

Electronic Supplementary Information

DOUBLE THERMORESPONSIVE PENTABLOCK COPOLYMERS: SYNTHESIS BY ONE-POT RAFT POLYMERIZATION AND SELF-ASSEMBLY IN AQUEOUS SOLUTIONS

P. Radzevicius, M. Steponaviciute, T. Krivorotova, R. Makuska

Department of Polymer Chemistry, Vilnius University, Naugarduko 24, LT-03225 Vilnius, Lithuania

Synthesis of 4-cyano-4-(butylsulfanylthiocarbonyl) sulfanyl pentanoic acid (CBPA)

CBPA as RAFT CTA was synthesized according to the procedure described elsewhere [1] with slight adjustments. 1-Buthanethiol (5.76 g, 64.0 mmol) was added over 10 min to a stirred suspension of sodium hydride (60% in oil) (2.91 g, 72.8 mmol) in diethyl ether (150 ml) keeping the temperature below 10 °C. Carbon disulfide (7.06 g, 92.9 mmol) was added to the cooled reaction mixture to gain yellow crystals of sodium S-butyl trithiocarbonate, which was separated by filtration and dried. A suspension of sodium S-butyl trithiocarbonate (4.50 g, 23.9 mmol) in diethyl ether (80 ml) was processed by a portion-wise addition of solid iodine (11.94 g, 47.0 mmol). The reaction mixture was then stirred at room temperature for 1 h, and white precipitate of sodium iodide was removed by filtration. The red–brown organic layer was then washed with an aqueous 0.5 M solution of sodium thiosulfate to remove excess iodine, dried over magnesium sulfate, and concentrated by rotary evaporation giving bis- (butylsulfanylthiocarbonyl) disulfide (7.6 g, 23.0 mmol). A suspension of 4,4-azobis(4-cyanopentanoic acid) (9.67 g, 34.5 mmol) and bis-(butylsulfanylthiocarbonyl) disulfide (7.6 g, 23.0 mmol) in ethyl acetate (200 ml) was heated at reflux overnight in argon atmosphere. The solvent was removed under reduced pressure to yield a reddish oil, which was dissolved in chloroform and rinsed with the solutions of sodium carbonate, then hydrochloric acid, and finally with water, and dried again with magnesium sulfate. After removal of the solvent, the dried product was eluted through a silica gel column using ethyl acetate/hexanes (2/3, v/v) as eluent. The eluent was removed by rotary evaporation giving oily product (7.16 g, yield 53.5%). ¹H BMR (δ nuo TMS, CDCl₃) ppm: 0,94 (3 H, t, CH₃CH₂-), 1,26 (2 H, sext, CH₃CH₂CH₂-), 1,68 (2 H, pent, -CH₂CH₂S-), 3,34 (2 H, t,-CH₂CH₂S-), 1,88 (3 H, s, -S-C-CH₃-), 2,41 (2 H, t, -CCH₂CH₂-), 2,54 (2 H, t, -CH₂CH₂COOH).

