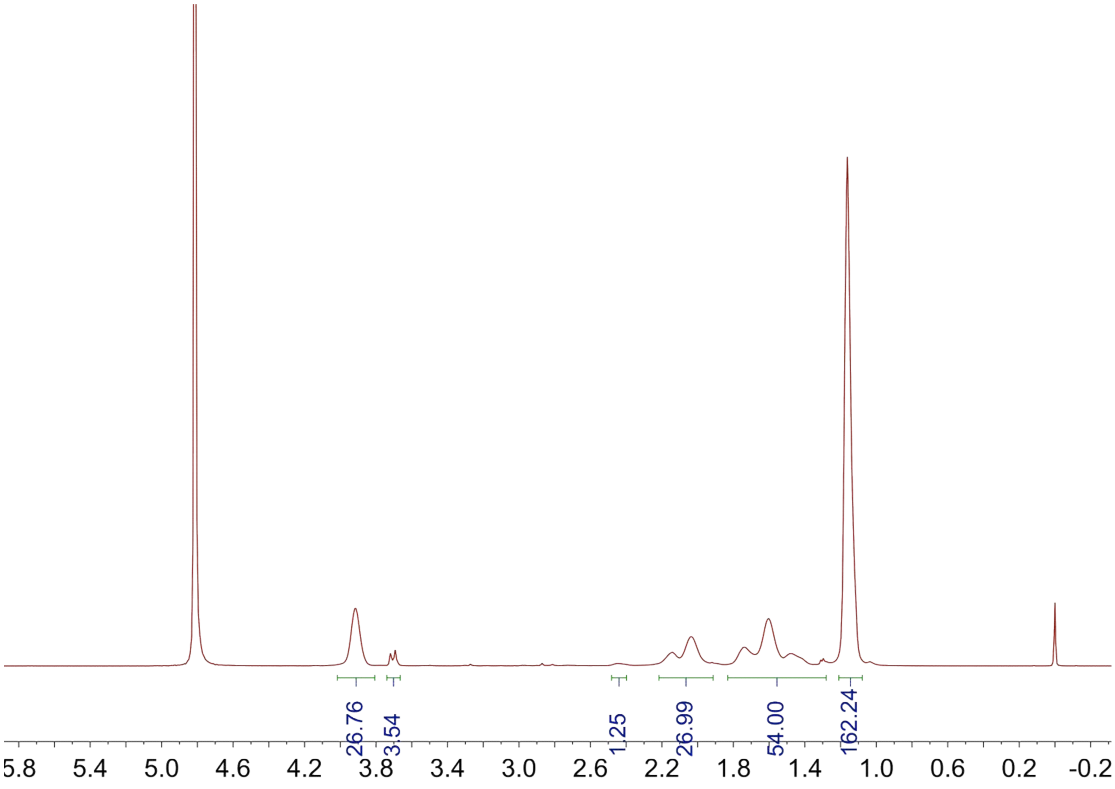


Figure S1. ^{1}H NMR spectrum (400 MHz, D_2O, 298 K) of **3**.

