

## Electronic Supplementary Information for

“Synthesis of PPEGMEA-*g*-PMAA Densely Grafted Double Hydrophilic Copolymer and  
Using It as Template for the Preparation of Size-controlled Superparamagnetic  
Fe<sub>3</sub>O<sub>4</sub>/Polymer Nano-Composite”

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## Experimental Section

### Materials

Poly(ethylene glycol) methyl ether acrylate (PEGMEA,  $M_n = 454$ , Aldrich, 99%) was passed through a column filled with basic alumina. Copper (I) bromide (CuBr, Aldrich, 98%) was purified by stirring overnight over acetic acid at room temperature, followed by washing the solid with ethanol, diethyl ether and acetone prior to drying at 40°C under vacuum for 1 day. Tris(2-(dimethylamino)ethyl)amine (Me<sub>6</sub>TREN)<sup>1</sup> and methoxymethyl methacrylate (MOMMA)<sup>2</sup> were synthesized according to previous literatures.

Diisopropylamine (Aldrich, 99.5%) was dried over KOH for several days and distilled from CaH<sub>2</sub> under N<sub>2</sub> prior to use. *N*-phenyl-1-naphthylamine (PNA, Alfa Aesar, 97%) was purified by recrystallization in ethanol for three times. Tetrahydrofuran (THF) was dried over CaH<sub>2</sub> for seven days and distilled from sodium and benzophenone under N<sub>2</sub> prior to use. Methyl 2-bromopropionate (2-MBP, Acros, 99%), 2-bromopropionyl chloride (Acros, 99%), *n*-butyllithium (*n*-BuLi, Aldrich, 1.6 M in hexane), *N,N,N',N',N''*-pentamethyldiethylenetriamine (PMDETA, Aldrich, 99%) and hexamethyltriethylenetetramine (HMTETA, Aldrich, 99%) were used as received.

## Measurements

FT-IR spectra were recorded on a Nicolet AVATAR-360 FT-IR spectrophotometer with 4 cm<sup>-1</sup> resolution. All <sup>1</sup>H NMR and <sup>13</sup>C NMR analyses were performed on a Varian Mercury 300 spectrometer (300 MHz) in CDCl<sub>3</sub>, DMSO-*d*<sub>6</sub> and D<sub>2</sub>O, TMS (<sup>1</sup>H NMR) and CDCl<sub>3</sub> (<sup>13</sup>C NMR) were used as internal standards. Elemental analysis was carried out on a Carlo-Erba 1106 system. Bromine content was determined by the titration with Hg(NO<sub>3</sub>)<sub>2</sub>. Conversion of methoxymethyl methacrylate was determined by gas chromatography (GC) using a HP 6890 system with an SE-54 column. Relative molecular weights and molecular weight distributions were measured by conventional gel permeation chromatography (GPC) system equipped with a Waters 1515 Isocratic HPLC pump, a Waters 2414 refractive index detector and a set of Waters Styragel columns (HR3, HR4 and HR5, 7.8×300 mm). GPC measurements were carried out at 35°C using THF as the eluent with a flow rate of 1.0 mL/min. The system was calibrated with polystyrene standards. The absolute molecular weights were determined by GPC equipped with a