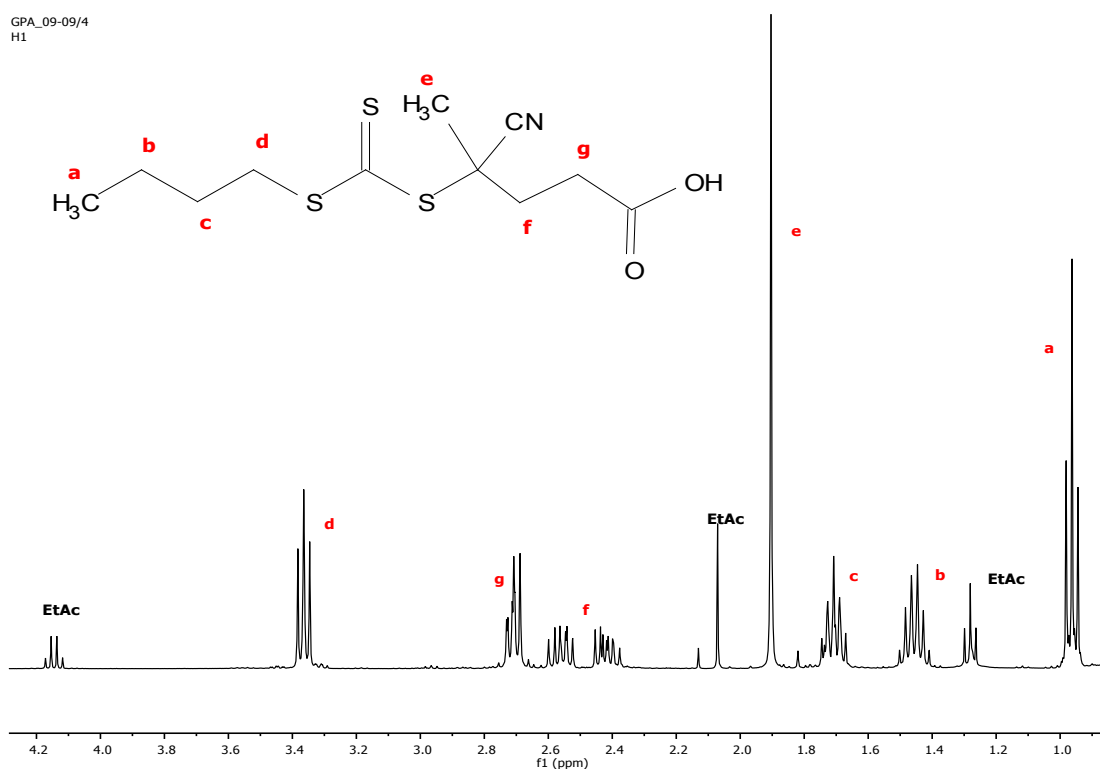


Fig. S1. ^1H NMR spectrum of RAFT CTA CBPA

Synthesis of ethylene glycol di((1-butyl)sulfanylthiocarbonylsulfanyl- 4-cyanopentanoate) (EGBP) as difunctional RAFT CTA

CBPA as RAFT CTA was synthesized according to the procedure described elsewhere [2]. CBPA (2.25 g, 7.70 mmol) and ethylene glycol (0.23 g, 3.68 mmol) were dissolved in 30 ml of dichloromethane, and the reaction mixture was cooled down to 0 °C in an ice bath. Dicyclohexylcarbodiimide (DCC) (1.60 g, 7.75 mmol) and 4-(dimethylamino)pyridine (DMAP) (0.095 g, 0.775 mmol) solution in dichloromethane (5 ml) was then added dropwise to the above solution under stirring. The solution was allowed to warm to room temperature and stirred overnight. The reaction mixture was then filtered, and the filtrate was concentrated by rotary evaporation. The crude product was isolated by silica gel column chromatography using ethyl acetate/hexanes (v/v, 2/3) as eluent. The eluent was removed by rotary evaporation to yield reddish oil (2.05 g, yield 92.5%). ^1H BMR (δ nuo TMS, CDCl_3) ppm: 0,94 (3 H, t, CH_3CH_2-), 1,26 (2 H, sext, $\text{CH}_3\text{CH}_2\text{CH}_2-$), 1,68 (2 H, pent, $-\text{CH}_2\text{CH}_2\text{S}-$), 3,34 (2 H, t, $-\text{CH}_2\text{CH}_2\text{S}-$), 1,88 (3 H, s, $-\text{S}-\text{C}-\text{CH}_3-$), 2,41 (2 H, t, $-\text{CCH}_2\text{CH}_2-$), 2,54 (2 H, t, $-\text{CH}_2\text{CH}_2\text{COOH}$) 4,32 (2 H, s, $-\text{CH}_2\text{COOCH}_2-$). Elemental analysis ($\text{C}_{24}\text{H}_{36}\text{N}_2\text{O}_4\text{S}_6$, 608.94 g mol $^{-1}$); C 47.34, H 5.96, N 4.60; O 10.51, S 31.50; found C 48.19, H 5.93, N 4.66, S 32.51.