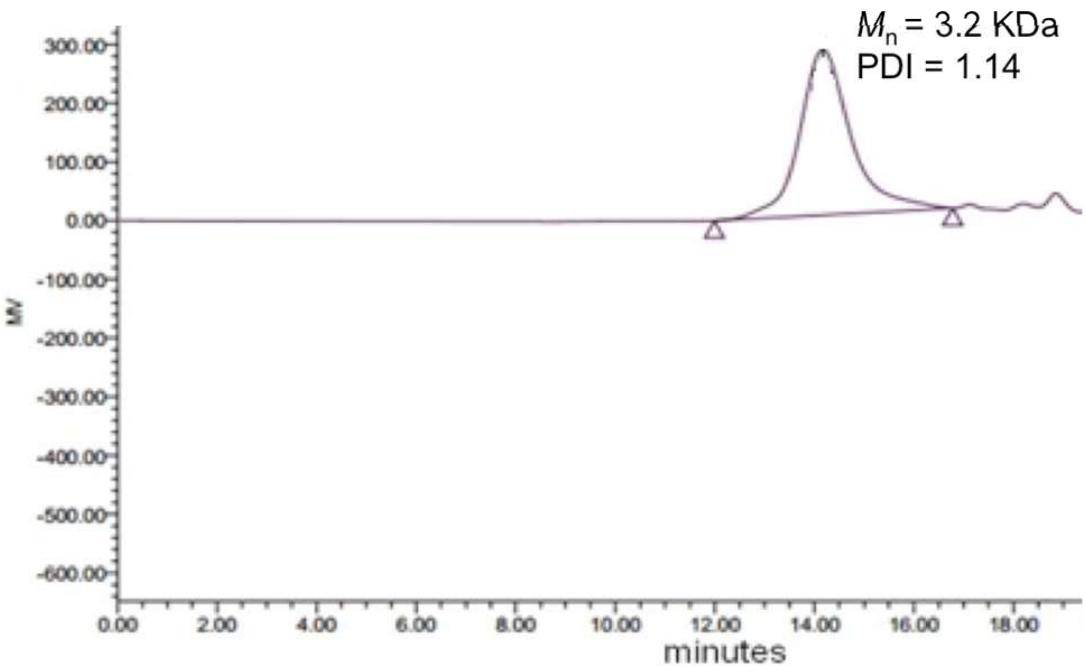


Figure S2. GPC trace of **3**.

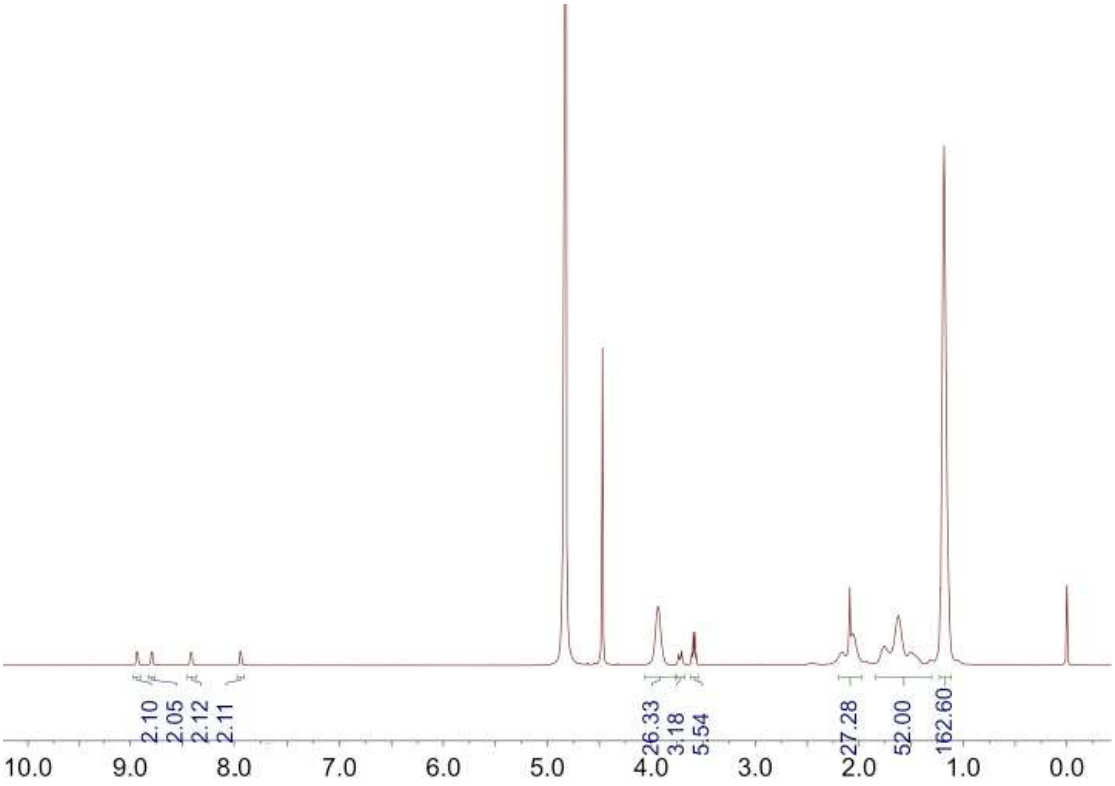


Figure S3. ^{1}H NMR spectrum (400 MHz, D_2O, 298 K) of **1**.