multi-angle light scattering detector (GPC/MALS). THF was used as the eluent with a flow rate of 1.0 mL/min. Detectors: Wyatt Optilab rEX refractive index detector and Wyatt DAWN HELEOS 18-angle light scattering detector with a 50 mW solid-state laser operating at 658 nm. Steady-state fluorescent spectra of PNA were measured on a Hitachi FL-4500 spectrofluorometer with the band width of 5 nm for excitation and emission, the emission intensity at 418 nm was recorded to determine the critical micelle concentration with a  $\lambda_{\text{ex}} = 340$  nm. Thermogravimetric analysis (TGA) measurements were run with a Perkin–Elmer Pyris 1 system, the temperature ranged between 50°C and 800°C with a heating rate of 30°C/min under N<sub>2</sub>. Transmission Electron Microscope (TEM) images were obtained using a Philips CM120 instrument operated at 80 kV. The hydrodynamic diameter ( $D_h$ ) and zeta potential of Fe<sub>3</sub>O<sub>4</sub>/polymer nano-composite were measured by dynamic laser light scattering (DLS) using a Malvern Nano-ZS90 Zetasizer. The crystal structure of nano-composite was investigated by X-ray diffraction (XRD) using a Philips X'Pert PRO X-ray powder diffractometer with CuK $\alpha$  (1.541 Å) radiation (40 kV, 40 mA), the samples were exposed at a scan rate of  $2\theta = 0.04244^\circ/\text{s}$  in the range of 25° and 65°. The magnetizations curve of Fe<sub>3</sub>O<sub>4</sub>/polymer nano-composite was measured by an EG & G Princeton Applied Research 155 Vibrating Sample Magnetometer (VSM) at room temperature with a maximum applied field of 3 T.

### **Homopolymerization of PEGMEA by ATRP**

ATRP of PEGMEA was carried out in H<sub>2</sub>O/THF under N<sub>2</sub>. To a 25 mL Schlenk flask (flame-dried under vacuum prior to use) sealed with a rubber septum, CuBr (0.1722 g, 1.2 mmol) was first added for degassing and kept under N<sub>2</sub>. Next, PEGMEA ( $M_n = 454$ ,

10 mL, 24 mmol) and Me<sub>6</sub>TREN (0.162 mL, 1.2 mmol) were introduced via a gastight syringe, and the mixture was stirred for several minutes. Then, the mixed solvent, H<sub>2</sub>O/THF (v:v = 10:1, 10.3 mL) which was purged with N<sub>2</sub> for 10 min and mixed under N<sub>2</sub>, was added via a gastight syringe. Finally, the initiator, 2-MBP (0.134 mL, 1.2 mmol) was charged via a gastight syringe. The solution was degassed by three cycles of freeze-pump-thaw followed by immersing the flask into an oil bath set at 40°C to start the polymerization. The flask was cooled by liquid nitrogen to terminate the polymerization after 5 hours. THF was added for dilution and the solution was filtered through a short Al<sub>2</sub>O<sub>3</sub> column to remove the copper catalyst. The resulting solution was concentrated and precipitated into hexane. After repeated purification by dissolving in THF and precipitating in hexane, 9.403 g of poly[poly(ethylene glycol) methyl ether acrylate] (PPEGMEA **1**) was obtained with a yield of 86.3%. GPC:  $M_n = 5,400$ ,  $M_w/M_n = 1.09$ . FI-IR (film),  $\nu$  (cm<sup>-1</sup>): 2869, 1728 (C=O), 1455, 1109 (C-O-C), 952. <sup>1</sup>H NMR:  $\delta$  (ppm): 0.86 (3H, CH<sub>3</sub>CH), 1.26, 1.65 (2H, CH<sub>2</sub>CH), 2.18 (1H, COCH(CH<sub>3</sub>)CH<sub>2</sub>), 2.22-2.53 (1H, CH<sub>2</sub>CH), 3.39 (3H, OCH<sub>3</sub>), 3.68 (4H, OCH<sub>2</sub>CH<sub>2</sub>O), 3.88 (3H, COOCH<sub>3</sub>), 4.18 (2H, COOCH<sub>2</sub>CH<sub>2</sub>O), 4.33 (1H, CHBr). <sup>13</sup>C NMR:  $\delta$  (ppm): 26.0, 29.7 (CH<sub>2</sub>CH), 35.2, 38.9 (CH<sub>2</sub>CH), 55.1 (CH<sub>2</sub>OCH<sub>3</sub>), 59.4-72.6 (OCH<sub>2</sub>CH<sub>2</sub>O), 174.0 (COOCH<sub>2</sub>).

The conversion of PEGMEA macromonomer was determined by <sup>1</sup>H NMR spectrum according to previous literature.<sup>3</sup> The procedure was same with the above-mentioned polymerization except that the mixed solvent was changed to D<sub>2</sub>O/THF (v:v = 10:1). The conversion of the macromonomer was 100% since the signal of the double bond of the macromonomer was not found in <sup>1</sup>H NMR spectrum.