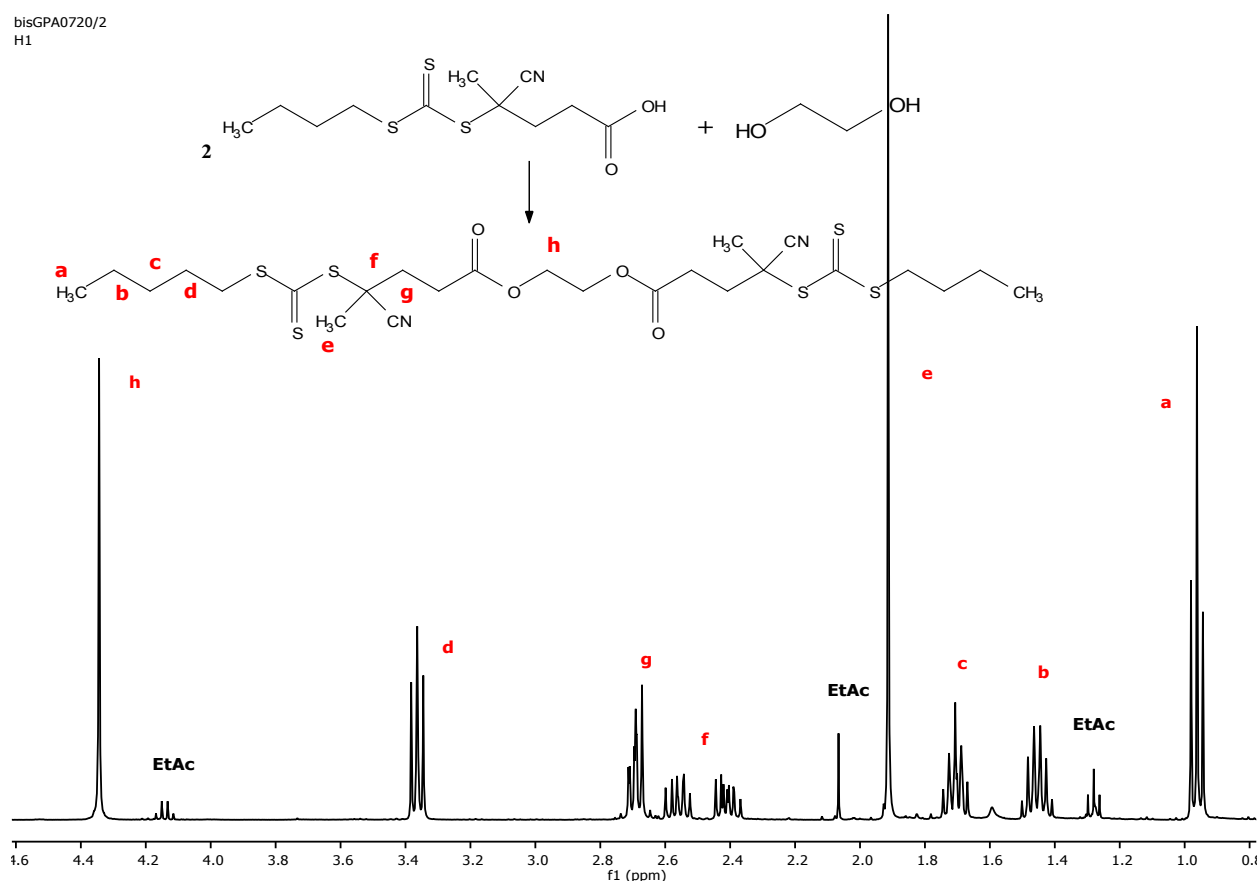


Fig. S2. ^1H NMR spectrum of RAFT CTA **EGBP**

Synthesis of diblock copolymer pHEMA-*b*-pDMAEMA

RAFT polymerization of HEMA initiated by AIBN was as follows: solution of NMP containing difunctional RAFT CTA CBPA (0.0278 g, 0.095 mmol), HEMA (0.6208 g, 4.77 mmol), AIBN (3.1 mg, 0.019 mmol), and a solvent (3.26 g) in a dry round bottomed 25 ml flask equipped with magnetic stirrer. The stirred solution was purged with argon for approximately 30 min., then the flask was sealed with rubber septum and placed in an oil bath at 65 °C for 24 hours. After 24 h the flask via gas-tight syringe was replenished by a mixture of the degassed DMAEMA (1.500 g, 9.54 mmol), AIBN (3.1 mg, 0.019 mmol), and a NMP (7.65 g). Polymerization producing the second block was carried out at the same conditions, i.e. at 65 °C for 24 h under stirring. At the end of the polymerization, the polymer was precipitated by pouring the solution into a large amount of hexane/Et₂O (8/2, v/v) (twice). The diblock copolymer pHEMA-*b*-pDMAEMA was dried under vacuum at 20 °C for at least 24 h.

^1H NMR (DMSO-*d*₆) ppm: 0.8-1.0 (broad d, 3H, -CH₃ from backbone); 1.63–2.0 (broad s, 2H, -CH₂C(CH₃)COO- from backbone); 3.65 (s, 2H, -CH₂OH); 2.63 (s, 2H, -CH₂N(CH₃)₂); 2.17 (s, 2H, -CH₂N(CH₃)₂); 3.90 (s, 2H, -C(O)OCH₂- from pHEMA); 3.99 (s, 2H, -C(O)OCH₂- from pDMAEMA); 4.80 (s, 1H, -CH₂OH).