*3. LCST behavior of polymer **1***

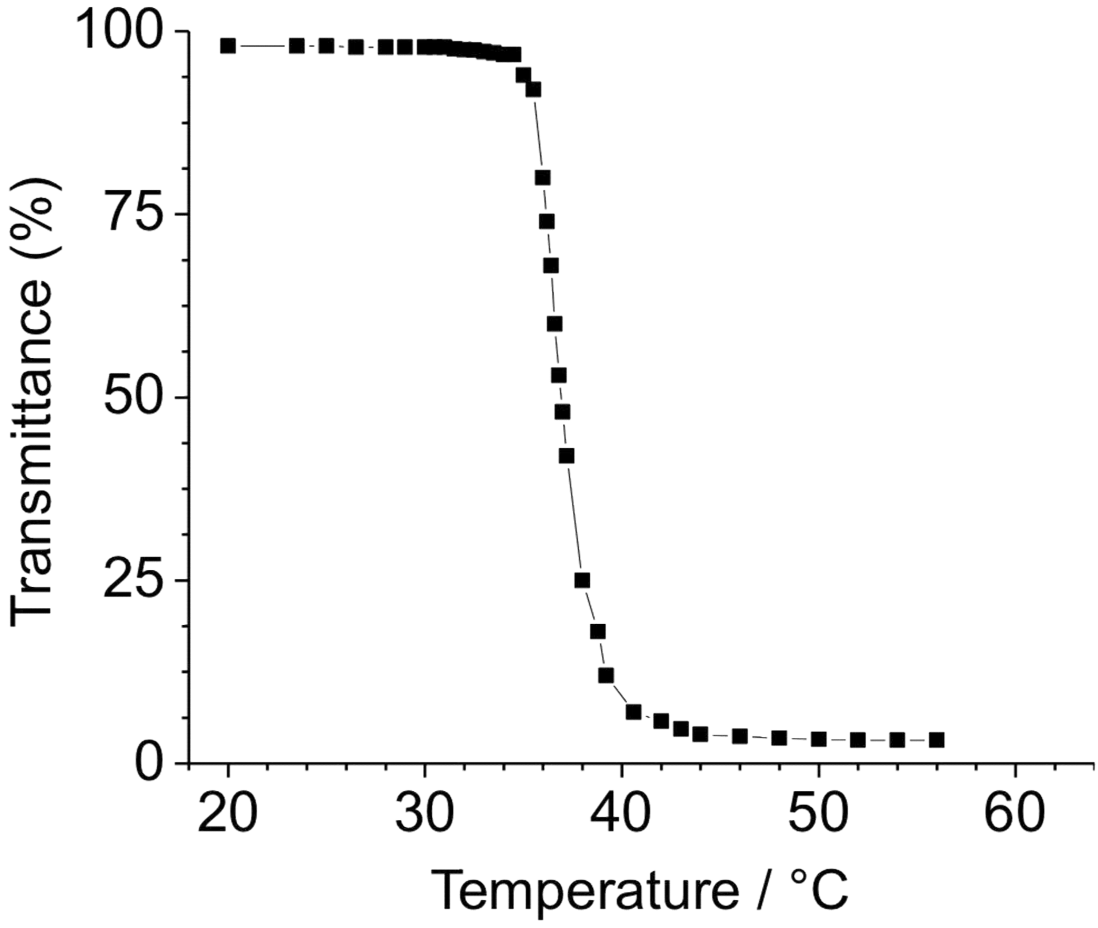


Figure S4. Temperature dependence of light transmittance of **1** (2.00 mg/mL) in aqueous solution.

*4. Electrospray ionization mass spectrometry of **WP10** and 2 equiv. **2***

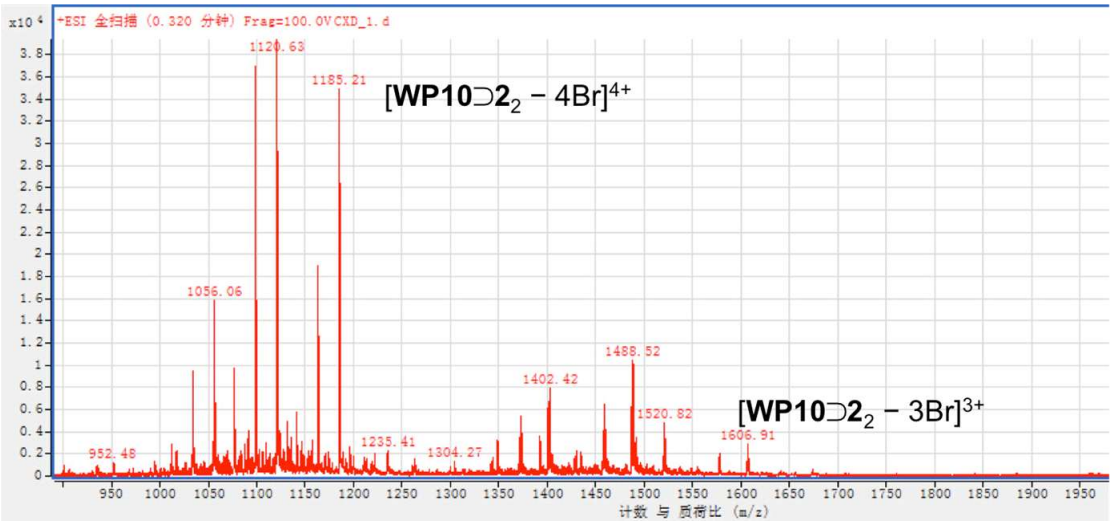


Figure S5. Electrospray ionization mass spectrum of **WP10** and 2 equiv. **2**.