### Synthesis of PPEGMEA-Br 2 Macroinitiator

In a 500 mL sealed three-neck flask, dried THF (40 mL) and diisopropylamine (1.12 mL, 8 mmol) were added under N<sub>2</sub>. The solution was cooled to -78°C and *n*-BuLi (5 mL, 8 mmol) was added slowly. After 1 hour, the mixture was treated with PPEGMEA 1 (3.632 g,  $M_n = 5,400$ ,  $M_w/M_n = 1.09$ ) in 160 mL of dried THF under -78°C. The reaction lasted for 3 hours. Next, 2-bromopropionyl chloride (0.8 mL, 8 mmol) in 10 mL of dried THF was introduced. After 3 hours, the reaction was terminated by water. The solution was concentrated and dialyzed in water for a day. The aqueous solution was extracted by CHCl<sub>3</sub> and dried over NaSO<sub>4</sub> overnight. After filtration, the solution was concentrated, and precipitated into hexane. The product was dried under vacuum to give 3.8279 g of PPEGMEA-Br 2 macroinitiator. GPC:  $M_n = 5,000$ ,  $M_w/M_n = 1.03$ . FT-IR (film):  $\nu$  (cm<sup>-1</sup>): 2871, 1734, 1453, 1351, 1105, 951, 855. <sup>1</sup>H NMR:  $\delta$  (ppm): 0.86 (3H, CH<sub>3</sub>CH), 1.26, 1.71 (2H, CH<sub>2</sub>-CH), 1.90 (3H, CH(CH<sub>3</sub>)Br), 2.28 (1H, COCH(CH<sub>3</sub>)CH<sub>2</sub>), 3.38 (3H, -OCH<sub>3</sub>), 3.67 (4H, OCH<sub>2</sub>CH<sub>2</sub>O), 3.89 (3H, COOCH<sub>3</sub>), 4.19 (2H, COOCH<sub>2</sub>CH<sub>2</sub>O), 4.33 (1H, CHBr). <sup>13</sup>C NMR:  $\delta$  (ppm): 18.7-21.0 (CH(CH<sub>3</sub>)Br), 26.2-34.0 (CH<sub>2</sub> on PPEGMEA backbone), 41.0, 42.3 (CH on PPEGMEA backbone), 47.1 (CH(CH<sub>3</sub>)Br), 52.2 (*tert*-C on PPEGMEA backbone), 54.7 (CH<sub>2</sub>OCH<sub>3</sub>), 58.6-72.4 (OCH<sub>2</sub>CH<sub>2</sub>O), 169.7-174.0 (O-C=O), 211.1 (C=O). Element analysis: C% = 50.06%, Br% = 10.06%.

### Synthesis of PPEGMEA-g-PMOMMA 3 Graft Copolymer

PPEGMEA-g-PMOMMA 3 amphiphilic graft copolymer was synthesized by ATRP of MMOMA initiated by PPEGMEA-Br 2 macroinitiator. CuBr and PPEGMEA-Br 2 macroinitiator ( $M_n = 5,000$ ,  $M_w/M_n = 1.03$ ) in THF were added to a 25 mL Schlenk flask