Table S1. Results of diblock copolymer pHEMA-b-pDMAEMA one-pot RAFT polymerization.

Polymer	q^{overall} , mol%	q^{step} , mol%	$M_{\text{theor}} \cdot 10^{-3}$	$M_n \cdot 10^{-3}$	\bar{D}
pH ₄₆	93		6.3	7.9	1.31
pH ₄₈ -pD ₉₂	94	95	12.3	13.4	1.20

Calculation of the parameters of one-pot block copolymerization

Overall conversion of the monomers q_{Σ} (mol %) was calculated by the equation [2, 3]:

$$q_{\Sigma}^i = \frac{\int_{3.90}^i}{(\int_{3.90}^i + \int_{3.99}^i)} \quad (\text{S1}),$$

where i is the step of polymerization (1, 2, 3), and $\int_{3.90}^i, \int_{3.99}^i$ are integrals of the signals at 3.90 ppm and 3.99 ppm in ^1H NMR spectra of the reaction mixtures, attributed to the protons of the oxymethylene group in a polymer and a monomer, respectively.

Residual concentrations of HEMA and DMAEMA in the reaction mixtures were calculated by the equations:

$$C_{HEMA}^i = C_{0(HEMA)}^i \cdot \left(1 - q_{\Sigma}^i\right) \cdot X_{HEMA}^i \quad (\text{S2}),$$

$$C_{DMAEMA}^i = C_{0(DMAEMA)}^i \cdot \left(1 - q_{\Sigma}^i\right) \cdot X_{DMAEMA}^i \quad (\text{S3}),$$

where C_{HEMA}^i and C_{DMAEMA}^i are residual concentrations of HEMA and DMAEMA, respectively; X_{HEMA}^i and X_{DMAEMA}^i are molar fractions of the monomers in a polymerization mixture calculated from ^1H NMR spectrum using the equations:

$$X_{HEMA}^i = \frac{\int_{6.07}^i}{(\int_{6.07}^i + \int_{6.02}^i)} \quad (\text{S4}), \quad X_{DMAEMA}^i = \frac{\int_{6.02}^i}{(\int_{6.07}^i + \int_{6.02}^i)} \quad (\text{S5}),$$

where $\int_{6.02}^i$ and $\int_{6.07}^i$ are integrals of the signals of vinyl protons at 6.02 ppm and 6.07 ppm in ^1H NMR spectra of DMAEMA and HEMA, respectively.

Conversion of the monomers in terminal blocks (q_t , mol %) was calculated by the following equation:

$$q_t^i = \frac{(q^i \cdot C_{0(\text{monomer})}^i) - (q^{i-1} \cdot C_{0(\text{monomer})}^{i-1})}{C_{\Sigma(\text{monomer})}^i + (1 - q^{i-1}) \cdot C_{0(\text{monomer})}^{i-1}} \quad (\text{S6})$$