5. NOESY NMR analysis of ***WP10⊃2***$_2$

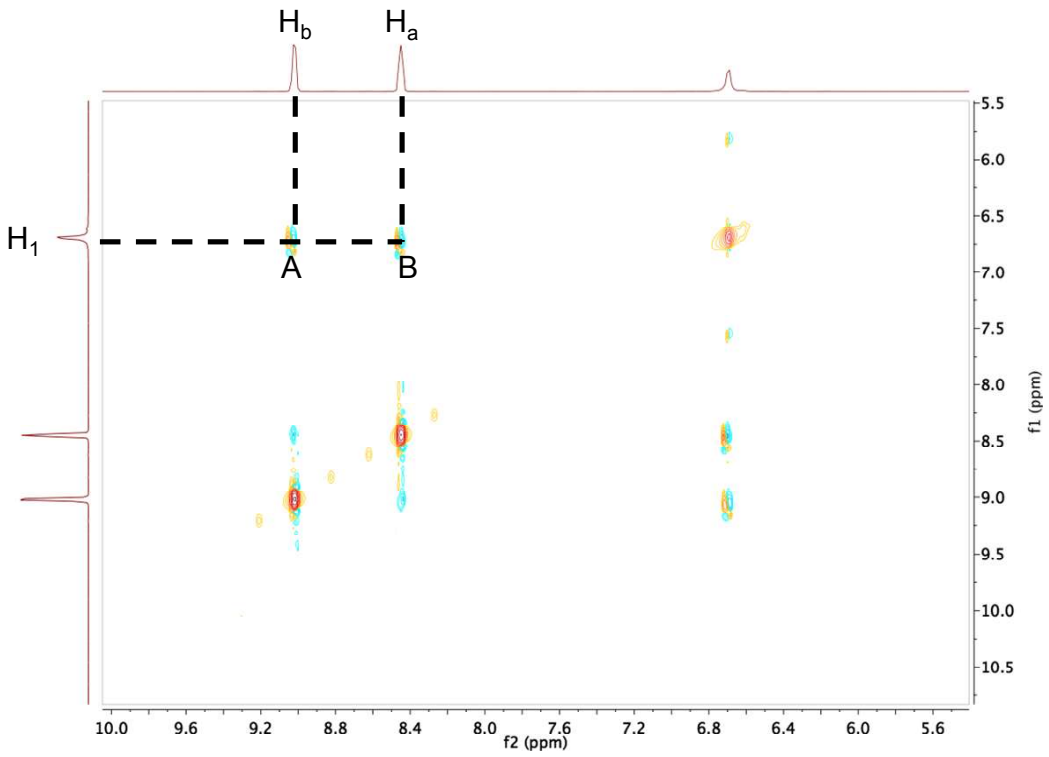


Figure S6. Partial NOESY NMR spectrum of **WP10⊃2**$_2$ (3.00 mM) in D_2O with a mixing time of 800 ms (500 MHz, 298 K).

*6. Stoichiometry and association constant determination for the complexation between **WP10** and **2***

To determine the stoichiometry and association constant for the complexation between **WP10** and **2**, ^{1}H NMR titration experiments were done with solutions which had a constant concentration of **WP10** (1.00×10^{-3} M) and varying concentrations of **2**.[S3] The non-linear curve-fitting was based on the equation:

$$\Delta\delta = (\Delta\delta_{HG}K_1[G] + \Delta\delta_{HG2}K_1K_2[G]^2) / (1 + K_1[G] + K_1K_2[G]^2)$$

Where $\Delta\delta$ is the chemical shift change of H_1 on **WP10** at [G], $\Delta\delta_{HG}$ is the chemical shift change of H_1 when **WP10** is completely complexed by the first paraquat unit, $\Delta\delta_{HG2}$ is the chemical shift change of H_1 when **WP10** is completely complexed by the second paraquat unit. [H] is the fixed initial concentration of **WP10**. [G] is the concentration of paraquat derivative **2**.