(flame-dried under vacuum prior to use) sealed with a rubber septum under N<sub>2</sub>. After three cycles of evacuating and purging with N<sub>2</sub>, MMOMA and diphenyl ether (internal standard of GC measurement for the conversion of MMOMA) were charged via a gas-tight syringe. Finally, Me<sub>6</sub>TREN was introduced via a gas-tight syringe. The flask was degassed by three cycles of freezing-pumping-thawing followed by immersing the flask into an oil bath set at 30°C. The polymerization was terminated by putting the flask into liquid nitrogen after certain time. The reaction mixture was diluted by THF and passed through an alumina column to remove the residual copper catalyst. The solution was concentrated and precipitated into cold ether. The white viscous solid was dried under vacuum overnight to obtain the final product, poly[poly(ethylene glycol) methyl ether acrylate]-*g*-poly(methoxymethyl methacrylate) (PPEGMEA-*g*-PMOMMA **3**). FT-IR (film):  $\nu$  (cm<sup>-1</sup>): 2960, 2833, 1737, 1487, 1394, 1152, 1075, 918. <sup>1</sup>H NMR:  $\delta$  (ppm): 0.88, 1.02 (3H, CCH<sub>3</sub>), 1.40-2.20 (2H, CH<sub>2</sub> and 1H, CH), 3.41 (3H, OCH<sub>2</sub>OCH<sub>3</sub>), 3.50 (4H, OCH<sub>2</sub>CH<sub>2</sub>O), 5.17 (2H, OCH<sub>2</sub>O). The data of relative molecular weight, molecular weight distribution and absolute molecular weight are listed in Table 1.

### Determination of Critical Micelle Concentration of PPEGMEA-*g*-PMOMMA **3**

PNA was used as fluorescence probe to measure the critical micelle concentration (*cmc*) of PPEGMEA-*g*-PMOMMA **3**. The acetone solution of PNA (1 mmol/L) was added to a large amount of water until the concentration of PNA reached 2×10<sup>-6</sup> mol/L. Different amounts of THF solutions of PPEGMEA-*g*-PMOMMA **3** (1 mg/mL, 0.1 mg/mL or 0.001 mg/mL) were added to water containing PNA ([PNA] = 2×10<sup>-6</sup> mol/L). All fluorescence spectra were recorded at 20°C.

### TEM Images of PPEGMEA-*g*-PMOMMA 3

To prepare micelles, THF solution of PPEGMEA-*g*-PMOMMA **3** (0.2 mg/mL) was filtered through a membrane with a nominal pore size of 0.2  $\mu\text{m}$ . Next, 0.25 mL of de-ionized water was added to 1.00 g of THF solution by a micro-syringe and the solution was dialyzed against water with stirring for 5 days. For TEM studies, a drop of micellar solution was deposited on an electron microscopy copper grid coated with carbon film.

### Hydrolysis of PMOMMA Side Chains

PPEGMEA-*g*-PMOMMA **3** was dissolved in THF and treated with excess 1 M HCl at room temperature for 5 hours. The reaction mixture was concentrated and precipitated into dichloromethane. After filtration, the white powder was dried overnight at 40°C under vacuum to obtain PPEGMEA-*g*-PMAA **4** densely grafted double hydrophilic copolymer. FT-IR (film):  $\nu$  ( $\text{cm}^{-1}$ ): 3700-2700 (broad, -COOH), 1705, 1485, 1391, 1266, 1176.  $^1\text{H}$  NMR:  $\delta$  (ppm): 0.92, 1.02 (3H,  $\text{CCH}_3$ ), 1.42-2.1 (2H,  $\text{CH}_2$  and 1H,  $\text{CH}$ ), 3.50 (4H,  $\text{OCH}_2\text{CH}_2\text{O}$ ), 12.38 (1H,  $\text{COOH}$ ).

### Preparation of $\text{Fe}_3\text{O}_4$ /Polymer Nano-Composite

In a typical process, 0.602 g of PPEGMEA-*g*-PMAA **4a**, 0.2910 g of  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  and 0.1116 g of  $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$  were dissolved in 50 mL of water with vigorous stirring of 400 rpm at room temperature under  $\text{N}_2$ . To initiate the formation of  $\text{Fe}_3\text{O}_4$ , 1 M NaOH was added to basify the solution until the color turned from orange to black. The reaction lasted for 30 minutes under  $\text{N}_2$ . Next, the temperature was raised to 80°C for the

maturation of the crystal. Nano-composites were purified and harvested by ultra-centrifugation of 10,000 rpm for 20 minutes followed by lyophilization.

Sample of native Fe<sub>3</sub>O<sub>4</sub> nano-particles were prepared under the same condition just without the double hydrophilic graft polymer as template.

### References and Notes

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