MWD curves of multiblock copolymers

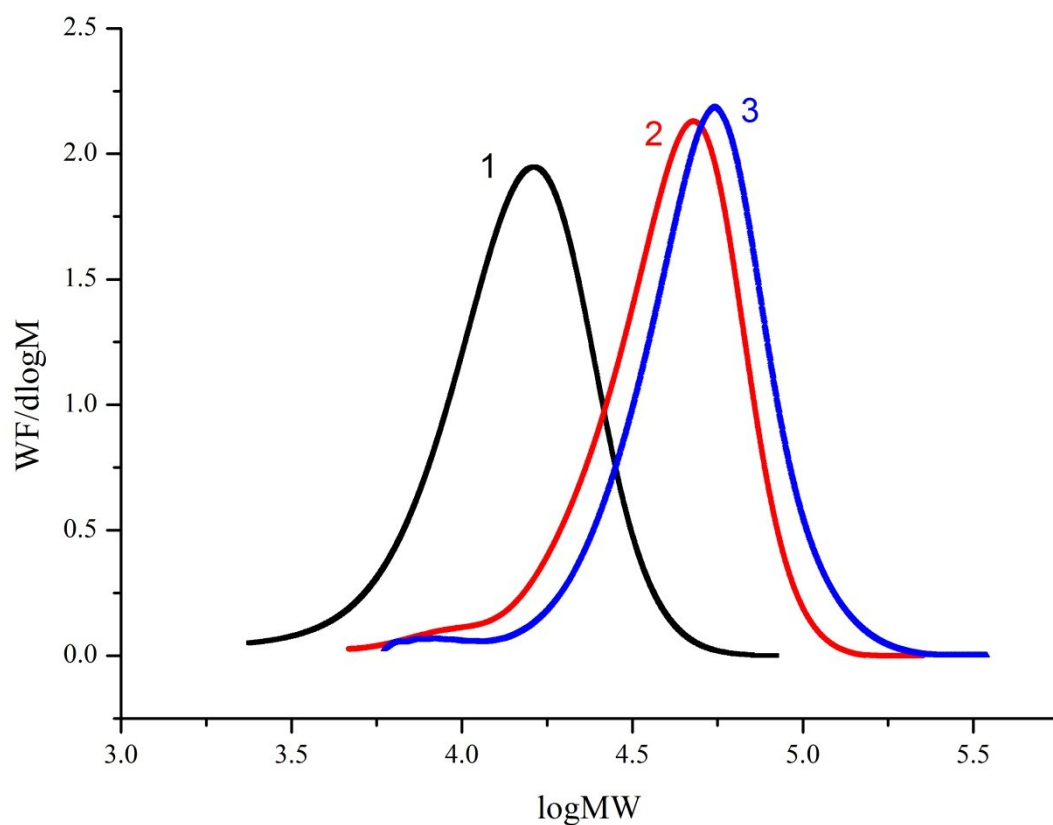


Fig. S3. MWD curves of of pDMAEMA (1), triblock copolymer (2) and pentablock copolymer (3) (run 8, Table 2)

Temperature induced self-assembly of homopolymers DMAEMA₄₉ and HEMA₅₀

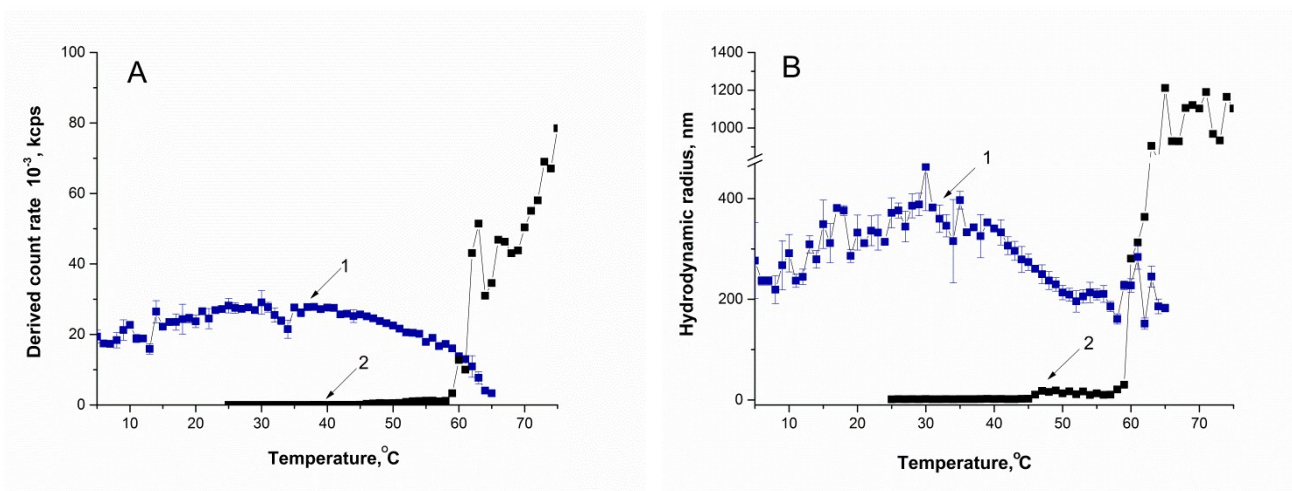


Fig. S4. Changes in intensity of the scattered light (A) and the hydrodynamic radius of the particles (B) of DMAEMA₄₉ (1) and HEMA₅₀ (2) during heating.

References:

1. Graeme Moad, Y.K. Chong, Almar Postma, Ezio Rizzardo, San H. Thang, *Polymer*, 2005, **46**, 8458.
2. T. Krivorotova, P. Radzevicius, R. Makuska, *Eur. Polym. J.*, 2015, **66**, 543.
3. P. Radzevicius, T. Krivorotova, R. Makuska, *Eur. Polym. J.*, 2017, **87**, 69.