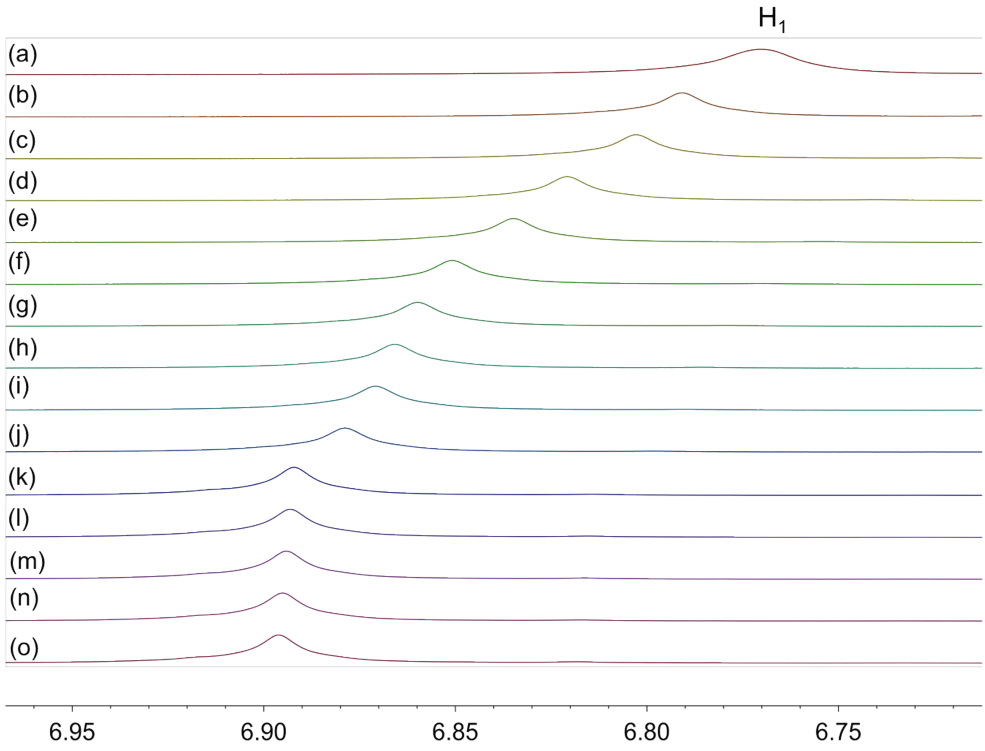


Figure S7. ^{1}H NMR spectra (400 MHz, D_2O, 25 °C, 1.00 mM) of **WP10** with different concentrations of **2**: (a) 0.00 mM; (b) 0.300 mM; (c) 0.500 mM; (d) 0.800 mM; (e) 1.10 mM; (f) 1.40 mM; (g) 1.60 mM; (h) 1.90 mM; (i) 2.10 mM; (j) 2.40 mM; (k) 2.80 mM; (l) 3.20 mM; (m) 3.60 mM; (n) 4.00 mM; (o) 4.40 mM.

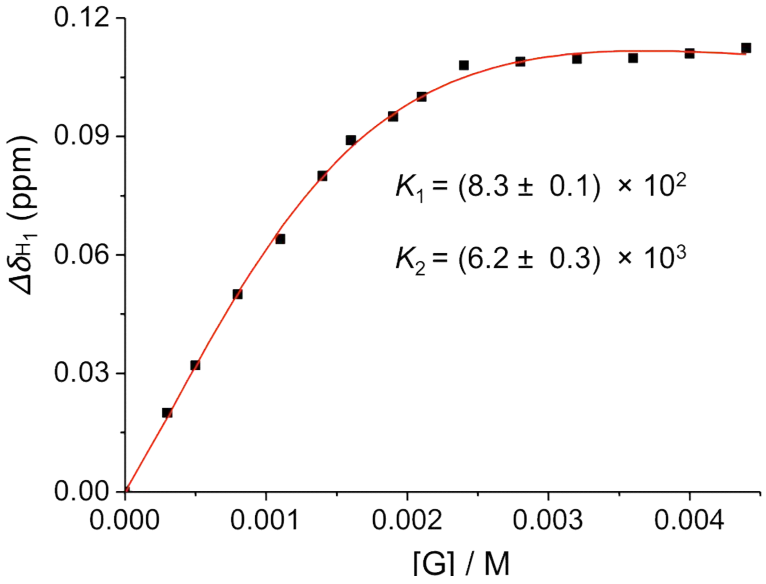


Figure S8. The chemical shift changes of H_1 on **WP10** upon addition of **G**. The red solid line was obtained from the non-linear curve-fitting using the above equation.

*7. UV-vis spectroscopy studies of the interactions between **WP10** and polymer **1***

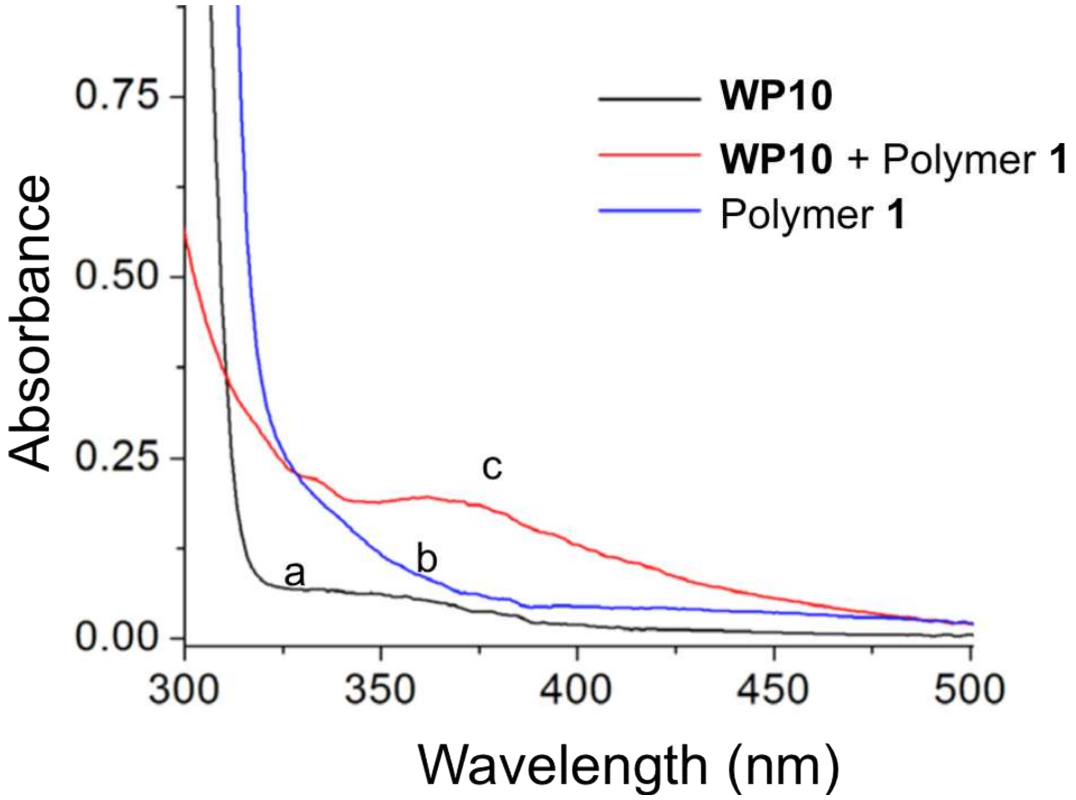


Figure S9. UV-vis spectra in water: (a) **WP10** (2.00×10^{-4} M); (b) polymer **1** (2.00×10^{-4} M); (c) polymer **1** (2.00×10^{-4} M) in the presence of **WP10** (1.00×10^{-4} M).

8. Critical aggregation concentration (CAC) determination of ***WP10⊃1₂***

The critical aggregation concentration (CAC) of **WP10⊃1**$_2$ was measured by the fluorescent probe method, using pyrene as a probe molecule.[S4] Pyrene in acetone (1×10^{-4} mM) was added to **WP10⊃1**$_2$ aqueous solutions with different concentrations and the solutions were sonicated for 10 min before fluorescent emission measurements. The results showed that the CAC of **WP10⊃1** was 0.12 mg/mL. The CAC value was chosen as the concentration when pyrene exhibited an apparent decrease in the I_1/I_3 ratio with an increasing concentration of **WP10⊃1**$_2$, indicating that the aggregation of **WP10⊃1**$_2$ occurred.

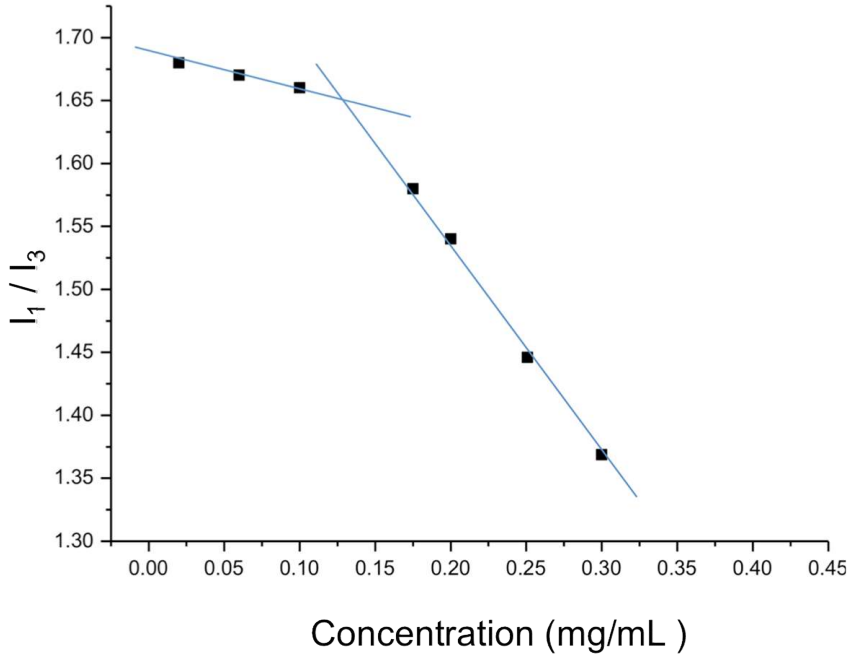


Figure S10. Determination of CAC for the amphiphilic [3]pseduorataxtane **WP10⊃1**$_2$ by using the fluorescent method with pyrene as a probe.

*9. TEM image of polymer **1** in water at 37 °C*

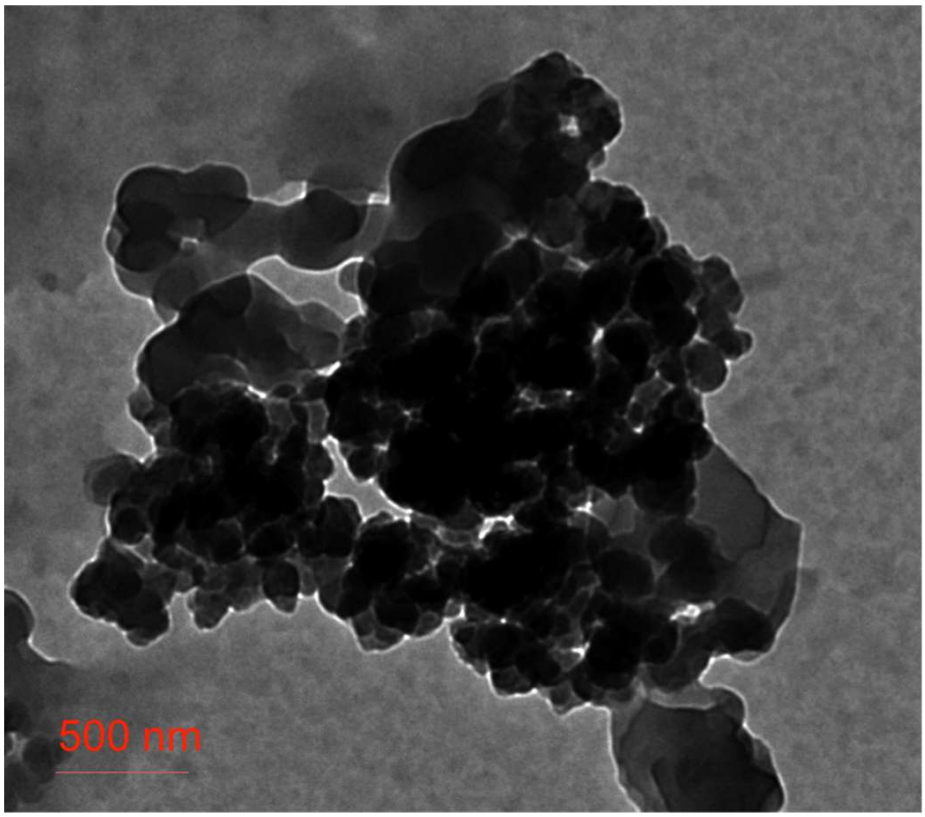


Figure S11. TEM image of polymer **1** in water at 37 °C.

10. Controlled release experiments

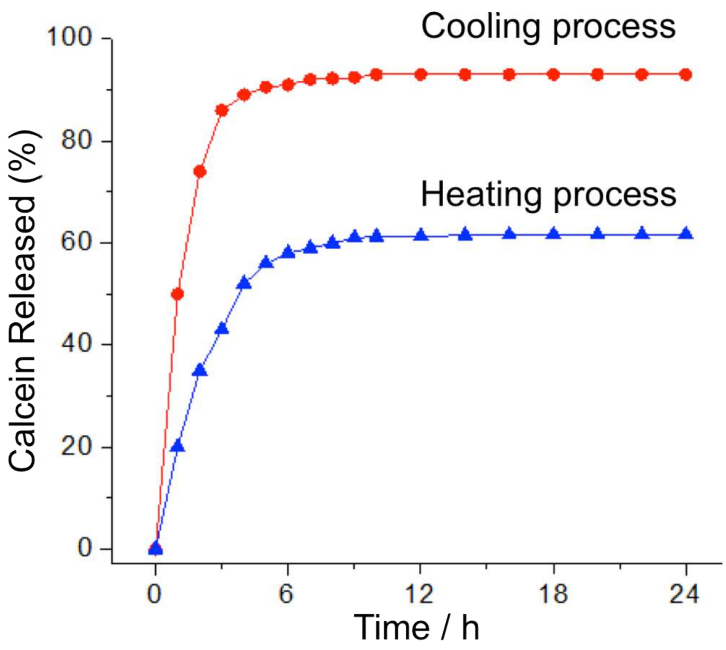


Figure S12. Controlled release of calcein from the polymeric vesicles as drug nanocapsules upon dual-thermo stimuli. Heating rate is 10 °C / h; Cooling rate is 10 °C / h.

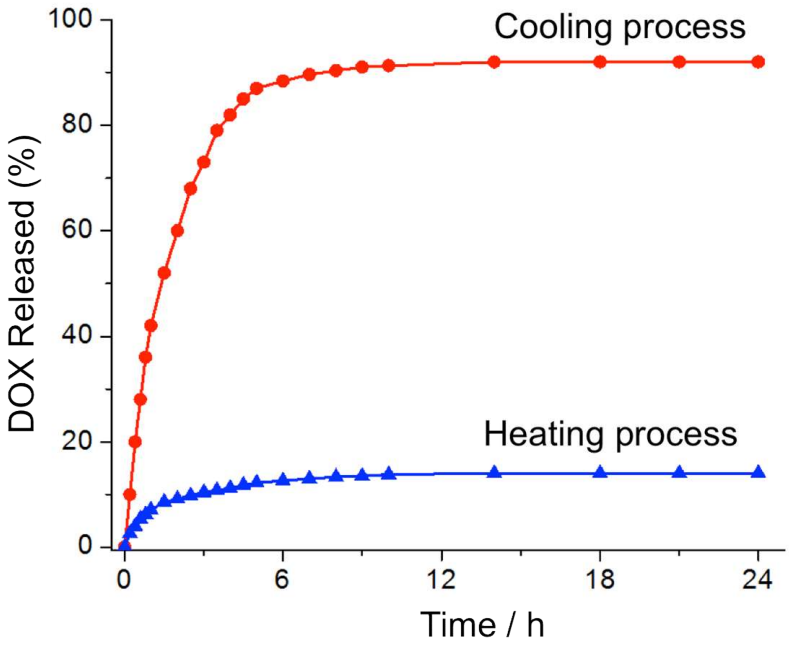


Figure S13. Controlled release of doxorubicin (DOX) from the polymeric vesicles as drug nanocapsules upon dual-thermo stimuli. Heating rate is 10 °C / h; Cooling rate is 10 °C / h.

References:

S1. Chi, X.; Xue, M. *Chem. Commun.* **2014**, *50*, 13754–13756.

S2. Nelissen, H. F. M.; Kercher, M.; De Cola, L.; Feiters, M. C.; Nolte, R. J. M. *Chem. - Eur. J.* **2002**, *8*, 5407–5414.

S3. (a) Thordarson, P. *Chem. Soc. Rev.* **2011**, *40*, 1305–1323. (b) Hu, X.-B.; Chen, Z.; Chen, L.; Zhang, L.; Hou, J.-L.; Li, Z.-T. *Chem. Commun*. **2012**, *48*, 10999–11001.

S4. (a) Wang, K.; Guo, D.-S; Wang, X; Liu, Y. *ACS Nano* **2011**, *5*, 2880–2894. (b) Li, Z.; Yang, J.; Yu, G.; He, J.; Abliz, Z.; Huang, F. *Org. Lett.* **2014**, *16*, 2066–2069.